ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT NUMBER: FHWA-AZ97-416

I-10 / I-17 PHASE I FMS EVALUATION

Final Report

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July 1997

Prepared for:
Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

Technical Report Documentation Page

1. Report No. FHWA-AZ-97-416	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

I-10/I-17 PHASE I FMS EVALUATION

5. Report Date July 1997

6. Performing Organization Code

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8. Performing Organization Report No.

9. Performing Organization Name and Address
TRANSCORE
110 S. Church Avenue, Suite 2470
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10. Work Unit No.

11. Contract or Grant No. SPR-PL-1(43)-416

12. Sponsoring Agency Name and Address
ARIZONA DEPARTMENT OF TRANSPORTATION
206 S. 17th Avenue
Phoenix, Arizona 85007
Project Manager: Sarath Joshua

13. Type of Report & Period Covered
Final Report
April 1993 - July 1997

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

This report describes the procedures and results of a study to evaluate the impacts of Phase I of the I-10/I-17 freeway management system (FMS) on freeway traffic operations in the Phoenix, Arizona metropolitan area. A "before and after" study design was used to evaluate several measures of effectiveness (MOEs) for 57 kilometers of freeway that was outfitted with ramp meters, variable message signs, traffic loop detectors, and closed circuit television cameras (CCTVs). The primary MOEs consisted of mainline travel time, on-ramp travel time, driver response to the variable message signs (measured by the distribution of traffic volume), freeway accidents, incident response time, incident duration, and estimated noise and vehicle emission levels. The before period consisted of 10 months during 1993/1994 and the after period consisted of the same 10 months during 1995/1996. Although several extraneous factors limited the extent of the analysis, the results were generally positive. Travel time improved between 2 and 6 percent on the 7 kilometer section of the freeway where the ramp meters were in operation, significant positive response by drivers was measured as a result of the variable message signs, and vehicle emissions on the freeway were estimated to have gone down in the after period. No significant change was measured overall in incident response time or incident duration even though these values did decline in the after period. Freeway accident rates increased in the after period, but this is not necessarily a reflection of the FMS due to other factors that may have affected this result.

17. Key Words
Freeway management system, evaluation, travel time, variable message signs, ramp meters, driver response, traffic operations.

18. Distribution Statement
Document is available to the U.S. Public through the National Technical Information Service, Springfield, Virginia, 22161

23. Registrant's Seal
Registered Professional Engineer (Civil) Certificate No. 17751 DAVID D. PERKINS ARIZONA U.S.A. 8-8-97

19. Security Classification	20. Security Classification	21. No. of Pages	22. Price
Unclassified	Unclassified	145	

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.452	centimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3.

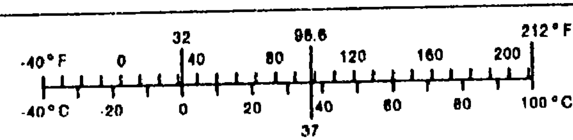
Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

These factors conform to the requirement of FHWA Order 5190.1A

*SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
yd	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
yd^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	millimeters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I. INTRODUCTION

PROJECT BACKGROUND AND PURPOSE

The Arizona Department of Transportation (ADOT) through Phase I of the Interstate 10/Interstate 17 (I-10/I-17) Freeway Management System (FMS) has deployed significant new traffic management technologies within the Phoenix, Arizona freeway network, as well as procedural improvements, to achieve enhancements in traffic flow, safety, and environmental quality. The first major construction phase (Phase I) of the FMS, valued in excess of $20 million, began in March 1993 and a fully operational system was turned over to ADOT in October of 1995. The FMS provides ADOT with monitoring, surveillance, and traffic control capabilities on approximately 57 kilometers (total for both directions of travel) of the I-10/I-17 freeway system that were included in the project study area as shown in Figure 1.

The major elements of Phase I of the FMS involved the installation of closed-circuit television cameras (CCTV), variable message signs (VMS), traffic signal controllers at crossroad intersections, in-pavement vehicle detectors (loop-detectors), and ramp metering equipment at each of the on-ramps within the Phase I area. Phase I also involved the construction and implementation of a new Traffic Operations Center (TOC) which acts as the control, operations, and maintenance center for the FMS. Through the TOC, the FMS carries out its major functions, which include:

- 100 percent video surveillance of the FMS area through 29 color CCTVs spaced approximately 1.6 kilometers apart, mid-way between interchanges. Each camera is equipped with a remote control iris, zoom lens, and tilt/pan capabilities, and is encased in a weatherproof enclosure.

- Monitoring of freeway traffic operations through the vehicle detection and travel speed information provided by the loop detectors. The loop detectors are buried beneath the pavement surface and are spaced approximately every 536 meters.

- Detection of freeway incidents through the loop detector information and facilitation of a more rapid response to incidents.

- Verification of the nature of freeway incidents via the CCTV surveillance system, and facilitation of the management of incidents via the ramp meters, and variable message signs.

- Dissemination of traffic and freeway operating condition information to motorists through the VMS system. Twenty-four light-emitting, fiber optic, overhead variable message signs have been strategically located on the freeway system throughout the Phase I area to provide motorists advance warning of traffic conditions.

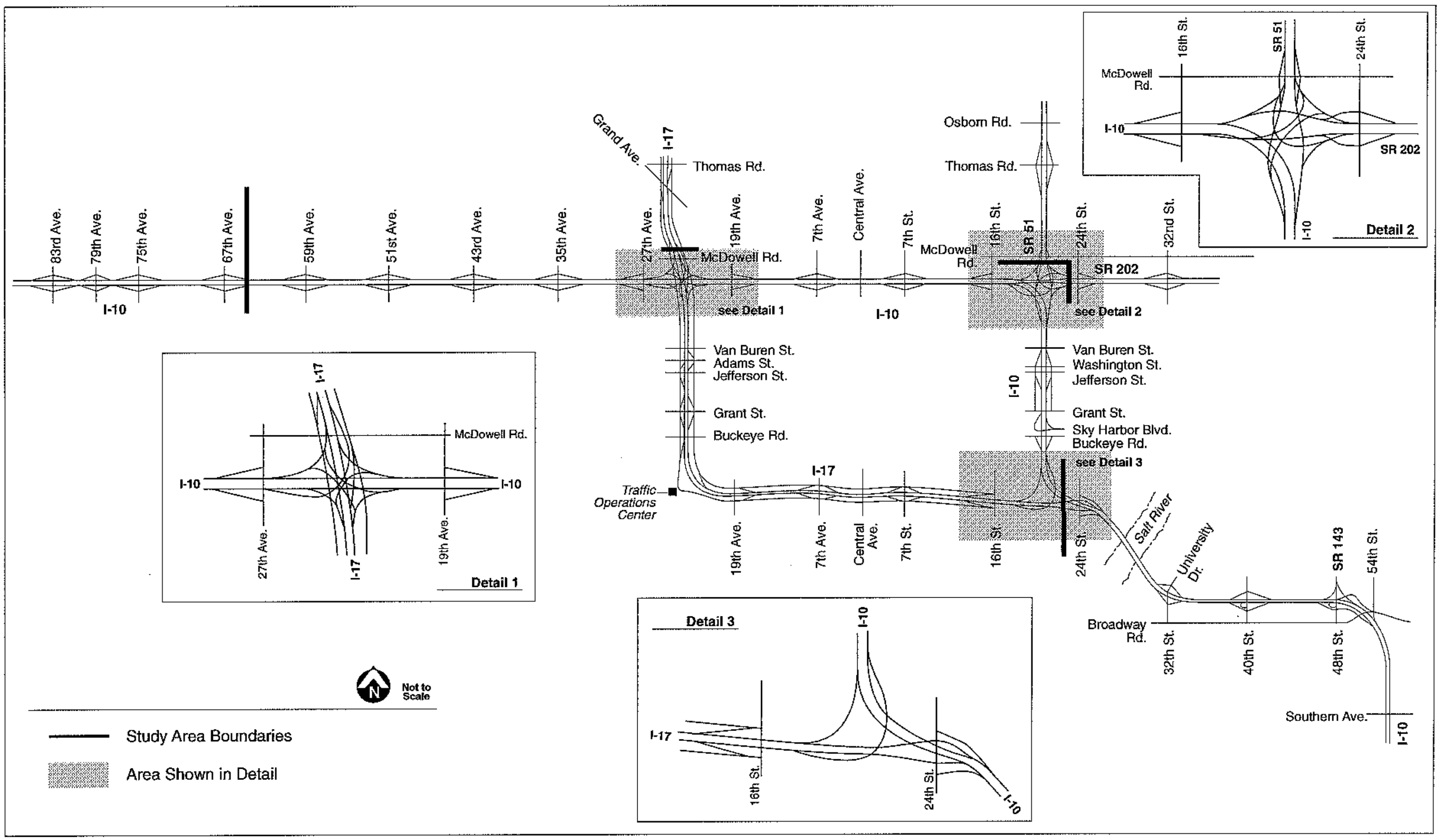


Figure 1
PROJECT STUDY AREA

- Control of freeway traffic operations through the use of ramp metering. Thirty-eight ramp meters have been incorporated into the ramps on the Phase I portion of the freeway system. These ramp meters control access to the freeways allowing traffic controllers to spread out, or totally restrict, vehicles from entering the highway, allowing safer merging into "mainline" lanes and reducing the potential for rear-end collisions on the ramps.

- Collection and storage of freeway traffic volume data. The TOC computers automatically store traffic data collected through each of the loop detectors providing the capability to evaluate freeway traffic operations over time.

- Control of the freeway pump stations. Pump stations which keep highways clear of storm water run-off can be monitored and controlled as part of the FMS system.

- Other controls. Lighting, ventilation, fire suppression and other I-10 Deck Tunnel operations can also be controlled via the FMS.

The major traffic management elements of Phase I of the FMS are summarized in the following sections.

Ramp Metering

This element of the FMS involved the construction of ramp meters at on-ramps throughout the study area. The traffic interchanges and specific on-ramps with ramp meter control are shown in Figure 2. Three ramp meters were installed prior to Phase I construction of the FMS and these meters were subsequently integrated into the Phase I system operation. The ramp-metering system consists of a traffic signal on each of the on-ramps. The traffic signal can be programmed to release a vehicle to enter the freeway at either a fixed time interval (e.g., every 15 seconds) or at a time interval that is established by the traffic conditions on the freeway and on the on-ramp. Under low or uncongested traffic conditions on the freeway the signals can be turned off (no metering), and under extreme congestion or for incident management, the signals can be set to rest on red and not allow any vehicles to enter the freeway.

Variable Message Signs

Variable message signs are currently operating at 15 locations within the study area and at nine other locations that can affect traffic management within the study area. The locations of these signs are provided in Figure 3. These signs are controlled by fiber optic links from the TOC. Phase I of the FMS construction installed new VMSs and retrofit existing VMS installations into the total system.

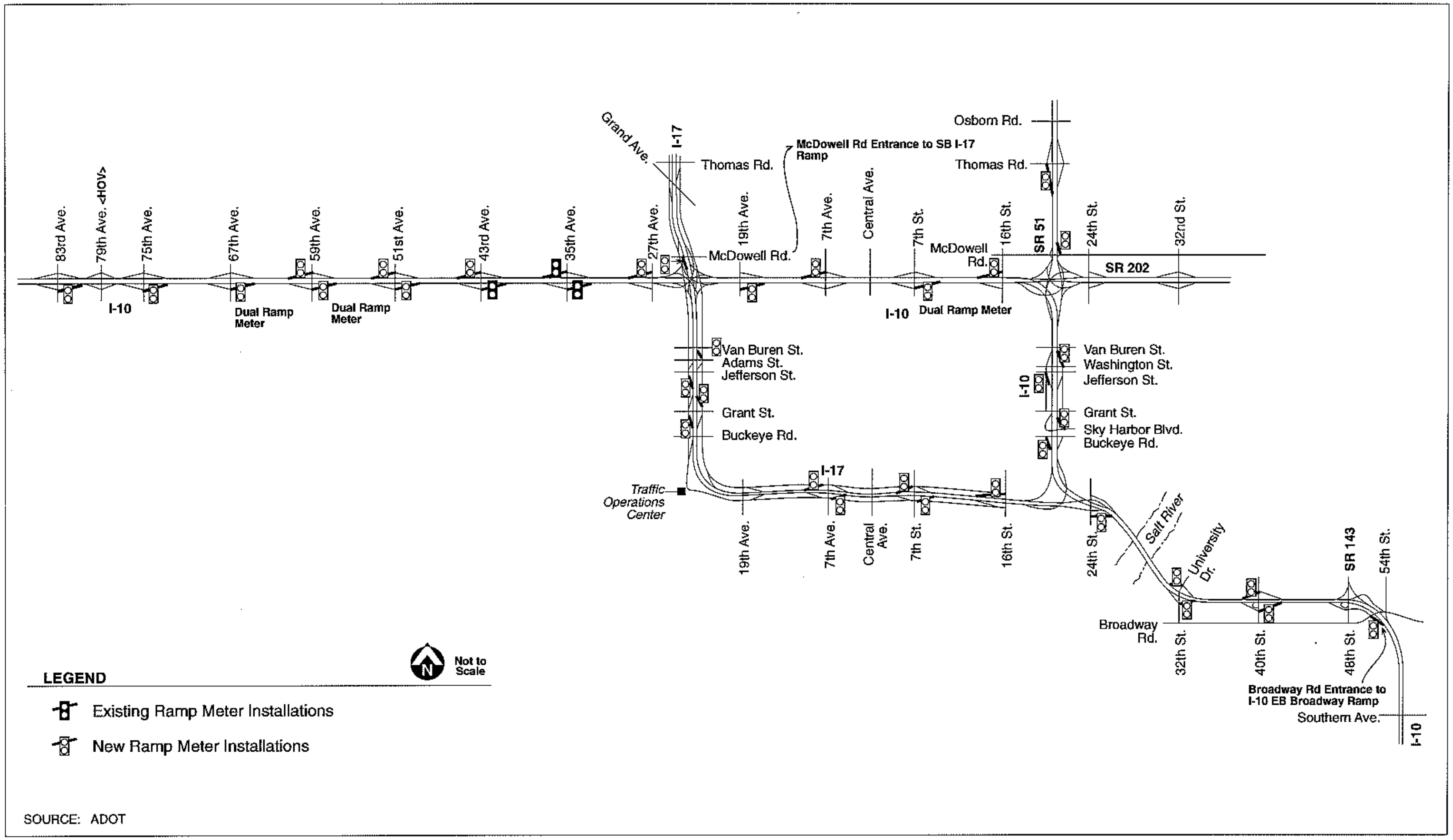


Figure 2
PREVIOUSLY EXISTING AND NEW RAMP METER INSTALLATIONS

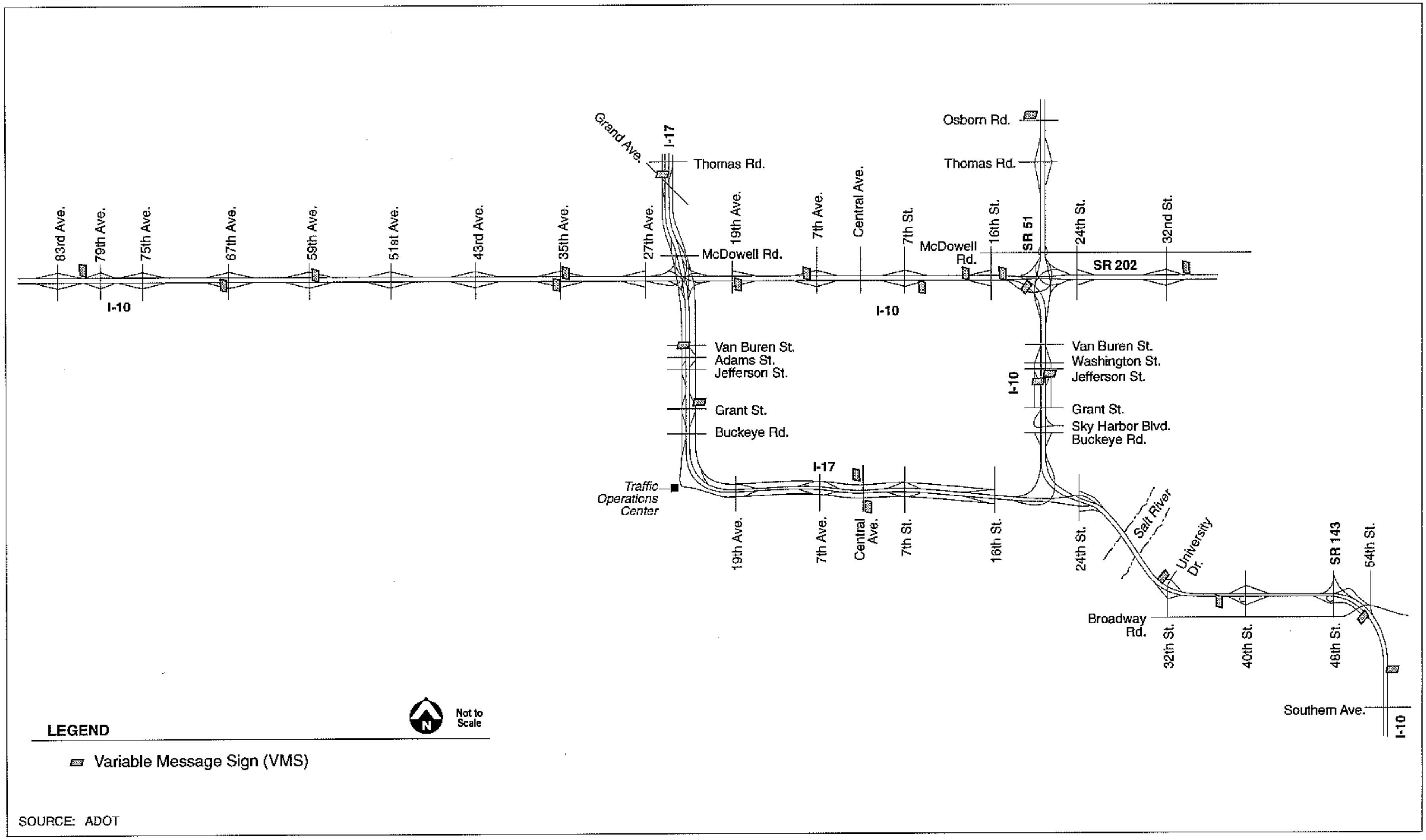


Figure 3
VARIABLE MESSAGE SIGN (VMS) LOCATIONS

The signs are primarily used to provide advisory information to motorists on the traffic conditions downstream on the freeway. Motorists can be alerted to congested conditions and delays caused by traffic accidents, maintenance activities, construction, or other problems, and be advised on the use of alternate routes or the need to change lanes due to lane closures. Different messages can be posted on individual signs either from a pre-programmed library of messages covering a variety of situations or manually by an operator in the TOC. Each sign has limited display capability, so that messages must be concise and to the point.

Traffic Detection

Traffic detection is accomplished through loop-detectors that are placed in the pavement at a spacing of approximately 536 meters in each of the freeway lanes. Detectors have also been installed on the ramps within the study area, except that detectors have not been placed on the system interchange ramps between the freeways.

The loop-detectors collect data on traffic volume, vehicle classification (two types of trucks), travel time and vehicle speed, and lane occupancy. These data are transmitted to the TOC for the mainline freeway where they are stored and used in the TOCs traffic and incident management functions. The traffic volume, occupancy, and travel time data are used to estimate the average traffic operating conditions along segments of the freeway, and can be used in establishing the ramp metering rates at downstream ramps.

Incident Detection

The FMS analyzes traffic data provided through the traffic detection system using multiple algorithms to detect potential traffic incidents (e.g., increasing traffic congestion due to an accident). Traffic volume, occupancy, and travel time data are used to identify and report the location of suspected incidents to the TOC. Incident confirmation is achieved by technicians in the TOC through the use of the CCTV system. If an incident is confirmed, the FMS incident management system is implemented.

Incident Management

Incident management is achieved through several elements of the FMS. The existence of an incident requiring traffic management response is first confirmed by the TOC using the CCTV system (see Figure 4). The general nature of the incident, for example, the number and type of vehicles involved, number of lanes blocked, and type of traffic control needed can be determined through the use of the CCTV system. The type of emergency response required can also be determined through CCTV surveillance. Traffic management can be achieved through the use of the ramp metering system and the variable message signs. Traffic entering the freeway can be controlled by the ramp meters, and drivers on the freeway can be provided information on the use of alternate routes or lane closures through the VMS displays. Incident response time and the time required to restore freeway operations can be reduced as a result of the FMS.

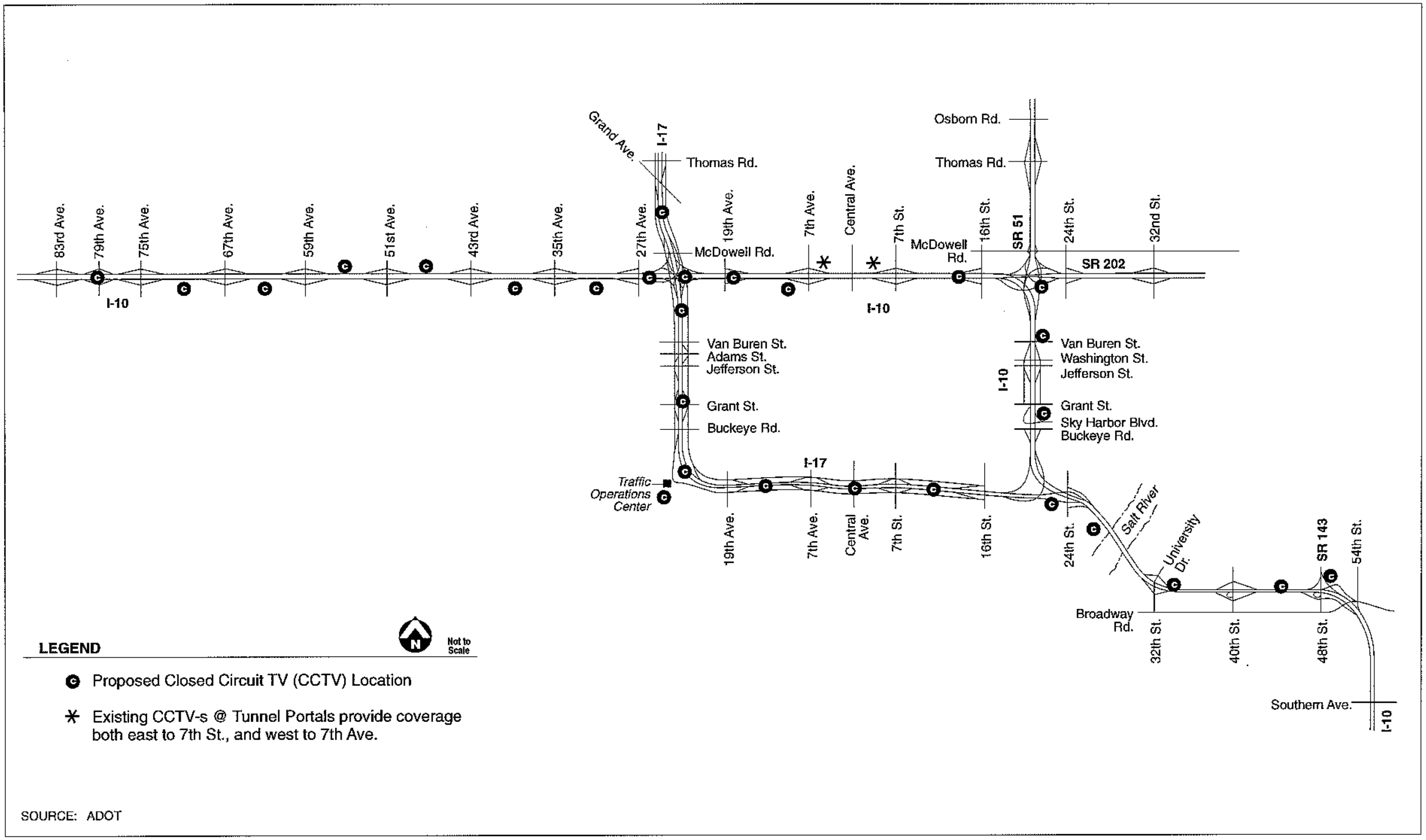


Figure 4
PREVIOUSLY EXISTING AND NEW CLOSED CIRCUIT TV (CCTV) LOCATIONS

Project Purpose

Phase I of the FMS is the first installment of a system that will eventually encompass over 320 kilometers of the metropolitan Phoenix area freeways. The purpose of the FMS is to maximize the effectiveness and efficiency of the freeway system. This purpose is to be accomplished through the use of the FMS technologies to provide effective traffic management to reduce congestion and improve freeway travel time. The FMS is intended to provide safety enhancements, allow for accommodation of increased travel demand, reduce vehicle travel time, reduce fuel consumption and air pollution, and provide improved mobility through the rapid and appropriate response to freeway incidents and accidents.

STUDY GOAL AND OBJECTIVES

The primary goal of this study is to evaluate the effectiveness of various elements of the Phase I FMS on a systemwide basis in terms of improving freeway traffic operations, safety, and environmental quality. The major objectives of the FMS evaluation study are:

- To evaluate the effect of the FMS ramp metering system on freeway traffic operations.
- To evaluate driver response to the FMS variable message sign system during traffic accidents.
- To evaluate the systemwide changes in freeway accident patterns as a result of the FMS.
- To evaluate the potential impacts of the FMS on freeway vehicle emissions, air quality, and noise levels.
- To evaluate the impacts of the ramp metering system on ramp traffic operations.
- To evaluate the impact of the FMS on the Arizona Local Emergency Response Team (ALERT) response to freeway incidents.
- To provide the Arizona Department of Transportation with guidance on potential methods for evaluating the impacts of the FMS on freeway traffic operations.

LIMITATIONS OF THE STUDY

The intent of this study is to evaluate a rather broad spectrum of potential measures of effectiveness to assess the general impacts of the FMS on freeway traffic operations. Rather than focus an in-depth evaluation on one or two measures, this study attempted to quantify several measures in order to evaluate various aspects of the FMS. There were several limitations of the study that were a result of either the study design, data collection/retrieval limitations, or other factors beyond the control of the study team. Several of the more important of these limitations are briefly discussed below.

Changes to the Freeway System Within the Study Area

There were three significant changes to the freeway system within the study area that occurred after the "before" period data collection and before the implementation of the FMS. These changes are not elements of the FMS and represent a changed condition from the before to the after periods that may have affected the results of the study. These changes are the following:

- The restriping of I-10 from I-17 to SR 51 to add a new basic lane and increase roadway capacity (occurred during June and July 1993).
- I-17 northbound was restriped from Van Buren to I-10 to reduce the number of basic lanes from three to two (occurred on May 16, 1996).
- I-17 northbound was restriped from I-10 to Thomas Road to add one basic lane and increase capacity (occurred on June 6, 1996).

Other Changes in the Highway System

Possibly the most important factor that could have affected the results of this study was the continued construction and implementation of new portions of the highway system affecting travel patterns within the study area. The most important changes include the opening of the Red Mountain freeway (SR 202) and the opening of the Squaw Peak freeway (SR 51), both of which were opened to traffic before Phase I of the FMS was completed but after the "before" period data collection was conducted. It is quite possible that these new facilities resulted in changes in travel time, congestion, and travel patterns within the study area that affected the study results.

Changes in Background Travel Demand

The population and employment of the Phoenix metropolitan area has continued to grow during the period of this study. This has resulted in an overall increase in travel demand for the metropolitan area and changes in travel patterns within the study area.

This, along with the opening of new elements of the freeway system, has resulted in a changes in traffic conditions from the period before the FMS was implemented to the time when the FMS was completed.

Limitations in the Traffic Data Collection Procedures

During the before period, traffic volume data collection on the freeway system was limited to the seven permanent count stations that existed within the study area. These were the only locations where traffic volume information could be readily provided for correlation with travel time and other aspects of the evaluation. Therefore, traffic volume reporting for the analysis was limited to these seven locations (see Chapter 2 for more details) even though there were many more potential locations for volume data available after the implementation of the FMS. In addition, at one of the seven locations the count station was never functioning during the before period in one direction of travel, and no data were available for that direction.

A problem with loop detector technology in general is that periodically the reporting of traffic volume information is interrupted due to a system failure. This occurred both before and after implementation of the FMS. Therefore, traffic volume data are incomplete in both the before and after periods of the study. This occurrence reduced the number of data points available for analysis in several of the statistical evaluations that were conducted.

Limitations Due to the Scope of the Study

Several of the evaluations used to assess the impacts of the FMS were limitec by the scope of the study. As mentioned earlier, this was a broad spectrum analysis that by design limited the in-depth nature of the individual evaluations. Study resources were focused early in the study on those areas that were deemed to have the greatest potential to reveal significant impacts of the FMS. Travel time on the freeway was evaluated extensively as was the impact of the VMS system on driver response. Other areas, such as the accident analysis, vehicle emissions, noise levels, and on-ramp operations were, by design given a less intensive evaluation.

Limitations Due to FMS Capabilities and Operations

Even with the extensive data capture capabilities that are built into the FMS technology, there were some limitations of the FMS that affected the study design and evaluation procedures. For example, there are no loop detectors on the ramps of the system interchanges between freeways, and therefore no direct measure of traffic volume on these ramps. This was a factor in the VMS evaluation process in determining sites for data analysis. In addition, even with the extensive video surveillance capability of the FMS, the system is not set up to simultaneously record video at multiple locations.

Limitations of the Incident Response Analysis

The analysis of the FMS to improve ADOT's capability to respond to freeway incidents focused on incident response time and incident duration as the measures of effectiveness. Perhaps the single incident management variable that has been most affected by the FMS has been incident detection time. However, this variable could not be measured in the before period, and therefore was not an element of the study.

Incident duration is greatly affected by the specific characteristics of each individual incident. The number and types of vehicles and injuries involved, existence of cargo spills, or other factors can greatly affect the time required to clear an incident. Rarely do two incidents have identical characteristics. Accident characteristics were not controlled for in the analysis and no attempt was made to match characteristics in the before and after comparison. Therefore, it is doubtful that the before and after incident populations have the same characteristics, and the evaluation of incident duration could be based on incidents of different types in the before and after periods.

ORGANIZATION OF THE REPORT

The remainder of this document is organized into seven chapters. Chapter 2 describes the research study design, including the measures of effectiveness employed and the data collection procedures. Each of the remaining six chapters describes the analysis procedures and results of the evaluation of a specific measure or measures of effectiveness. Supporting materials, such as data and statistical test results, are contained in appendices.

SUPPORTING DOCUMENTATION

Two additional reports have been prepared for the Arizona Department of Transportation through this research effort. Each of these reports is bound under a separate cover. These reports provide detailed information on the data collection procedures and methods, and data collected as part of this project. The first of the two reports describes the data collection and analysis activities for the period before the implementation of the FMS. The second report describes the data collection and analysis activities after the implementation of the FMS. Together these reports provide the detail on the data collection activities for the project. These reports are:

1. Before Evaluation Period Conditions -- Study to Evaluate I-10/1-17 Freeway Management System, Arizona Department of Transportation, prepared by JHK & Associates, June 1994.

2. After Evaluation Period Conditions -- Study to Evaluate I-10/I-17 Freeway Management System, Arizona Department of Transportation, prepared by JHK & Associates, March 1997.

II. STUDY DESIGN AND TIMING OF EVENTS

BEFORE-AND-AFTER STUDY DESIGN

The evaluation of the effects of the I-10/I-17 FMS was primarily conducted through a before-and-after study design. That is, measures of effectiveness were identified and an analysis methodology was developed to compare operating conditions on the freeway before the implementation of the FMS to the operating conditions after the implementation of the FMS. It is assumed that any difference in the measures of effectiveness are due to the effects of the FMS, all other factors being either equal or properly accounted for in the before and after conditions. The assumption that all other factors are equal in the before and after conditions is generally not true. The analysis methodology attempted to account for changed conditions wherever possible and isolate the impact of the FMS from other factors that may have affected the results.

The evaluation of VMS deviated from the before-and-after study design. The evaluation of the impacts of the variable message signs was based on driver response to messages posted by the system, which occurred only in the after condition. The evaluation of air and noise impacts was based on a comparison of modeled vehicle emissions and noise levels using before and after traffic volume and speed data. Actual vehicle emissions and noise levels were not taken in the field.

Construction of the FMS began in 1993. The entire system was completed, tested and turned over to ADOT control in October of 1995. Before period data collection began in March 1993 and was completed in February 1994. After period data collection began in November of 1995 and was completed in October of 1996. The data collection program was developed such that there was correspondence between the timing (i.e., month, week, day of week, time of day) of the data collection in the before and after periods to account for the seasonal variation in traffic characteristics. A 10-month period was used for after period data collection to duplicate duration, seasonal characteristics, and sample sizes experienced in the before period.

Details on the specific data that were collected, and data collection methods are presented later in this chapter. Details on the data analysis procedures used in the comparison of the before and after data, and a summary of the conclusions drawn from the analysis are presented in separate chapters for each measure of effectiveness.

The use of the before-and-after experimental design for the FMS evaluation was assessed recognizing the harshness of the evaluation environment, the opportunity for factors other than the FMS to influence the measures of effectiveness, and maturation effects associated with a long evaluation period duration. The following steps were taken to minimize the threats to evaluation validity.

- Traffic volumes were tracked on the freeway mainline in order to statistically account for traffic volume changes. Comparisons attempted to account for the effect of changes in traffic conditions to facilitate isolation of the effect of the FMS.

- Continued communications were maintained with ADOT and other local jurisdictions on construction, maintenance, and other transportation influences that may have affected traffic in the study area. Problem data (i.e., data collected during periods of freeway traffic disruptions or other atypical events) were removed from the analysis.

- Statistical analyses were performed using matched pairs experimental designs, and using parametric statistics tests when feasible to allow for statistical assessments of outside biases.

MEASURES OF EFFECTIVENESS

Identification of the study objectives and measures of effectiveness (MOEs) form the foundation of the evaluation design. The study objectives are described in Chapter 1 of this document. These objectives state the subject of the evaluation and the specific analysis questions to be answered. The MOEs represent a statement of the measures to be obtained from the data analysis efforts that were compared in order to answer the analysis questions and ultimately allow for effectiveness determination.

The evaluation was designed in such a way as to provide for the analysis of individual subelements of the FMS, including ramp metering, variable message signs, and incident management. In addition, the evaluation design provided systemwide information on vehicle emissions, noise levels, and accidents. The primary MOEs used in the evaluation at the subelement and systemwide level of analysis are provided in Table 1. A description of the data collected for the evaluation of the MOEs is provided in the next section of this chapter.

Table 1

FMS EVALUATION OBJECTIVES AND MOEs

Evaluation Objectives	Measures of Effectiveness
Subelement Analysis:	
1. Evaluate the effect of ramp metering on freeway traffic operations.	1. Travel time for the entire FMS circuit before and after. 2. Travel time on an individual segment before and after.
2. Evaluate the effect of ramp metering on ramp traffic operations.	1. On-ramp travel time before and after.
3. Evaluate driver response to the variable message signs.	1. Distribution of traffic between alternate routes. 2. Lane distribution of traffic.
4. Evaluate the effect of the FMS on the Arizona Local Emergency Response Team (ALERT) response to freeway incidents.	1. Response time to incidents/ accidents before and after. 2. Incident duration time before and after.
Systemwide Analysis:	
1. Evaluate impacts on air quality.	1. Estimated vehicle emissions levels before and after.
2. Evaluate freeway traffic noise levels.	1. Estimate freeway traffic noise levels before and after.
3. Evaluate freeway accident patterns.	1. Freeway accident rate and frequency before and after.

OVERVIEW OF DATA COLLECTION PROCEDURES BEFORE AND AFTER

The following sections describe the data collection procedures and the data collected in the before and after periods as part of this study. Complete detail on the data collection efforts is contained in the supporting documentation for this study identified in Chapter 1 of this report.

The following information and data were either collected or estimated during both the before and after periods to accomplish the evaluation objectives and analysis of the MOEs.

- Freeway speed and travel time.
- Traffic volumes.
- Freeway accidents.
- Data for the air quality analysis.
- Data for the noise analysis.
- Travel time data on selected on-ramps.
- Incident response times for freeway incidents.
- VMS messages and duration of display during freeway traffic accidents.

The procedures used for collecting each type of data and information is described in the following sections for both the before and after periods. The statistical and other analysis procedures used to evaluate the data and provide for the before and after comparisons are described in separate chapters for each of the MOEs.

Freeway Speed and Travel Time

Data Collection Device

Freeway speed and travel time data were collected in both the before and after conditions using the "floating car" technique, utilizing a vehicle equipped with a global positioning system (GPS) device and tape recorder. The GPS technology was utilized as a mapping tool to identify position, time and speed of the vehicle every two seconds during data collection runs.

Data Collection Procedure

A routing plan was established with two routes to provide for travel time data collection in both directions of travel on the portions of the freeway system within the study area that was referred to as the FMS circuit. The travel time routing plan was developed using the reference points shown in Figure 5. A route began at either 67th Avenue on I-10 and followed the circuit defined by reference points ABCDEF in Figure 5, or it began at McDowell Road on I-17 and followed the circuit defined by reference points FEDCBA. Shorter reference links within the circuit were defined as being the distance between the back of the gores between the on- and off-ramps.

Travel time and speed data were collected during the before period during the months of May 1993 through February 1994, and for the after period during the months of November 1995 through February 1996 and May 1996 through October 1996. Data were collected in two phases during the after period so that the months of data collection corresponded exactly to the before period. Data were collected over these months in an effort to account for the known heavy seasonal variation in traffic volume that was thought to potentially affect the results of the analysis.

Travel time and speed data were collected on Tuesdays, Wednesdays, and Thursdays during one or two weeks of each month in the before period and one week of each month during the after period. Each week of the after period was selected to correspond to the same week during the before period. Each week was selected to avoid the occurrence of holidays. Travel times and speeds were collected during the morning peak period (6:30 AM to 8:30 AM) and the afternoon peak period (4:00 PM to 6:00 PM) of traffic volume on each day of data collection. Four data collection travel time runs were conducted during each peak period on each day (eight runs total per day), with two runs in each direction of the circuit during each peak period. Each travel time run was conducted during one of the four half-hour periods of each peak period. A total of 336 travel time runs were conducted in the before period with 240 conducted in the after period. A data collection plan was established such that data were collected on each circuit during each of the four half-hour time periods during the peak period for each week of data collection.

Travel time runs were made by having the floating car maintain its position in the traffic stream by traveling at a speed consistent with the surrounding traffic except to pass slower moving vehicles. For the purposes of data collection, the left-most general purpose lane was designated lane 1, the lane to the right was lane 2, and the next general purpose lane to the right was lane 3. Travel time runs were conducted in lanes 2 and 3 only. Lane 3 represents the right-most continuous general purpose lane over the circuit. Lanes 2 and 3 were selected for use to obtain data for evaluating the overall freeway traffic flow conditions and the effect of the ramp meters on freeway traffic.

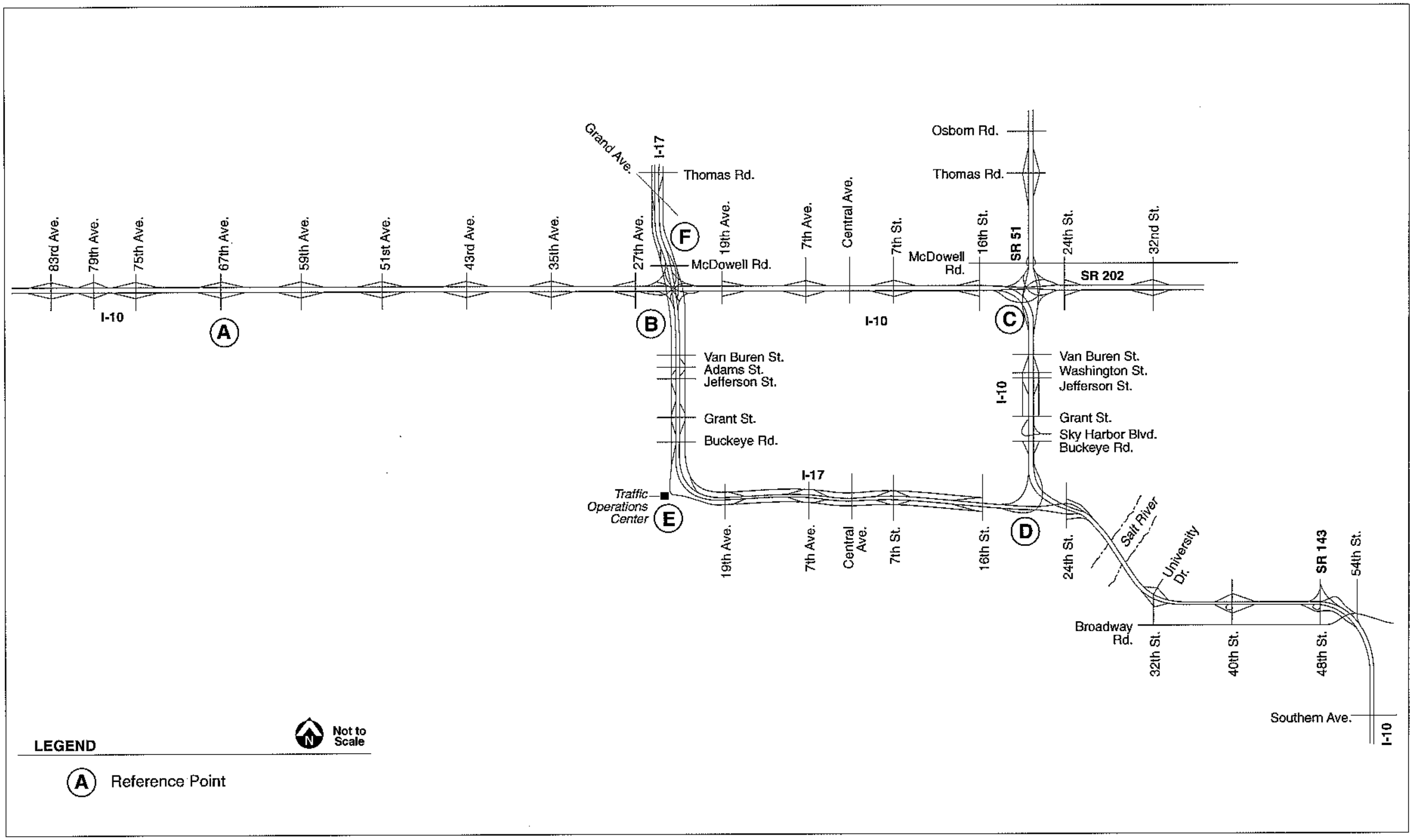


Figure 5
TRAVEL TIME ROUTING PLAN REFERENCE POINTS

In general, the floating car traveled at the normal speed of traffic and maintained a "safe" headway of approximately one car length for each 16 kilometers per hour of speed. The floating car generally did not pass slow-moving vehicles ahead unless a majority of the vehicles sharing the lane also passed the vehicle. When traveling in lane 3 adjacent to ramp junctions or weaving areas, the floating car slowed with traffic without changing lanes so that impacts of ramp junction turbulence could be compared in the before and after periods with the existence of ramp metering as part of the after condition.

During periods of serious congestion, the floating vehicle stayed in the designated lane unless the lane was blocked due to a traffic incident. Cases where accidents or other incidents inhibited normal traffic flow were removed from the data prior to use in the evaluation of the impacts of the FMS on travel time.

Traffic Volume Data Collection

Traffic volume data were used in several aspects of the study. Peak period traffic volume information was used in the evaluation of travel time to adjust for different traffic volume conditions in the before and after periods. Traffic volume data by lane during freeway incidents/accidents were used in the evaluation of driver response to the VMS system, and daily traffic volumes were used in the evaluation of accident rates. These data were provided by ADOT through seven permanent count stations that were available for the before period and through the array of loop detectors constructed as part of the FMS for the after period.

Traffic volume data for the evaluation of travel time were provided for the before period from seven permanent count stations located within the study area before the FMS was constructed. The location of these count stations is provided in Figure 6. At site 1 only the counter in the westbound direction of travel was functioning during the before period, and no eastbound data at this locations were available for the study. During the after period, data were provided through loop detectors in close proximity to the count station locations used in the before study. Specific loop detectors were selected such that the data from these locations would represent the same data provided for the before condition. Daily traffic volumes for the accident analysis were provided from the same locations as used in the travel time evaluation.

Volume data used in the VMS analysis was provided from the FMS loop detectors. Five-minute traffic counts by lane were provided at specific sites selected for use in the case studies of VMS system effectiveness. Details on the locations these sites can be found in the case study descriptions of the VMS evaluation contained in Chapter 5.

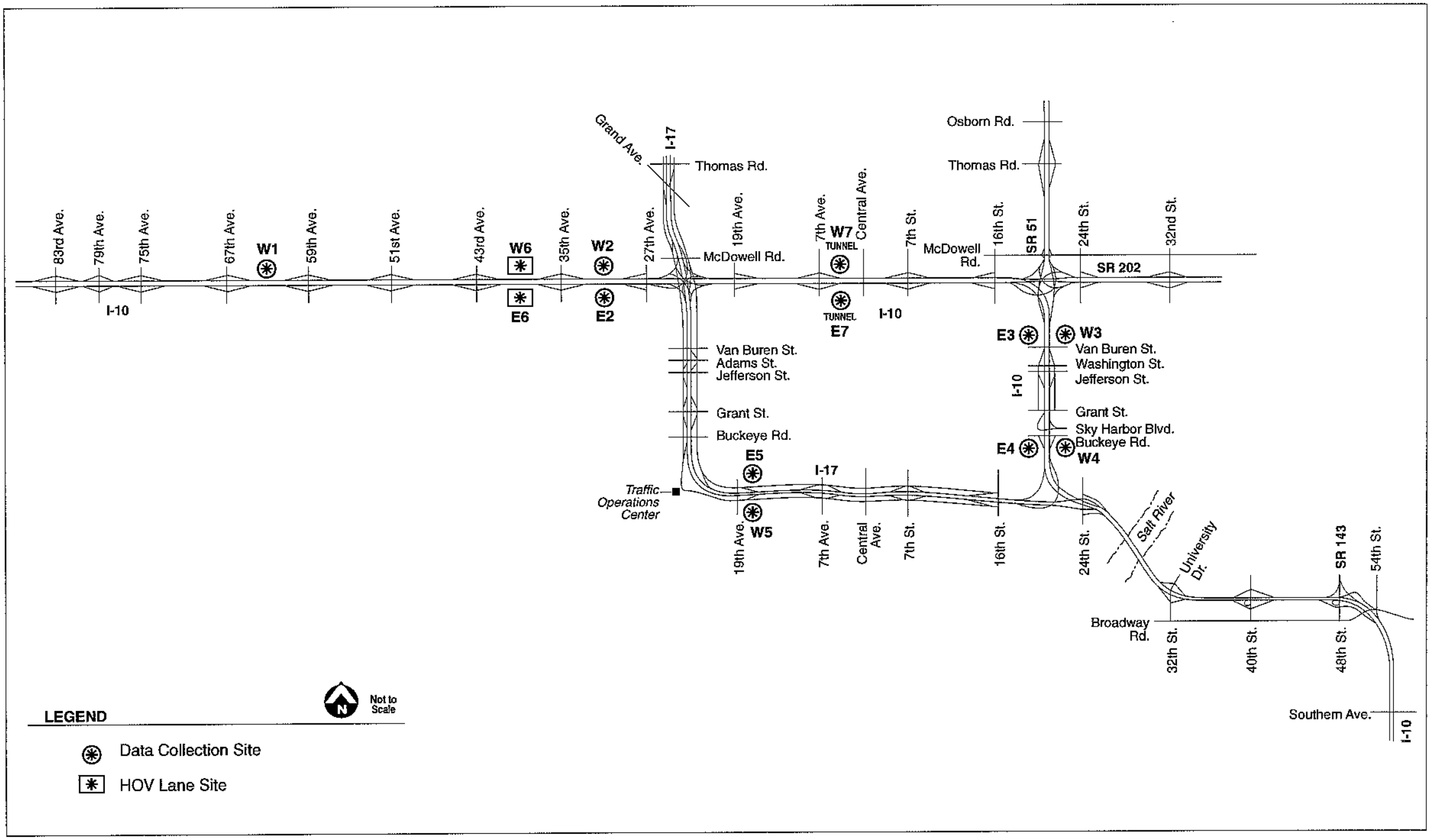


Figure 6
TRAFFIC VOLUME DATA COLLECTION SITES FOR BEFORE PERIOD ANALYSES

Accident Data

Accident data for the before and after periods were obtained from Arizona Department of Public Safety (DPS). The data included the accident location by milepost, date and time of each accident, number of vehicles involved, commercial vehicle involvement, and accident severity.

The accident data provided by DPS included all accidents associated with the freeway and the ramps. DPS could not facilitate sorting the data between mainline and ramp accidents. Data from the ADOT, ALISS system were not used because of the time lag between accident occurrence in the after period and entry of the data into the ALISS system.

Incident Data for the VMS Analysis

The evaluation of the VMS system consisted of an analysis to the driver response to the VMS displays for three case studies. The case studies consisted of three accidents that were selected based on the following criteria:

- Incident duration of approximately 30 minutes or more.
- Message display for approximately 30 minutes or more.
- Incidents occurring between 6:00 AM and 8:00 PM on a weekday.
- Incidents causing the blockage of at least one mainline traffic lane or the closure of an off-ramp.

Three accidents were selected based on these criteria and the following information was obtained from ADOT for each of the accidents:

- Location of the accident.
- Date and time of the accident.
- Location and text of each VMS message display.
- The time each message display was turned on and off.
- Five-minute traffic volumes by lane at selected locations for at least the 30 minutes before the message was displayed, the time during which the message was displayed, and for at least the 30 minutes after the message display was turned off. This same traffic volume information was also obtained for non-accident days that were used as additional controls for the analysis.

Incident Response Data

An Arizona Local Emergency Response Team (ALERT) unit is called out for major incidents to provide traffic control and assistance in clearing the incident and returning traffic to normal operations as soon as possible. When an incident occurs, and the Department of Public Safety (DPS) and/or ADOT Operations estimates that the roadway and/or one lane will be closed for one hour or more an ALERT unit is dispatched. During the before period 17 ALERT responses were made for accidents within the study area. In the after period 28 accidents resulted in an ALERT unit response. Copies of the ADOT incident response log reports for each incident were provided by ADOT. These reports include a description of the incident, date and time of the incident, incident location, the incident response time (time from the first notification of the incident to arrival at the incident location), and duration of the incident (time from the first notification of the incident to the return to normal traffic operations). The time data were used in an assessment of the incident response time and incident duration before and after implementation of the FMS.

On-Ramp Analysis Data

Three consecutive I-10 on-ramps within the study area were selected for data collection for the on-ramp evaluation. These ramps were the eastbound on-ramps at 51st, 43rd, and 35th Avenues. The ramp at 51st Avenue was not metered in the before condition but was metered in the after condition. The ramps at 43rd and 35th Avenues were both metered in the before and after condition. (Note that due to limitations in the availability of traffic volume data for lane 3 and for the on-ramps in the before period, the analysis of on-ramp travel time described in Chapter 4 was limited to only the 43rd Avenue on-ramp.)

Travel Time and Delay

On-ramp data collection was conducted for three consecutive days in January 1994 and October 1996 from 6:30 AM to 9:00 AM for the before and after periods, respectively. In addition, data were collected on a single day under free flow ramp traffic operations during both the before and after periods as a baseline for determination of the ramp delay during the peak period. Data collection procedures were the same for the before and after periods. A GPS equipped vehicle with a tape recorder was driven on the freeway, the vehicle would exit the freeway at each interchange and immediately re-enter the freeway using the subject on-ramp. The GPS equipment was used to record the vehicle position every two seconds. The GPS data were used to identify travel time on the ramp, and on-ramp delay. These variables were defined as follows:

- On-ramp travel time: The time required to travel the length of the on-ramp measured from the first crosswalk bar at the top of the ramp to the back of the gore at the bottom of the ramp.

- On-ramp delay: The difference in time between the peak period travel time on the ramp and the non-metered free flow travel time on the ramp.

Mainline and On-Ramp Traffic Volumes

Freeway mainline lane 3 and on-ramp traffic volumes were collected during the before period at only the 43rd Avenue on-ramp. A video camera was used to record traffic activity in lane 3 and on the ramp during the time periods of the travel time data collection. Traffic volume counts were recorded manually from a review of the video tape and summarized into 15-minute volume counts.

Freeway lane 3 and on-ramp traffic volumes were provided through the FMS loop detectors for the after period. Lane 3 volumes were provided through loop detectors immediately upstream of the on-ramps, and on-ramp volumes were calculated from mainline lane 3 detector data provided by detectors immediately upstream and immediately downstream of the ramp.

Data for Air Quality and Noise Level Estimation

The before and after assessment of the impacts of the FMS on vehicle emissions and noise levels was based on estimations generated using air quality and noise level models. The traffic volume and speed data used in the models were provided from the data collected as part of data collection activities described above. The volume data were taken form the data provided via the permanent traffic count stations in the before period and from the loop detector sites selected for the after period at the locations shown in Figure 7. The speed data were taken from the travel time runs and represents the speed recorded in the vicinity of the traffic volume collection location. Other data needed for the air quality analysis model were provided by the Maricopa Association of Governments (MAG) and represent the data used by MAG in performing Federally required air quality conformity assessments as part of the transportation planning process for the Phoenix metropolitan area.

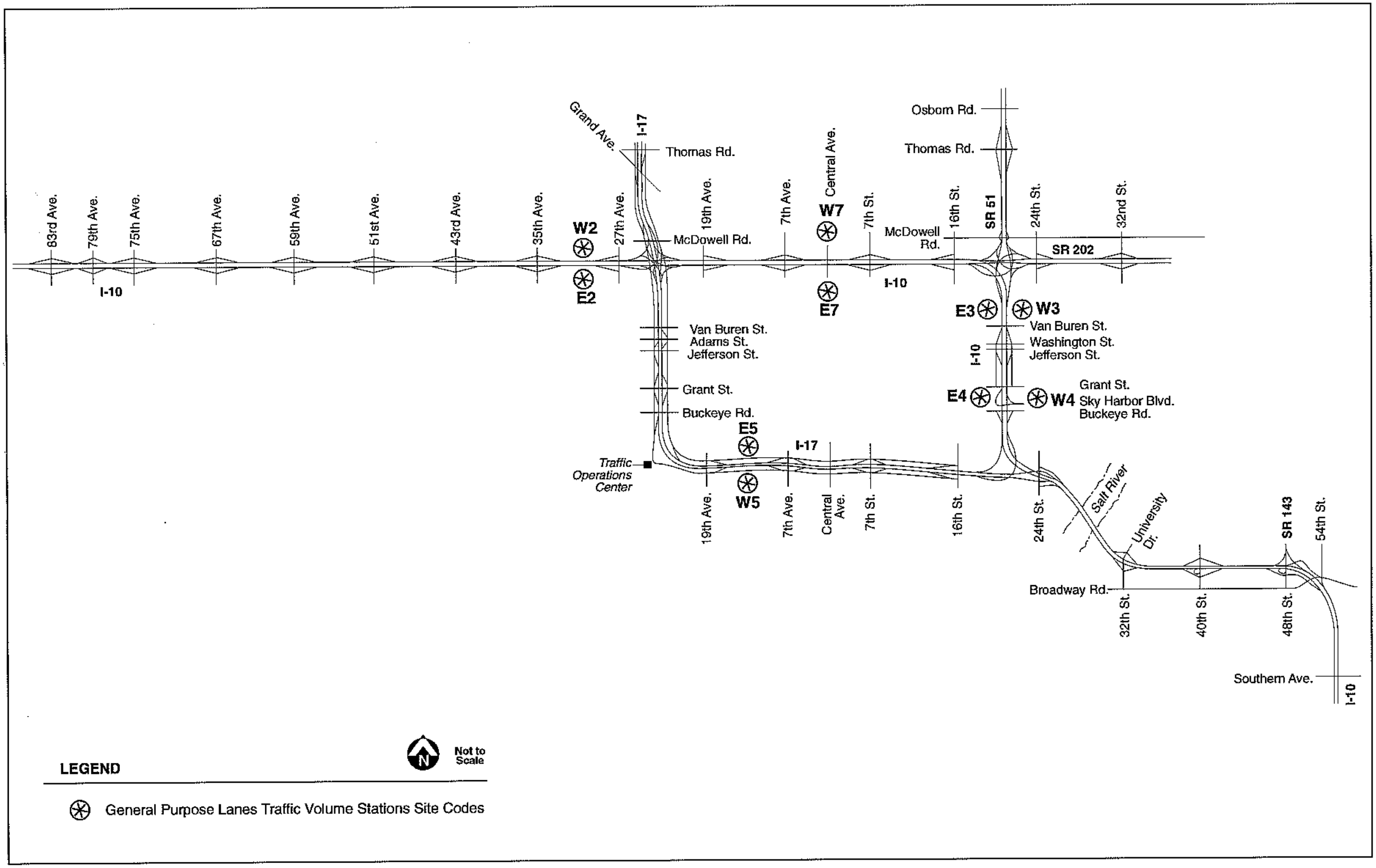


Figure 7
LOCATIONS FOR VOLUME AND SPEED DATA USED IN NOISE AND AIR ANALYSES

III. ANALYSIS OF FREEWAY TRAVEL TIME

STATISTICAL ANALYSIS OF TRAVEL TIMES

Freeway travel time data were collected for the complete circuit using a vehicle equipped with a global positioning system (GPS) device traveling in accordance with a specified procedure described in Chapter 2 of this report. Date, day of week, time of day, run number, lane, and direction of travel (clockwise or counterclockwise) of the route were laid out in a balanced data collection design.

Collected data were entered into a statistical linear regression model in which seconds of travel time was the dependent variable. Independent factors were day-of-week, AM/PM, peak period run number (1 through 4), direction of travel (clockwise or counterclockwise), lane occupied by the test vehicle (lane 3 was the right most continuous through lane, and lane 2 was the lane immediately to the left of lane 3), 'before' or 'after' 10-month period, and bimonthly classes of the study periods (May-June, July-August, etc.). Independent covariates were 30-minute traffic counts at seven counting stations located as described in Chapter 2 of this report. These counts were specific to the date, direction of travel, time of the travel time run (30-minute period in which the travel time run occurred) and the lane. The plan was to collect traffic count data at all seven stations for each run, but this objective was not fully accomplished due to the complete failure of count station 1 in the eastbound direction during the before study, and intermittent failure of other count stations to record data in both the before and after periods.

The theory underlying the linear regression model envisioned incorporating important factors and covariates known to influence freeway travel times in the hope they would account for a major portion of the variance in those travel times. A before-after term (B/A) was also included as a binary factor (0 or 1) in the regression. It was anticipated that, if the other terms in the model accounted for enough travel time variance, the B/A term would have a significant coefficient. This would indicate that something other than the factors and covariates included was accounting for a meaningful number of seconds in travel times as estimated by the model. If the coefficient were negative and statistically and operationally significant, then it would suggest that beneficial changes in the freeway management system (FMS) made between the before and after periods could be an important component of the beneficial change in travel times.

Two principal types of analysis were carried out. The first type examined travel times within the statistical model described above for complete circuits of the research routes. Recall that one of these routes begins near the northwest interchange of I-17 and I-10, runs south and east on I-17 to again intersect with I-10, then runs north and west on I-10 to 67th Avenue. This is the counterclockwise circuit. The second route runs in the opposite direction, starting where the first route ends. This is the clockwise circuit. The results of this type of analysis are reported in the section entitled FULL CIRCUIT ANALYSIS.

The second type of analysis examined travel times over only a portion of the counterclockwise route -- the segment of I-10 running west from near the northwest interchange with I-17 just east of 27th Avenue to 67th Avenue. The results of this type of analysis are reported in the section entitled SEGMENT ANALYSIS.

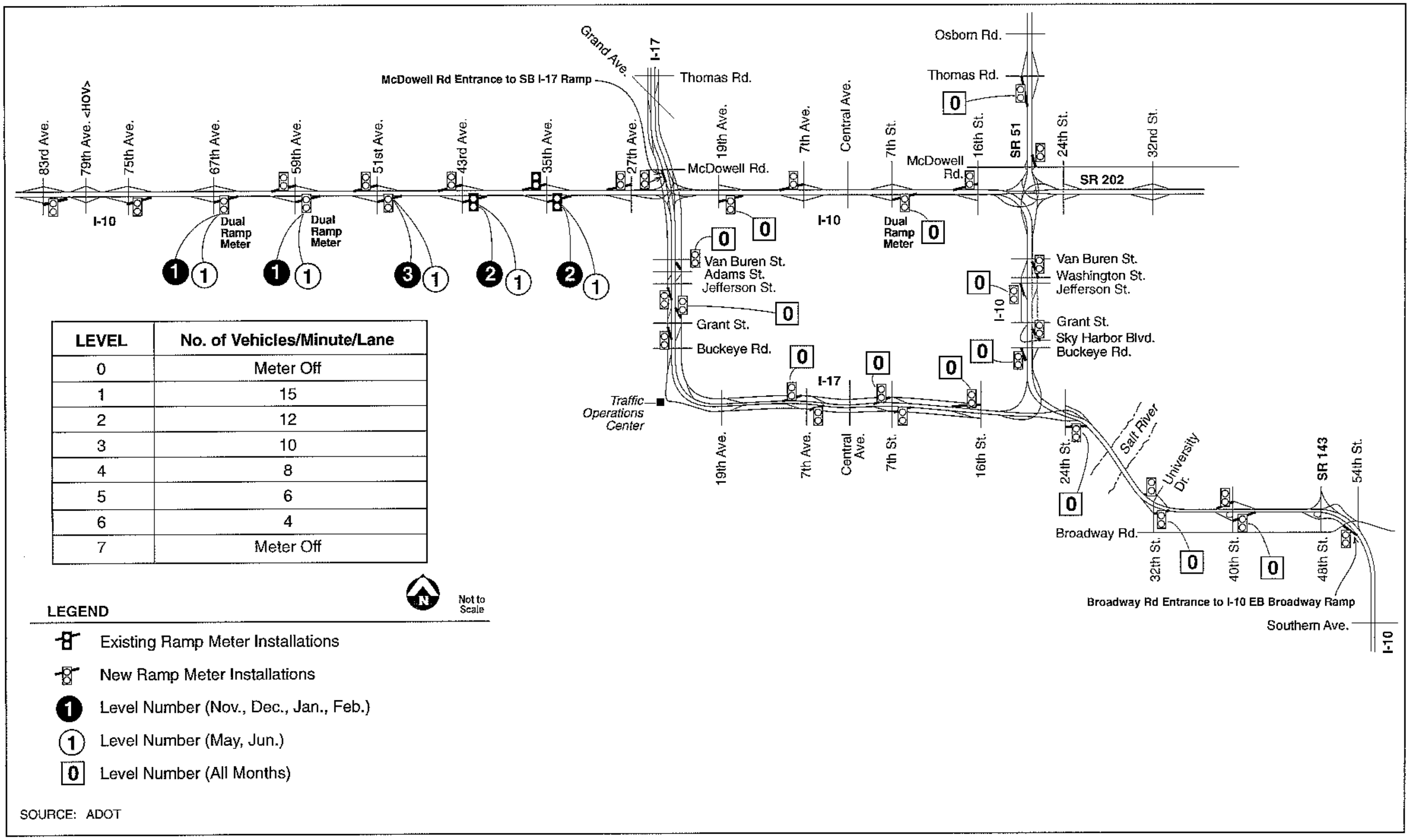
RAMP METER OPERATIONS

It was hypothesized that the existence and operation of the ramp meters during the after period would improve traffic flow in lanes 2 and 3 in comparison to the before condition. The location of the ramp meters for the before and after conditions was provided earlier in Figure 2 contained in Chapter 1 of this report. Ramp meters existed in the before condition only on the eastbound on-ramp at 43rd Avenue, and the east and westbound on-ramps at 35th Avenue. Ramp meters were installed at an additional 24 on-ramps within the study area for the after condition.

At the outset of this study, throughout the before data collection period, and through the implementation of the FMS, it was anticipated that all of the ramp meters within the study area would be functioning during the after period. The entire evaluation plan and travel time data collection effort were developed based on the expectation that all of the ramp meters would be operating during the after period. Travel time runs were made over the entire circuit of the freeway system within the study area during the before and after periods based on this expectation. This proved not to be the case as the majority of the ramp meters within the study area, although functional, were not operating during the after period. Figures 8 and 9 provide information on the typical operating condition of the ramp meters during the after period. As can be seen, only the ramp meters on I-10 west of the I-17 interchange were operating during the after period. This represents a 7.4 kilometer section of the 57 kilometer study area circuit.

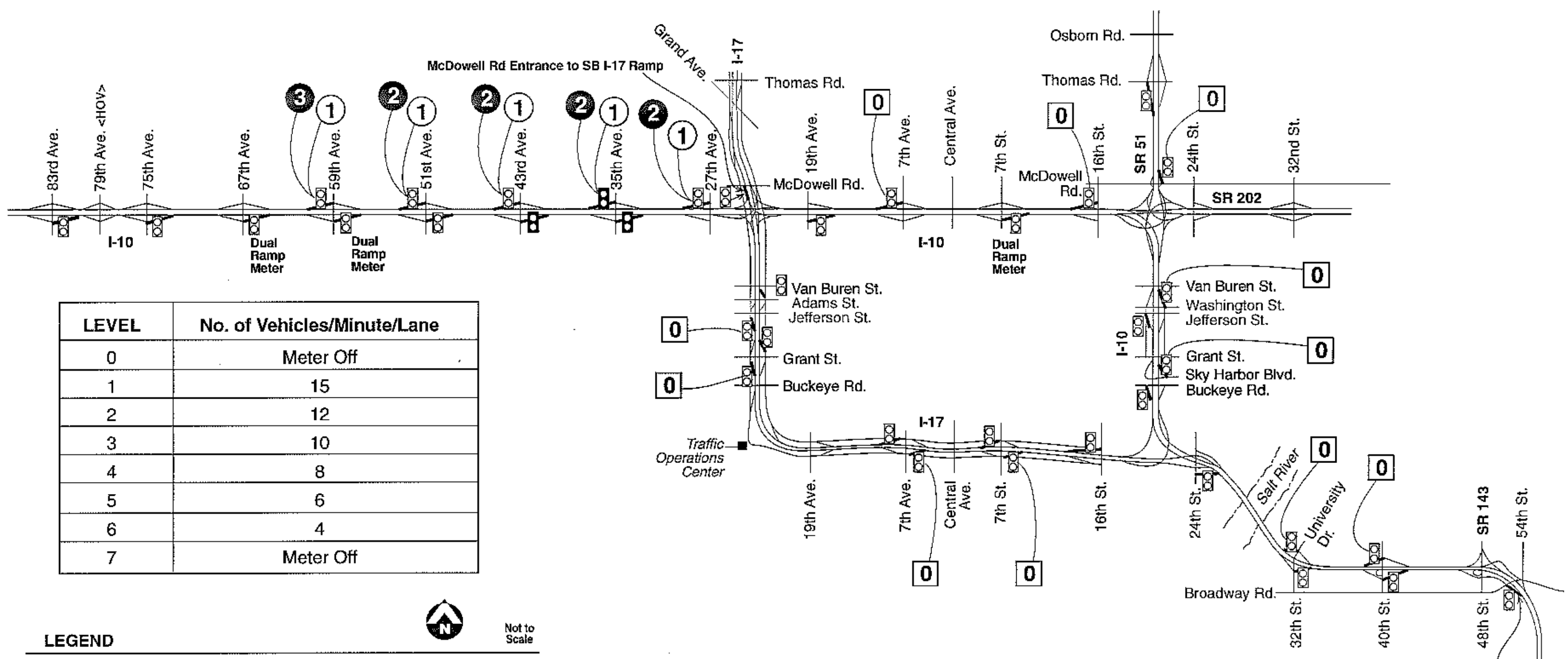
The ramp metering system is designed to operate in either of two modes. The system can operate in a fully traffic demand responsive mode where the ramp metering rates are established and vary based on lane 3 and on-ramp traffic volumes. The system can also operate in a fixed time mode where the metering rate is set at any one of several established metering rates. The fixed time rate can be set to vary by time of day. The ramp metering system was run in the fixed time mode during the entire after period. The typical metering rates used during the AM and PM peak periods are provided in Figures 8 and 9.

In addition, on each of the on-ramps a loop detector was installed at the top of the ramp to detect the presence of a queue. Under typical system operating conditions, if a queue was detected on the on-ramp, the ramp meter would release traffic to the freeway until the queue was cleared. When this occurs it is in effect a no-metering condition as in the before period. Information was not available to evaluate how often this condition might have occurred during the after period.



LEVEL	No. of Vehicles/Minute/Lane
0	Meter Off
1	15
2	12
3	10
4	8
5	6
6	4
7	Meter Off

Figure 8
TYPICAL RAMP METERING SYSTEM OPERATIONAL LEVELS DURING AFTER PERIOD FROM 6:30-7:00 AM EB DIRECTION



LEVEL	No. of Vehicles/Minute/Lane
0	Meter Off
1	15
2	12
3	10
4	8
5	6
6	4
7	Meter Off

LEGEND

- Existing Ramp Meter Installations
- New Ramp Meter Installations
- (1, filled) Level Number (Nov., Dec., Jan., Feb.)
- (1, circled) Level Number (May, Jun.)
- (0, boxed) Level Number (All Months)

SOURCE: ADOT

Figure 9
TYPICAL RAMP METERING SYSTEM OPERATIONAL LEVELS DURING AFTER PERIOD FROM 4:00-5:30 PM WB DIRECTION

The evaluation of the travel time data and the investigation of the impacts of the FMS on travel time were altered during the after period because the operation of the ramp meters did not meet the expectation that was the basis for establishing the evaluation plan. The evaluation of the travel time on the entire circuit was still conducted, but an additional evaluation of the travel time on only the segment of the freeway where the ramp meters were operating during the after period was added to the evaluation and is also reported on in this chapter.

FULL CIRCUIT ANALYSIS

Gaps in traffic count data caused curtailment of full-model analysis in which all seven stations could be included. If counts were not available for a given station in either the before or after period for a sequence of several observations, then that covariate had to be deleted from the statistical model to be applied to observations over that time period. Often more than one station had to be excluded for this reason.

Alternatively, some stations reported counts in only one direction for considerable periods. Station 1 (see Figure 6), for example, reported counts for only counterclockwise circuits during the entire before period. This meant that, when station 1 was included in the model, all observations for clockwise circuits had to be deleted. Similar directional gaps were encountered for all other stations.

Because of gaps, a number of partial analyses were run covering as much as possible of the 10-month observation periods. None of these produced B/A coefficients which were negative and significant.

November through February provided the longest period with nearly complete traffic counts, except for station 1 and station 2. Station 1 eastbound (clockwise) observations were missing, as noted above. Because of this limitation, only counterclockwise route data were used. Over half of station 2 traffic counts were missing so it was omitted from the November-February analyses to be described.

Although station 2 was largely missing from November-February, that station was available in several blocks of data for May through October. Hence these two time periods were analyzed separately. The following sections describe the full circuit evaluations that were performed and the results.

May-October, Lane 2, AM

Twenty eight observations (14 from the before period and 14 from the after period) were available for this analysis. Only counterclockwise observations were used in order to include station 1. The observations are shown in Table 2. In Table 2, OBS is the observation number from the master list of all observations, S1 through S7 refer to traffic counting stations, B and A denote before and after periods, and SEC is seconds of travel time to traverse the entire circuit in one direction. Means and percentage changes

Table 2
MAY - OCTOBER
LANE 2, AM, COUNTERCLOCKWISE
TRAFFIC COUNTS AND TRAVEL TIMES

	30-Minute Traffic Counts								Travel Time (seconds)	
OBS	S1B	S1A	S2B	S2A	S5B	S5A	S7B	S7A	SECB	SECA
50	368	432	513	551	661	729	857	985	1107	1053
52	369	433	451	525	601	647	730	818	1106	1096
57	402	435	526	563	674	797	794	919	***1136***	1022
59	375	392	529	525	699	772	850	957	1114	1056
130	395	229	505	287	694	562	741	864	1091	1057
132	342	266	473	283	641	490	698	803	1057	1055
137	356	431	501	594	689	488	749	854	1055	1042
139	362	413	461	571	694	756	808	959	1079	1086
146	382	420	526	539	675	733	781	925	1046	1039
148	425	407	464	524	602	592	718	773	1083	1058
153	394	449	489	651	631	758	740	763	1063	1082
155	400	427	498	573	688	693	835	854	1062	1056
210	430	484	498	567	680	738	824	675	1300	1055
212	401	438	435	492	674	714	782	640	1241	1051
Mean	386	404	491	518	665	676	779	842	1110	1058
Change%		4.7		5.5		1.8		8.1		-4.7
Without outliers:										
Mean	386	430	491	548	665	708	779	842	1078	1058
Change%		11.5		11.6		6.5		8.1		-1.9

S1 - S7 are count stations
OBS = observation number
B = Before
A = After
Underlined data = outliers deleted before regression
Bold, italicized data = outliers identified during regression and also deleted

appear at the bottom of the table both for complete data and with outliers omitted. Boxplots identified underlined observations as outliers. Boxplots are graphical devices which use probability theory to describe observations that belong to a given distribution as well as any that do not. Boxplot outliers (underlined in Table 2) were deleted before regression analysis. Observations in bold italic type were identified as outliers during regression runs and were also deleted. In general, outliers were eliminated from the regression analysis because they exert undue influence on the results in comparison to the remainder of the data. This influence can result in an unreasonable change in the generated regression coefficients.

The regression equation for the data after outliers were omitted was:

$$SEC = 1220 - 31.27TUE - 2.78WED - 28.9RN1 + 18.7RN2 + 7.45RN3 + 43.1MJ + 0.315S1 - 0.407S5 - 17.4B/A \quad (1)$$

Where: SEC is the total travel time in seconds to traverse the entire circuit in one direction,
TUE and WED represent Tuesday and Wednesday, respectively,
RN1, RN2, and RN3 represent run numbers 1, 2, and 3, respectively,
MJ represents the coefficient for the bimonthly period (May through June is +1, July through August is 0, and September through October is -1),
S1 and S5 represent the 30-minute traffic counts from stations 1 and 5, respectively and,
B/A represents the before/after condition (B/A = 1 in the after condition)

Both weekdays and runs remained in the relationship. Tuesday deducts 31.3 seconds from travel time, Wednesday deducts 2.78 seconds and Thursday adds 34 seconds (by substituting -1 for TUE and WED). Corrections for runs 1 through 3 are as given, and run 4 adds 2.8 seconds (again by substituting -1 for the earlier runs). May-June adds 43.1 seconds, July-August adds nothing (by substituting 0) and September-October deducts 43.1 seconds (by substituting -1). Note however that only two observations in the after period came from September-October, while both observations for the before period were eliminated as outliers. Stations 2 and 7 dropped out, leaving stations 1 and 5 as the most effective. All factors and covariates contributed significantly to the relationship. The apparent anomaly in the relationship between May-June and September-October cannot be explained.

The regression relationship is statistically significant ($F = 5.64,9,11$; $p = 0.005$), and 82.2% (R^2) of variance in travel times can be attributed to the relationship (As a technical note: R^2 adjusted = 67.6%).

The final term, -17.4B/A is coded "0" for before period observations and "1" for after period observations. This coefficient indicates that after allowing for the effects of all other factors and covariates in the equation there is a 17.4 second deduction from travel time in the after period. This is the type of favorable result the model was designed to detect. Changes in the Freeway Management System could be a contributor to this result.

The circuit length in the counterclockwise direction of travel was 29.1 kilometers. From the data in Table 2 which excludes outliers, the average travel speed over the entire circuit in the before period was 97.2 kph (60.1 mph) and in the after period it was 99.0 kph (61.3 mph).

May-October and Other Analyses

Analyses were also conducted for counterclockwise travel in lane 2, PM; lane 3, AM; and lane 3, PM. None of these analyses produced negative coefficients for the B/A terms. Data were insufficient to analyze clockwise travel for any of these combinations of lane and peak period.

November-February, Lanes 2 & 3, AM

Forty six observations (24 from the before period and 22 from the after period) were available for this analysis. Recall that only counterclockwise observations are used so that station 1 can be included. These data are shown in Table 3. In Table 3, OBS is the number of the observation as given in the master list for the entire study, S1 through S7 refer to traffic recording stations, B and A denote before and after periods, and SEC is seconds of travel time for the entire circuit in one direction. Means and percentage changes from the before to the after period appear at the bottom of Table 3. These results are for all the data and for the data after omission of outliers. Boxplots identified underlined observations as outliers. Boxplot outlier observations were deleted before regression analysis. Observations in bold italic type were identified during regression runs as outliers and were deleted.

The regression equation for the data after outliers were omitted was:

$$SEC = 1108 + 7.19TUE - 18.51WED + 33.8LN3 + 0.018S1 - 0.086S3 + 0.078S7 - 14.1B/A \qquad (2)$$

Where: The variables in this equation are defined in the same manner as in Equation 1 above.

Days of the week did a better job of prediction with this set of data than did travel time run numbers. This is not typical of most regression runs. Tuesday through Thursday were chosen because it was believed that they would not prove to be statistically different, but such was not the case here. Seven and 19 hundredths seconds must be added for Tuesday, 18.51 seconds subtracted for Wednesday and 11.32 seconds added for Thursday (found by substituting -1 for Tuesday and Wednesday and summing). Lane 3 added 33.8 seconds to travel time and lane 2 subtracted 33.8 seconds (found by

Table 3
CIRCUIT ANALYSIS,
NOVEMBER - FEBRUARY
LANE 2 OR 3, AM, COUNTERCLOCKWISE
TRAFFIC COUNTS AND TRAVEL TIMES

		30-Minute Traffic Counts										**Travel time (seconds)**	
OBS	LANE	S1B	S1A	S3B	S3A	S4B	S4A	S5B	S5A	S7B	S7A	SECB	SECA
242	2	418	465	489	555	858	870	755	731	859	767	1103	1100
244	2	348	397	479	523	793	805	601	666	772	752	***1059***	1106
249	2	<u>86</u>	468	425	388	759	772	771	825	846	858	1058	1074
251	2	<u>41</u>	<u>283</u>	507	297	919	661	749	558	849	<u>558</u>	1062	1072
258	3	446	500	574	710	1092	983	649	582	874	758	1204	1151
260	3	382	445	509	743	1062	884	570	580	734	709	1167	1123
265	2	424	483	815	374	982	720	608	849	899	950	1117	1139
267	2	410	420	755	993	915	944	596	747	808	891	1088	1037
274	3	460	492	653	889	798	942	703	543	855	842	1158	1115
276	3	407	417	625	725	835	828	816	656	756	826	1122	1134
281	3	489	457	583	747	759	850	815	682	861	786	1192	1146
283	3	413	458	665	995	882	1058	768	611	905	841	***1084***	1152
290	3	424	499	780	872	1067	851	573	716	898	903	1174	<u>1262</u>
292	3	375	458	912	848	1127	947	562	537	781	746	1115	1121
297	3	409		747		971		597		874		1117	
299	3	368		990		1232		635		900		1112	
306	2	477	492	633	542	811	856	789	805	811	1031	1110	1106
308	2	363	506	704	614	863	827	649	647	821	683	1100	1070
313	3	404	494	748	780	932	876	647	693	901	802	1144	<u>1245</u>
315	3	407	506	990	870	1112	<u>1145</u>	571	590	943	843	1139	1182
322	2	476	538	638	229	779	940	785	838	882	942	***1174***	1085
324	2	399	425	662	375	832	845	728	649	769	840	1090	1089
329	2	499	520	604	492	696	768	838	892	901	924	1085	***1066***
331	2	437	428	660	413	867	926	761	801	906	822	1113	1099
Mean		390	461	673	635	914	877	689	691	850	822	1120	1122
Change%			18.3		-5.6		-4.1		0.3		-3.4		0.1
		Without outliers:											
Mean		420	470	673	635	914	864	689	691	850	834	1122	1111
Change%			11.9		-5.6		-5.5		0.3		-1.9		-1.1

S1 - S7 are count stations

OBS = observation number

B = Before

A = After

Underlined data = outliers deleted before regression

Bold, italicized data = outliers identified during regression and also deleted

substituting -1 for lane 3). Station 2 was not included in any of the November through February analyses. In this analysis, stations 4 and 5 dropped out. The three terms for stations 1, 3, and 7 represent the most effective combination of traffic counts. Each of the included factors and covariates contributed significantly to the regression relationship.

The regression relationship as a whole is statistically significant (F = 15.94,7,28; p = 0.000), and 79.9% (R^2) of variance in travel times can be attributed to the relationship. (As a technical note: R^2 adjusted = 74.9%).

The final term, -14.1B/A, is coded "0" for before period observations and "1" for after period observations. This coefficient indicates that after allowing for the effects of all other factors and covariates in Equation 2, there is a 14.1 second deduction from travel time in the after period. This is an example of the result sought in the design of the statistical model. A possible factor contributing to this saving consists of changes made in the Freeway Management System between the before and after periods.

From the data in Table 3 excluding outliers, the average travel speed over the entire 29.1 kilometer circuit was 93.4 kph (57.8 mph) in the before period and 94.3 kph (58.4 mph) in the after period.

November-February, Lanes 2 & 3, PM

There were 46 observations (24 from the before period and 22 from the after period) available for this analysis. Only counterclockwise observations are used so that station 1 can be included. The data are shown in Table 4 where column headings are as defined previously for Table 3. Means and percentage changes both with and without outliers are shown at the bottom Table 4. Underlining identifies outliers resulting from boxplotting. Bold italics identifies outliers resulting from regression analysis.

The regression equation for the data after outliers were omitted was:

$$SEC = 1294 + 16.9RN1 + 28.5RN2 + 14.3RN3 + 30.8LN3 - 0.202S4 - 0.931S5 + 0.618S7 + 144B/A \quad (3)$$

Where: The variables in this equation are defined in the same manner as in Equation 1 above.

Runs 1 through 3 add from 16.9 to 14.3 seconds to travel time. Run 4 deducts 59.7 seconds (found by substituting -1 for runs 1 through 3 and summing). Lane 3 adds 30.8 seconds while Lane 2 deducts 30.8 seconds. Stations 1 and 3 drop out, while stations 4, 5, and 7 combine as shown. All included factors and covariates contributed significantly to the relationship.

Table 4
CIRCUIT ANALYSIS
NOVEMBER - FEBRUARY
LANE 2 OR 3, PM, COUNTERCLOCKWISE
TRAFFIC COUNTS AND TRAVEL TIMES

		30-Minute Traffic Counts										**Travel Time (seconds)**	
OBS	LANE	S1B	S1A	S3B	S3A	S4B	S4A	S5B	S5A	S7B	S7A	SECB	SECA
246	2	277	783	500	407	679	795	632	668	970	803	1159	1154
248	2	430	778	447	340	640	616	602	501	823	714	1140	1265
253	2	79	634	539	371	685	637	602	651	912	680	1076	1101
255	2	35	817	492	403	690	768	591	872	896	640	1288	1424
262	3	903	981	269	1016	1065	934	530	598	1029	813	1239	1686
264	3	890	1111	236	926	922	898	475	542	892	950	1144	1346
269	2	876	584	990	375	967	482	532	504	925	833	1099	1365
271	2	1063	796	1076	286	1082	618	551	641	943	889	1164	1239
278	3	830	999	499	1085	707	1067	612	665	936	879	1476	1166
280	3	885	922	496	900	640	859	533	528	731	756	1452	1171
285	3	721	930	576	1051	697	983	641	572	943	899	1140	1338
287	3	808	1096	573	1057	758	1007	616	581	995	861	1250	1325
294	3	980		1042		1020		570		1012		***1103***	
296	3	884		1053		937		501		863		1178	
301	3	942	972	1016	1057	1003	1003	565	594	1036	909	1252	1353
303	3	1083	1039	1097	1058	1107	1009	551	602	984	920	1178	***1504***
310	2	765	721	604	406	733	731	649	629	998	866	1145	1269
312	2	718	715	521	209	643	683	498	539	830	764	1124	2186
317	3	915	918	1033	1045	1027	994	574	614	945	889	1268	1227
319	3	1030	1020	1081	994	1118	997	574	589	971	933	***1399***	1268
326	2	776	796	632	393	744	796	674	666	980	901	1200	1187
328	2	695	661	487	449	639	652	502	561	871	844	1078	1227
333	2	767	797	635	298	740	812	650	705	1011	900	1195	1102
335	2	768	961	525	542	735	742	646	658	902	926	***1238***	1203
Mean		755	865	684	667	832	822	578	613	933	844	1208	1323
Change%			14.6		-2.5		-1.3		6.0		-9.6		9.5
		Without outliers:											
Mean		865	865	684	667	832	822	578	600	933	854	1175	1249
Change%			0.0		-2.5		-1.3		3.9		-8.5		6.3

S1 - S7 are count stations
OBS - observation number
B = Before
A = After
Underlined data = outliers deleted before regression
Bold, italicized data = outliers identified during regression and also deleted

The regression relationship is statistically significant (F = 6.93,8,24; p = 0.000), and 69.8% (R^2) of variance in travel times can be attributed to the relationship. (As a technical note: R^2 adjusted = 74.9%).

The final term, +144B/A, is coded "0" for before period observations and "1" for after period observations. After allowances for all other terms in the relationship, 144 seconds must be added to after-period observations. For the PM peak period on counter-clockwise travel in November through February, travel times in the after period were much longer than the other terms in the equation indicated.

From the data in Table 4 excluding outliers, the average travel speed over the entire 29.1 kilometer circuit was 89.2 kph (55.4 mph) in the before and 83.9 kph (52.1 mph) in the after period.

SEGMENT ANALYSIS

A portion of the entire circuit used to measure travel times was defined for segment analysis. This segment consisted of approximately 7.4 kilometers of I-10 westbound from just east of 27th Avenue to 67th Avenue. Traffic counts were made at two stations: I-10 East of 63rd Avenue (station 1) and I-10 West of 31st Avenue (station 2) as shown in Figure 6. The segment was selected because ramp metering was not in operation during the before period except at 35th Avenue, but was in operation during the after period, and traffic counts were available at the two stations in the westbound direction. Hence, by using the before period as a criterion, this data base held promise of providing measures of ramp metering effectiveness.

Sixty four matched cases were available for analyses of travel times for the segment analysis. These 64 matched cases, when separated into before and after subsets, potentially provided 128 cases for regression analyses.

Recall that the regression model for this study contains factors for day of the week (Tuesday through Thursday), AM or PM, research vehicle run number (1 through 4), lane (2 or 3), bimonthly period, and whether the observation was for the before or after period. Covariates include run-and-lane-specific traffic counts at traffic stations. The dependent variable is research vehicle travel time in seconds.

Analyses on the entire data set for the segment study failed to produce any useful results. This set was then sorted into 4 subsets: lane 2 for PM runs, lane 3 for PM runs, lane 2 for AM runs and lane 3 for AM runs. Results of these four analyses are described in the following sections of this report.

Lane 2, PM

Thirty six observations (18 from the before period and 18 from the after period) were available for this analysis. These data appear in Table 5. In Table 5, OBS is the number of the observation as determined from the master list for the entire study. S1 refers to traffic recording station 1 and S2 refers to station 2 as described above. "B" and "A" denote observations in the before and after periods of the study. SEC is seconds of travel time for the research vehicle to traverse only the segment being evaluated. Means and before-to-after percentage changes in traffic and travel times appear at the bottom of the table. Boxplots identified the underlined observations as outliers, and the entire before or after observation was deleted before making the regression runs. Observations in bold italic type were identified as outliers during regression runs and were deleted from subsequent runs.

The regression equation for the data edited as described above was:

$$SEC = 497 - 14.9RN1 - 4.0\,RN2 + 42.0RN3 - 23.9MJ - 29.9JA + 52.1SO - 0.136S1 - 0.066S2 + 23.3B/A \quad (4)$$

Where: RN1, RN2, and RN3 refer to the research vehicle run number 1, 2, and 3, respectively,
MJ, JA, and SO refer to the bimonthly period May-June, July-August, and September-October, respectively,
S1 and S2 represent the traffic volume at station 1 and 2, respectively, and,
B/A represents the before/after binary variable 0 for the before period and 1 for the after period.

Day-of-week dropped out because this factor did not contribute significantly to the relationship. Run 3 (5:30-6:00 PM) added 42 seconds to travel time while run 1 deducted 14.9 seconds and run 2 deducted 4 seconds. The effect for run 4 can be found by substituting -1 for runs 1 through 3 and summing (14.9 + 4.0 - 42.0 = - 23.1 seconds). Travel times during May-June (MJ above) require deducting 23.9 seconds. The November-December (ND) observations were eliminated as outliers. To find the JF (January-February) effect, substitute -1 for MJ, JA, and SO and sum (23.9 + 29.9 - 52.1 = 1.7 seconds). The S1 and S2 terms are a weighted combination of the lane 2 traffic counts at the two stations. There appears to be a slight negative relationship between travel times and traffic. The heavier the traffic the less the travel time. These coefficients are, however, not statistically significant from 0 while all other terms in the equation have coefficients that are significant.

The regression relationship as a whole is significant ($F = 10.67,9,18$; $p = 0.000$), and 84.2% (R^2) of variance in travel times is attributable to the relationship. (As a technical note: R^2 adjusted = 76.3%.)

Table 5
SEGMENT ANALYSIS,
LANE 2, PM
TRAFFIC COUNTS AND TRAVEL TIMES

	30-Minute Traffic Counts				**Travel Time (seconds)**	
OBS	S1B	S1A	S2B	S2A	SECB	SECA
54	764	808	879	737	308	320
56	719	717	907	680	301	340
61	625	792	785	954	305	318
63	765	872	874	474	361	383
134	725	772	834	945	324	304
136	700	769	797	882	294	304
141	665	736	837	984	299	327
143	763	827	841	920	345	331
150	699	775	799	1017	329	304
152	668	714	813	830	304	311
157	743	776	798	1001	295	310
159	716	826	852	820	388	393
214	748	857	246	860	307	390
216	767	851	234	690	295	394
246	277	783	827	931	338	***337***
248	430	778	700	811	335	***419***
310	765	721	889	854	335	379
312	718	715	731	841	317	342
Mean	681	783	758	846	321	345
Change%		14.9		11.6		7.4
		Without outliers:				
Mean	722	783	823	868	317	341
Change%		8.4		5.5		7.4

S1 - S2 are count stations
OBS = observation number
B = Before
A = After
Underlined data = outliers deleted before regression
Bold, italicized data = outliers identified during regression and also deleted

The final term, + 23.3B/A, is coded "0" for before period observations and "1" for after period observations. The coefficient indicates that, after correcting for the effects of all factors and covariates in the equation, there is a 23.3 second addition to travel time in the after period for travel in lane 2 westbound during the PM peak period. It appears that the heavy westbound traffic movement in the PM with heavier off-ramp movements on this segment overpowers any beneficial effect of the ramp metering.

This is a 7.4 kilometer segment of the freeway system. Based on the data in Table 5 excluding outliers, the average travel speed was 83.7 kph (52.0 mph) in the before condition and 77.8 kph (48.3 mph) in the after condition.

Lane 3, PM

Twenty eight observations (14 from the before and 14 from the after period) were available for this analysis. These data are presented in Table 6. The column identifiers for Table 6 are the same as those for Table 5 described earlier. Boxplots identified the underlined observations as outliers, and, in each case, the observation was deleted prior to regression analysis.

The regression equation for the data edited as described was:

$$\begin{aligned} SEC = \; & 339 - 39.2TUE + 38.5WED - 51.9RN1 + 34.8RN2 + 1.0RN3 \\ & - 85.7MJ + 86.2JA - 0.078S1 + 0.107S2 + 44.6B/A \end{aligned} \tag{5}$$

Where: The variables in this equation are defined in the same manner as in Equation 4 above.

Day of the week remained in the equation this time. This factor shows a heavy negative correction (-39.2 seconds) for Tuesday and a heavy positive correction (+38.5 seconds) for Wednesday. Coding both of these factors with -1 for Thursday makes the correction +0.7 seconds. Factors for September-October (SO) and for November-December (ND) dropped out because of high intercorrelations. January-February observations, however, are included by using -1 codes for MJ (May-June) and JA (July-August). Again, coefficients for traffic counts at stations 1 and 2 are not significantly different from 0.

The regression relationship as a whole is significant ($F = 5.53, 13, 10$; $p = 0.003$), and 81.0% (R^2) of variance in travel times is attributable to the relationship. (As a technical note: R^2 adjusted = 66.3%.)

The final term in Equation 5, + 44.6B/A, is again coded 0 for before period observations and 1 for after period observations. After correcting for all other terms in the equation, travel time in the after period requires an additional 44.6 seconds. Comparison of station 1 traffic counts in Table 5 with those for lane 3 Table 6 shows that

Table 6
SEGMENT ANALYSIS,
LANE 3, PM
TRAFFIC COUNTS AND TRAVEL TIMES

	30-Minute Traffic Counts				Travel Time (seconds)	
OBS	S1B	S1A	S2B	S2A	SECB	SECA
70	724	882	947	824	356	355
72	802	840	953	670	314	291
125	838	911	621	<u>406</u>	325	338
127	933	1027	535	<u>519</u>	381	369
198	882	800	<u>210</u>	792	360	413
200	992	751	<u>204</u>	731	397	354
205	839	753	531	739	313	402
207	959	826	468	721	374	421
262	903	981	713	792	359	456
264	890	1111	673	714	340	400
294	980	1058	665	854	297	374
296	884	931	553	720	333	395
301	942	972	696	954	327	396
303	1083	1039	737	849	369	419
Mean	904	920	608	735	346	385
Change%		1.8		20.9		11.1
Without outliers:						
Mean	904	920	674	780	346	385
Change%		1.8		15.7		11.1

S1 - S2 are count stations
OBS = Observation number
B = Before
A = After
Underlined data = outliers deleted before regression
Bold, italicized data = outliers identified during regression and also deleted

lane 3 traffic counts were much greater than those in lane 2. This segment exhibits conditions that could be considered typical for the outbound traffic movement during the afternoon peak period. The higher volume of traffic in lane 3 on this freeway segment may be overwhelming any effects from ramp metering.

Based on the data in Table 6 excluding outliers, the average speed over this segment was 76.7 kph (47.7 mph) in the before condition and 68.9 kph (42.8 mph) in the after condition.

Lane 2, AM

Thirty six observations (18 from before, 18 from after) were available and are shown in Table 7. Boxplots identified the underlined observations as outliers. Four observations in bold italic type were identified as outliers in regression runs and deleted, as were the boxplot outliers.

The regression equation for the edited set of data was:

$$SEC = 215 - 6.05RN1 - 3.91RN2 - 1.33RN3 + 9.58MJ - 4.46JA + 12.6SO - 0.123S1 + 0.251S2 - 17.4B/A \quad (6)$$

Where: The variables in this equation are defined in the same manner as those in Equation 4 above.

The regression relationship as a whole is significant ($F = 5.15, 9, 16$; $p = 0.002$), and 74.3% (R^2) of the variance in travel times is attributable to the relationship. (As a technical note: R^2 adjusted = 59.9%)

Day-of-week dropped out because this factor did not contribute significantly to the relationship. Each of the earlier three run times involves from 6.05 to 1.33 seconds decrease in travel time. But the fourth run adds 11.3 seconds (6.05 + 3.91 + 1.33) to travel time. All four January-February observations were deleted as outliers. Hence, the November-December effect can be had by substituting -1 for MJ, JA and SO. The result is -17.7 seconds (-9.58 + 4.46 - 12.6). The S1 and S2 terms comprise a weighted average of lane 2 traffic counts at the two stations. All factors and covariates in the equation contribute significantly to the overall relationship.

The final term, - 17.4B/A, is coded 0 for the before period and 1 for the after period. The coefficient indicates that, after allowing for the effects of all other factors and covariates in the equation, travel times in the after period are 17.4 seconds less than in the before period. It appears that ramp metering has been effective in reducing travel time in lane 2 in the morning peak period. There was an average traffic count of 501.6 per half hour for stations 1 and 2, or a total of 2006.4 for the two hours during which travel time data collection runs were made. A saving of 17.4 seconds per vehicle

Table 7
SEGMENT ANALYSIS,
LANE 2, AM
TRAFFIC COUNTS AND TRAVEL TIMES

OBS	30-Minute Traffic Counts S1B	S1A	S2B	S2A	Travel Time (seconds) SECB	SECA
50	368	432	513	551	309	290
52	369	433	451	525	307	294
57	402	435	526	563	308	287
59	375	392	529	525	303	283
130	395	229	505	287	283	295
132	342	266	473	283	272	286
137	356	431	501	594	285	283
139	362	413	461	571	280	292
146	382	420	526	539	289	274
148	425	407	464	524	282	286
153	394	449	489	651	298	291
155	400	427	498	573	290	274
210	430	484	498	567	293	288
212	401	438	435	492	305	288
242	418	465	533	616	289	296
244	348	397	435	520	288	294
306	477	492	534	653	288	***291***
308	363	506	445	706	***313***	284
Mean	389	418	490	541	293	288
Change%		7.3		10.5		-2.0
	Without outliers:					
Mean	384	439	490	564	293	289
Change%		14.2		15.2		-2.0

S1 - S2 are count stations
OBS = observation numbers
B = Before
A = After
Underlined data = outliers deleted before regression
Bold, italicized data = outliers identified during regression and also deleted

amounts to a saving of 34126.2 seconds, or 9.48 hours for the morning peak period. This represents a travel time reduction of approximately 6 percent over this segment in lane 2 during the AM peak period.

Based on the data in Table 7 excluding outliers, the average travel speed over this segment was 90.6 kph (56.3 mph) in the before condition and 91.8 kph (57.0 mph) in the after condition.

Lane 3, AM

Twenty eight observations (14 from before, 14 from after) were available and are shown in Table 8. Boxplots identified the underlined observations as outliers. Observations in bold italic type were identified as outliers in regression runs. Both types of outliers were deleted before final regression runs.

The regression equation for the edited set of data was:

$$SEC = 255 + 4.67RN1 + 2.89RN2 - 4.88RN3 + 2.65MJ - 20.6JA + 16.0SO + 0.0933S2 - 6.44B/A \quad (7)$$

Where: The variables in this equation are defined in the same manner as in Equation 4 above.

The regression relationship as a whole is only marginally significant ($F = 2.15, 8, 11$; $p = 0.119$), and 61.0% (R^2) of the variance in travel times is attributable to the relationship. (As a technical note: R^2 adjusted = 32.7%)

Day-of-week dropped out because this factor did not contribute significantly to the relationship. The first two run times add to travel time, the third subtracts 4.88 seconds, and the fourth subtracts 2.68 seconds. November-December drops out of the equation, but the January-February correction results from substituting -1 for the bimonthly terms in the equation (- 2.65 + 20.6 -16.0 = +1.95 seconds). Dropping station 1 from the analysis improved the relationship noticeably. All factors and the one covariate had coefficients which were not statistically significant. This result probably came about because of the small number of observations remaining after all deletions (20).

The final term, - 6.44B/A, is coded 0 for the before period and 1 for the after period. The coefficient indicates that, after allowing for the effects of all other factors and covariates in the equation, travel times in the after period are 6.44 seconds less than in the before period. It appears that ramp metering may have been effective in reducing travel time in lane 3 in the morning rush hour. There was an average traffic count of 479.0 per half hour for stations 1 and 2, or a total of 1916 for the two hours during which runs were made. A saving of 6.44 seconds per vehicle amounts to a saving of 12,339 seconds, or 3.43 hours for the morning peak period. This represents a travel time reduction of approximately 2 percent over this segment in lane 3 during the AM peak period.

Based on the data in Table 8 excluding outliers, the average travel speed over this segment was 87.7 kph (54.4 mph) in the before period and 88.4 kph (54.9 mph) in the after period.

TRAFFIC VOLUME, FREEWAY CONGESTION, AND TRAVEL TIME

The analysis procedures contained in the 1994 Highway Capacity Manual (HCM) indicate that the capacity of a six-lane freeway at an on-ramp junction is approximately 5,200 to 5,600 vehicles per hour in one direction of travel, with the combined capacity of the two right hand through lanes (referred to as lanes 3 and 2 in this study) being in the range of 3,600 to 3,900 vehicles per hour. Ramp meters are most effective at maintaining or improving travel speeds when the freeway traffic volume is at or near capacity and there is the danger of the additional on-ramp volume creating an unstable flow condition.

Review of the traffic volumes presented in Tables 7 and 8 indicates that the average of the total combined traffic volume in lanes 2 and 3 for the AM segment analysis was 1,960 vehicles per hour in the after period (without outliers). This is approximately two-thirds of the combined total volume for the two lanes where the ramp meters would be considered most effective. Therefore, it should not be expected that the ramp meters would be more effective than the 2 to 6 percent reduction in travel time found under the traffic conditions of this study.

Review of the 30-minute traffic volume data provided in Tables 2 and 3 reveals a similar situation for the entire circuit during the AM peak period. In general, the hourly traffic flow rates based on the 30-minute volumes appear well below the levels where ramp metering would be expected to be most effective. The hourly flow rates for lanes 2 and 3 can be estimated by assuming the lane 2 and 3 volumes to be approximately equal and then multiplying the 30-minute volumes in the table by a factor of four. There are individual cases at some traffic count stations where the volumes are high enough where ramp metering would be effective. However, as noted earlier, the ramp meters were in operation on only an 7.4 kilometer portion of the 57 kilometer study area.

As traffic volume on the freeway system increases, the effectiveness of the ramp meters in improving freeway travel time should become more apparent. This will be particularly true when the metering system is in operation over the entire circuit.

Review of the average travel speeds before and after installation of the FMS also indicates that the freeway was operating at a generally good level of service. Average speeds for the entire circuit exceeded 88 kph (55 mph), and average speeds on the segment where the ramp meters were turned on was also approximately 88 kph (55 mph)

Table 8
SEGMENT ANALYSIS,
LANE 3, AM
TRAFFIC COUNTS AND TRAVEL TIMES

	30-Minute Traffic Counts				Travel Time (seconds)	
OBS	S1B	S1A	S2B	S2A	SECB	SECA
66	<u>253</u>	420	533	438	306	299
68	<u>240</u>	381	488	422	303	283
121	321	<u>212</u>	339	<u>259</u>	***303***	306
123	353	<u>187</u>	462	<u>270</u>	<u>375</u>	297
194	387	506	372	518	315	<u>340</u>
196	371	411	342	488	292	315
201	347	451	333	518	309	309
203	395	463	360	481	300	302
258	446	500	479	530	308	291
260	382	445	423	471	***324***	293
290	424	499	508	558	306	298
292	375	458	440	463	286	300
297	409	518	452	606	301	319
299	368	446	534	504	305	290
Mean	362	421	433	466	310	303
Change%		16.3		7.6		-2.1
	Without outliers:					
Mean	381.5	458.2	433.2	499.8	302.8	300.2
Change%		20.1		15.4		-0.9

S1 - S2 are count stations
OBS = observation numbers
B = Before
A = After
Underlined data = outliers deleted before regression
Bold, italicized data = outliers identified during regression and also deleted

during the AM peak period where a travel time reduction was identified. It is conceivable that when traffic congestion worsens on the freeway system that the ramp metering system will have more of an impact on improving freeway travel times than was recorded in this study.

SUMMARY

The evaluation of travel time before and after the implementation of the FMS attempted to account for a number of factors that could influence the result. Time of day, day of week, month of year, travel lane, and traffic volume were among the variables considered in the analysis, as well as the presence of the FMS before and after. Travel time data were collected using a floating car equipped with a GPS device to record vehicle position every two seconds. These data were used to determine vehicle travel time over the entire freeway circuit and over individual segments of the study circuit. The vehicle traversed a 57 kilometer section of the freeway system in both directions of travel over a ten month period both before and after the FMS was installed. It was hypothesized that the presence of the ramp meters in the after condition would reduce vehicle travel time on the freeway, all other factors being accounted for in the analysis.

The analysis of travel time was conducted for the entire 57 kilometer freeway circuit within the study area, and for a 7.4 kilometer segment of the freeway on westbound I-10 from the interchange with I-17 to 67th Avenue. The 7.4 kilometer segment of the freeway was the only section of the entire circuit where the ramp meters were in operation during the after time period. There was a slight improvement in travel time over the entire circuit in lane 2 during the AM peak period, amounting to approximately 1.6 percent. This appears related to the presence of operating ramp meters on the 7.4 kilometer section of freeway on the west end of the study area.

The analysis of the isolated segment of the freeway where the ramp meters were functioning in the after period did identify a two to six percent reduction in travel time in the after period during the AM peak period after accounting for the effects of all other variables. Given the traffic volume and ramp metering conditions during the after period, this result is considered to be the minimum improvement in travel time that could be expected from the FMS. The analysis of the PM peak period did not reveal any improvement in travel time in the after condition for the segment analysis.

Traffic volumes and travel speeds on the freeway, and the operating conditions of the ramp metering system did not provide an after condition environment that would demonstrate a travel time savings over the entire circuit. In general, freeway traffic volumes are considered too low and travel speeds too high on several portions of the circuit to demonstrate the maximum effectiveness of the ramp metering system. In addition, the majority of the ramp meters were not operating during the after period. This condition reduced the effectiveness of the system overall, and resulted in a measurable travel time savings on only the segment of the freeway where the meters were in operation.

SUGGESTIONS TO IMPROVE STUDY PROCEDURES

The major suggestion to improve the analysis of the effectiveness of the ramp metering system on travel time would be to activate all of the ramp meters over the entire circuit for the after period. Given that the majority of the ramp meters were not operating during the after period of this study, the data collected during the after period of this study could function as the before period for a condition where all of the meters are turned on. This would eliminate the need for further before data collection and provide a sound database for comparison to the condition where all of the meters are operating. In addition, it appears beneficial to conduct travel time data collection with the meters operating in a fixed time mode and a demand responsive mode as separate evaluation tests. This additional information could be used to determine if there is any difference in the effects of the operating mode on travel time. The use of the after period database from this study as the before condition for a continued analysis would also provide an expanded traffic volume database for the study. Several problems existed with the before period traffic volume database that could not be overcome.

An alternative evaluation plan, which would provide a far more comprehensive traffic volume database for the analysis, would be to conduct a new before period data collection effort with all of the ramp meters turned off, and then repeat the travel time data collection effort with all of the meters turned on as discussed above. Traffic volume information would be available between every interchange from the FMS traffic detection and data retrieval system, which would strengthen the relationship between volume and travel time in the analysis.

IV. ON-RAMP TRAVEL TIME ANALYSIS

STATISTICAL ANALYSIS OF ON-RAMP TRAVEL TIME

The travel time analysis evaluated the on-ramp travel time at the 43rd Avenue eastbound on-ramp to I-10. This ramp was metered in both the before and after conditions. Travel time on the ramps was collected using a vehicle equipped with a global positioning device to record vehicle position every two seconds while traversing the ramp. These data were used to determine on-ramp travel time. Travel time on the ramp was defined as the time required to travel the length of the on-ramp measured from the first crosswalk bar at the top of the ramp to the back of the gore at the bottom of the ramp.

Two hypothesis were tested in the evaluation of the before and after data. The first was that on-ramp travel times are proportional to the lane 3 traffic volumes upstream of the on-ramp. The second was that the on-ramp travel times are proportional to the on-ramp traffic volume. These hypotheses were used to evaluate on-ramp travel times because the travel time can be affected by both the lane 3 traffic volume approaching the on-ramp junction and the on-ramp volume. Therefore, it was important to account for these factors in the analysis.

These hypotheses were tested using a chi square analysis in the comparison of the before and after data. The chi square analysis requires the use of matched pairs of data from the before and after period. Overall 30 on-ramp travel time runs were conducted in the before period and 16 were conducted during the after period. All of the runs were conducted between 6:30 AM and 9:00 AM. Due to limitations in the availability of traffic volume data for lane 3 and for the on-ramps, or the availability of travel time data for some runs, the analysis was confined to testing the hypotheses for only seven matched pairs from the before and after periods. Data for only a single day (Wednesday) were available in the after period, and the analysis was confined to only the analysis of Wednesday in the before and after periods to provide the required matched pairs.

Ramp Travel Time and Lane 3 Volume

The comparison of the on-ramp travel time data and the lane 3 volume data is contained in Table 9. The travel time in seconds is shown during the half hour time period in which the data were recorded. Two travel time runs were conducted during each half-hour time period except for the 8:30-9:00 half-hour. The associated half-hour traffic volume in lane 3 during the same half hour period as the travel time run is also provided. The expected travel time based on the lane 3 traffic volume was computed for each cell of the matrix by dividing the cell value of the volume by the row total volume and multiplying the result by the row total travel time.

Table 9

ON-RAMP TRAVEL TIME ANALYSIS*

NULL HYPOTHESIS: BY HALF HOUR, BEFORE AND AFTER TRAVEL TIMES ARE PROPORTIONAL TO TRAFFIC VOLUMES.

TRAVEL TIMES (SECONDS)

TIME PERIOD	BEFORE	AFTER	TOTAL
0630-0700	51	24	75
0630-0700	121	42	163
0700-0730	53	24	77
0730-0800	100	44	144
0800-0830	101	26	127
0800-0830	78	31	109
0830-0900	62	16	78
TOTAL	566	207	773

MAINLINE LANE 3 30-MINUTE VOLUME

TIME PERIOD	BEFORE	AFTER	TOTAL
0630-0700	337	347	684
0630-0700	302	277	579
0700-0730	372	317	689
0730-0800	371	278	649
0800-0830	300	290	590
0800-0830	317	264	581
0830-0900	262	275	537
TOTAL	2261	2048	4309

EXPECTED TIMES FROM LN3 VOLUME (SECONDS)

TIME PERIOD	BEFORE	AFTER	TOTAL
0630-0700	37.0	38.0	75
0630-0700	85.0	78.0	163
0700-0730	41.6	35.4	77
0730-0800	82.3	61.7	144
0800-0830	64.6	62.4	127
0800-0830	59.5	49.5	109
0830-0900	38.1	39.9	78
TOTAL	408.0	365.0	773

CHI SQUARE TABLE

TIME PERIOD	BEFORE	AFTER	TOTAL
0630-0700	5.3	5.2	10.5
0630-0700	15.2	16.6	31.8
0700-0730	3.1	3.7	6.8
0730-0800	3.8	5.1	8.9
0800-0830	20.5	21.3	41.8
0800-0830	5.8	6.9	12.7
0830-0900	15.1	14.4	29.4
TOTAL	68.9	73.1	142.0
PROBABILITY			0.00

CONCLUSION:

THE OVERALL CHI SQUARE (142.0) IS HIGHLY SIGNIFICANT. TRAVEL TIMES ARE NOT CONSISTENT WITH LANE 3 TRAFFIC VOLUME. LARGE DISCREPANCIES ARE SCATTERED THROUGHOUT THE TABLES.

43RD AVENUE TRAVELING EAST — DAY OF WEEK: WEDNESDAY

DATES: BEFORE-01/26/94; AFTER-10/16/96 — METERED BEFORE AND AFTER

*NOTE: ABSENCE OF DATA MAKE 43RD AVE., WED. THE ONLY CASE AVAILABLE FOR THIS TYPE OF ANALYSIS

The overall chi square value (142.0) is highly significant. The null hypothesis that the before and after travel times are proportional to lane 3 traffic volumes must be rejected. That is travel times are not consistent with lane 3 traffic volume. Large discrepancies are scattered throughout the analysis.

Ramp Travel Time and Ramp Volume

The comparison of the on-ramp travel time data and the on-ramp volume data is contained in Table 10. The travel time in seconds is shown during the half hour time period in which the data were recorded. The associated half-hour on-ramp traffic volume during the same half hour period as the travel time run is also provided. The expected travel time based on the on-ramp volume was computed for each cell of the matrix.

The information in Table 10 indicates that the overall chi square value (253.5) is significantly large. Discrepancies between observed and expected travel times occur in all cells. All travel times in the before period are greater than expected, and all travel times in the after period are less than expected. Therefore, there has been an improvement in the on-ramp travel time in the after period after accounting for the effects of on-ramp volume. Based on the data in Table 10 there has been approximately a 63 percent reduction in on-ramp travel time in the after period, even though on-ramp traffic volume increased by 20 percent in the after period.

On-Ramp Travel Delay

For this study on-ramp travel time delay is defined as the difference in time between the peak period travel time on the ramp and the non-metered free flow travel time on the ramp. Table 11 provides the data for the ramp delay for the seven before and after cases evaluated above. The delay data correspond to the travel time data in that the average delay in the before period was substantially higher (66.9 seconds) than in the after period (15.6 seconds) even though the on-ramp volumes were lower in the before than the after period.

Ramp Metering Rates

Information provided by ADOT indicated that the metering rate at 43rd Avenue may have been either 15 vehicles per minute or 12 vehicles per minute during the after period when the travel time data were collected. A review of the video tape recording of traffic operations during the before period revealed a metering rate of 10 vehicles per minute during the before period when travel time data were collected. If the metering rate during the after period were 15 vehicles per minute, this would account for nearly all of the measured change in ramp travel time. If the metering rate were 12 vehicles per minute in the after period, this would account for approximately one-third of the change in the on-ramp travel time. It appears as though the measured change in ramp travel time is primarily related to a change in the ramp metering rate from before to after.

Table 10

ON-RAMP TRAVEL TIME AND RAMP VOLUME ANALYSIS*

NULL HYPOTHESIS: BY HALF HOUR, BEFORE AND AFTER TRAVEL TIMES ARE PROPORTIONAL TO RAMP VOLUMES.

TRAVEL TIME

TIME PERIOD	BEFORE	AFTER	TOTAL
0630-0700	51	24	75
0630-0700	121	42	163
0700-0730	53	24	77
0730-0800	100	44	144
0800-0830	101	26	127
0800-0830	78	31	109
0830-0900	62	16	78
TOTAL	566	207	773

RAMP 30-MINUTE VOLUME

TIME PERIOD	BEFORE	AFTER	TOTAL
0630-0700	148	190	338
0630-0700	123	177	300
0700-0730	154	174	328
0730-0800	163	196	359
0800-0830	157	155	312
0800-0830	110	143	253
0830-0900	132	153	285
TOTAL	987	1188	2175

EXPECTED VALUES FROM RAMP VOLUMES (SECONDS)

TIME PERIOD	BEFORE	AFTER	TOTAL
0630-0700	32.8	42.2	75
0630-0700	66.8	96.2	163
0700-0730	36.2	40.8	77
0730-0800	65.4	78.6	144
0800-0830	63.9	63.1	127
0800-0830	47.4	61.6	109
0830-0900	36.1	41.9	78
TOTAL	348.6	424.4	773

CHI SQUARE TABLE

TIME PERIOD	BEFORE	AFTER	TOTAL
0630-0700	10.0	7.8	17.9
0630-0700	43.9	30.5	74.4
0700-0730	7.9	6.9	14.8
0730-0800	18.3	15.2	33.6
0800-0830	21.5	21.8	43.3
0800-0830	19.8	15.2	35.0
0830-0900	18.5	16.0	34.5
TOTAL	140.0	113.5	253.5
PROBABILITY			0.00

CONCLUSION:

THE OVERALL CHI SQUARE (253.5) IS SIGNIFICANTLY LARGE. DISCREPANCIES BETWEEN OBSERVED AND EXPECTED TRAVEL TIMES OCCUR IN ALL CELLS. ALL TRAVEL TIMES IN THE EARLIER PERIOD ARE GREATER THAN EXPECTED, AND ALL TRAVEL TIMES IN THE LATER PERIOD ARE LESS THAN EXPECTED.

43RD AVENUE TRAVELING EAST — DAY OF WEEK: WEDNESDAY

DATES: BEFORE-01/26/94; AFTER-10/16/96 — METERED BEFORE AND AFTER

*NOTE: ABSENCE OF DATA MAKE 43RD AVE., WED. THE ONLY CASE AVAILABLE FOR THIS TYPE OF ANALYSIS

Table 11

ON-RAMP TRAVEL TIME DELAY

Time	Delay (sec)	
	Before	After
0630 - 0700	37	10
0630 - 0700	107	28
0700 - 0730	39	10
0730 - 0800	86	30
0800 - 0830	87	12
0800 - 0830	64	17
0830 - 0900	48	2
Mean	66.9	15.6

SUMMARY

The analysis indicates that under the freeway volume conditions encountered in this study, there was no relationship between the lane 3 volume and on-ramp travel time. In the before period lane 3 volumes averaged 646 vehicles per hour, while in the after condition the average was 585 vehicles per hour during the AM peak period when ramp travel time data were collected. These volumes are well below the capacity of a single freeway lane at an on-ramp junction, which is in the range of 1600 to 1950 vehicles per hour. Under the low lane 3 volume conditions it is unlikely that the lane 3 volume would affect on-ramp travel time and this is consistent with the results of this investigation.

On-ramp travel time in the after period was significantly better than the before period. This occurred even though the on-ramp volumes in the after period were 20 percent higher than in the before period. In the before period the on-ramp volume flow rate averaged 282 vehicles per hour, and in the after period the average was 339 vehicles per hour. The reason for the decrease in on-ramp travel time in the after period appears related to an increase in the ramp metering rate from 10 vehicles per minute in the before period to either 12 or 15 vehicles per minute in the after period.

SUGGESTIONS TO IMPROVE STUDY PROCEDURES

An alternative approach to determining the impacts of the ramp metering system on on-ramp travel time would be to perform a delay study on ramp traffic operations. This might best be accomplished by video taping on-ramp traffic and measuring ramp travel time for individual vehicles during the peak-periods. This could be done with the ramp metering system on and off to provide a comparison between the metered and non-metered condition. On-ramp traffic volume could be captured from the video and lane 3 traffic volumes could be provided through the FMS traffic counting system. On-ramp travel time and delay should be measured under both fixed metering rate condition and with the meters operating in the demand responsive mode. Sites for measuring on-ramp travel time and delay should be selected where the mainline volumes are such that the impacts of high mainline volumes on ramp operations can be determined.

V. VARIABLE MESSAGE SIGN EVALUATION

INTRODUCTION

The evaluation of the effects of the variable message sign (VMS) system was conducted solely during the after period with the system in place. The analysis was structured based on three case studies of the impacts of the VMS system on driver response during three separate accidents that occurred on the freeway system within the FMS study area during the after period data collection time frame. This analysis is not a "before and after" study design as are other elements of the study.

Freeway accidents were screened based on the following criteria to identify candidates for three case studies for the evaluation of the VMS effectiveness.

- Incident duration of approximately 30 minutes or more.
- Message displayed for approximately 30 minutes or more.
- Incidents occurring between 6:00 AM and 8:00 PM on a weekday.
- Incidents causing the blockage of at least one mainline traffic lane or the closure of an off-ramp.

From the accidents meeting these criteria, the following three were selected for use as the case studies:

1. On Monday, April 29, 1996, an accident on westbound I-10 at 16th Street resulting in the closure of the right lane (lane 3), with VMS message displays from approximately 8:35 AM to 9:20 AM (see Figure 10). A message was posted on westbound I-10 west of University Drive advising drivers to use I-17 north, and a message was posted on westbound I-10 at Jefferson Street advising drivers that the right lane was blocked at 16th Street. Motorist response to these two signs was investigated by evaluating the traffic diversion from I-10 to I-17 in response to the sign posted at University Drive, and by evaluating the lane distribution of traffic downstream of the sign posted at Jefferson Street. Traffic volume data were provided through the FMS loop detectors at the count sites identified by count site number in Figure 10. The affects of the other three VMS messages that were posted for this accident were not evaluated. The sign on westbound I-10 east of 16th Street was deemed to be to close to the accident site to distinguish its effect from that of the traffic congestion resulting from the accident. The messages posted on State Route 202 and State Route 51 could not be evaluated because there are no traffic count sites on these routes as part of the FMS.

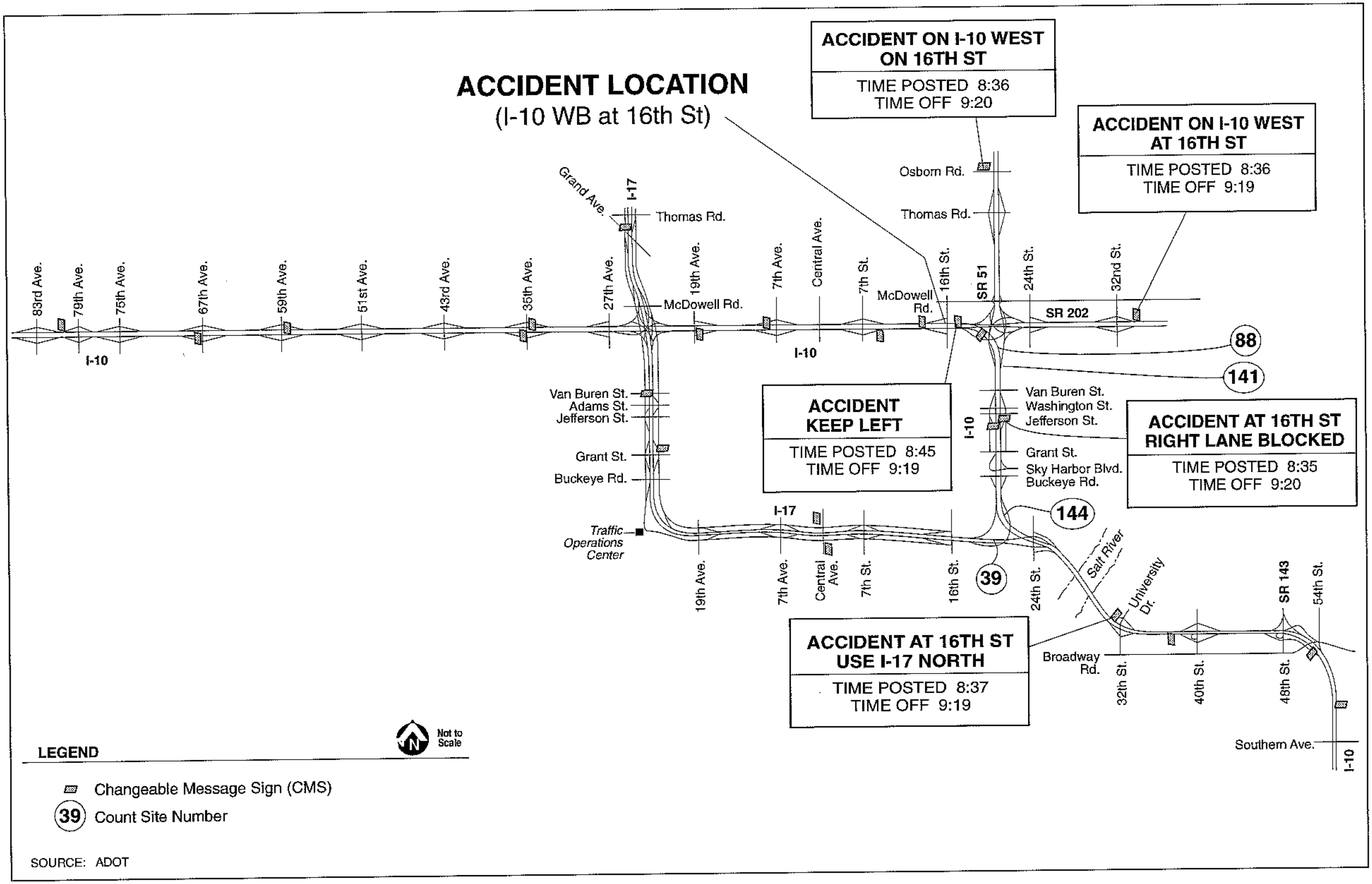


Figure 10
VARIABLE MESSAGE SIGNS (VMS) DISPLAYED DUE TO ACCIDENT ON APRIL 29, 1996 (CASE STUDY 1)

2. On Monday, July 22, 1996 an accident on westbound I-10 east of 19th Avenue with VMS message displays posted between 2:08 PM and 2:58 PM (see Figure 11). Six messages were posted on the VMS system as shown in Figure 11. Only one of these messages was deemed suitable for evaluation as part of this case study. That is the message that was posted on westbound I-10 west of University Drive advising drivers to use I-17 north as an alternate route. Driver response to this message was investigated by evaluating the traffic diversion from I-10 to I-17 through an analysis of the traffic volume data at the traffic count sites identified in Figure 11. The other messages posted for this accident were deemed to be unsuitable for analysis for various reasons. The message posted on westbound I-10 west of 7th Avenue was thought to be too close to the accident location to distinguish its affect from the affects of traffic congestion and queuing due to the accident. State Routes 51 and 202 do not have traffic count sites to provide traffic volume data to support an analysis. The sign posted on westbound I-10 south of Jefferson Street advised motorists to use other routes. There are several possibilities for other routes given the location of this sign, and as a result, there was no clear approach to isolating the affect of the message.

3. On Monday, September 30, 1996 an accident on southbound I-17 just west of 7th Avenue with VMS message displays posted between 11:50 AM and 12:29 PM (see Figure 12). Two of the three messages that were posted were deemed suitable for evaluation. The message posted on eastbound I-10 at 35th Avenue was investigated to determine if there was a possible diversion of traffic from I-17 southbound to I-10 eastbound, even though the message did not specifically advise drivers to take this action. The message posted on I-17 southbound at Van Buren Street, which advised drivers that the right lane was blocked at 7th Avenue, was investigated through the lane distribution of traffic downstream of the sign to determine driver response. The affects of the sign posted on I-17 southbound at Grand Avenue (north of I-10) could not be evaluated because there are not sufficient traffic count sites south of the sign prior to the system interchange to evaluate the diversion of traffic from southbound I-17 to eastbound I-10.

ANALYSIS METHODOLOGY

The analysis attempted to assess whether drivers responded to the message by either diverting to an alternate route or by changing lanes. This response was measured by the distribution of traffic volume downstream from a message display. To measure driver response to a message advising the use of a specific alternate route the distribution of total traffic volume between the two routes was investigated. To measure driver response to a message advising of a lane closure downstream the distribution of traffic between lanes downstream of the message was investigated.

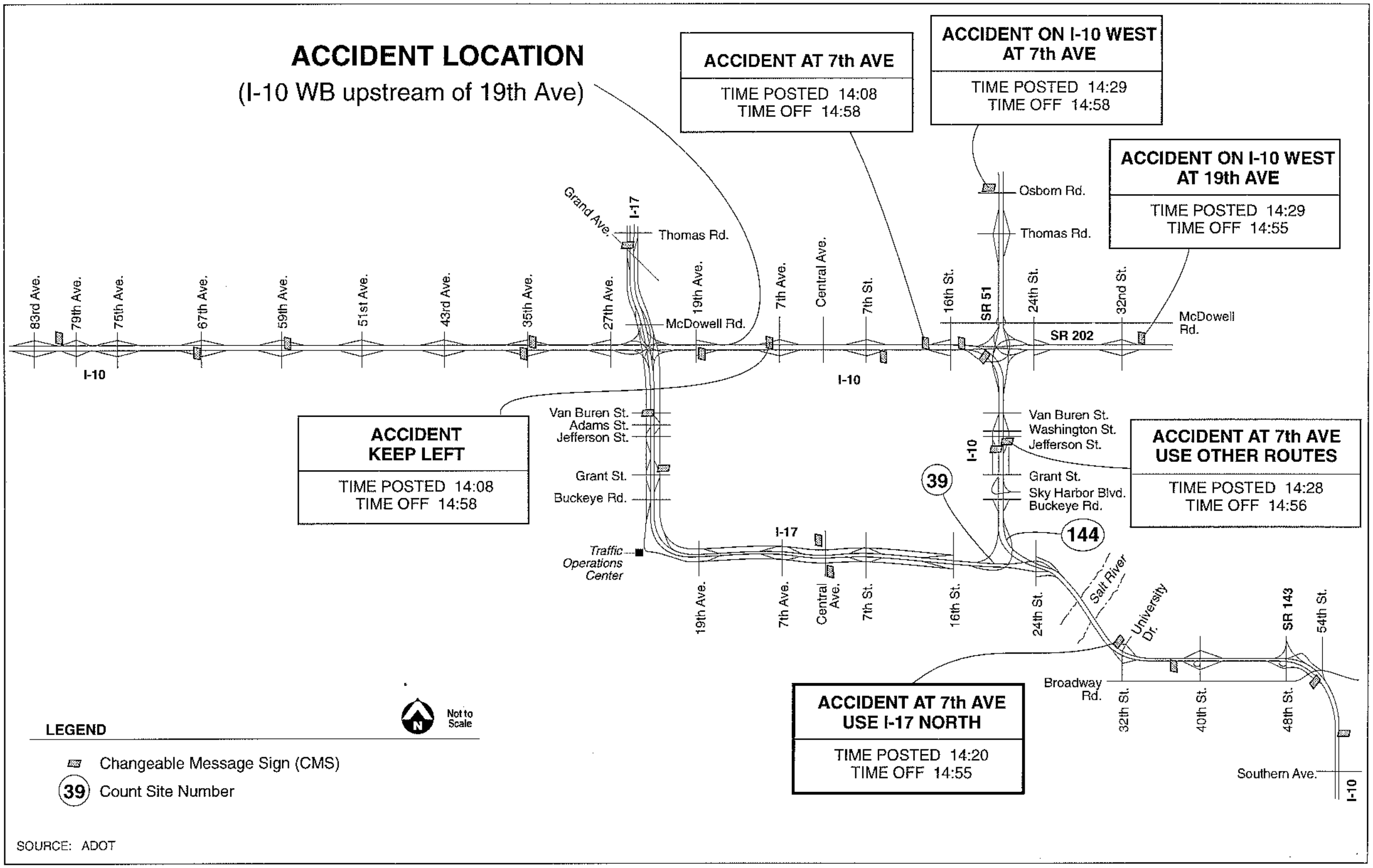


Figure 11
VARIABLE MESSAGE SIGNS (VMS) DISPLAYED DUE TO ACCIDENT ON JULY 22, 1996 (CASE STUDY #2)

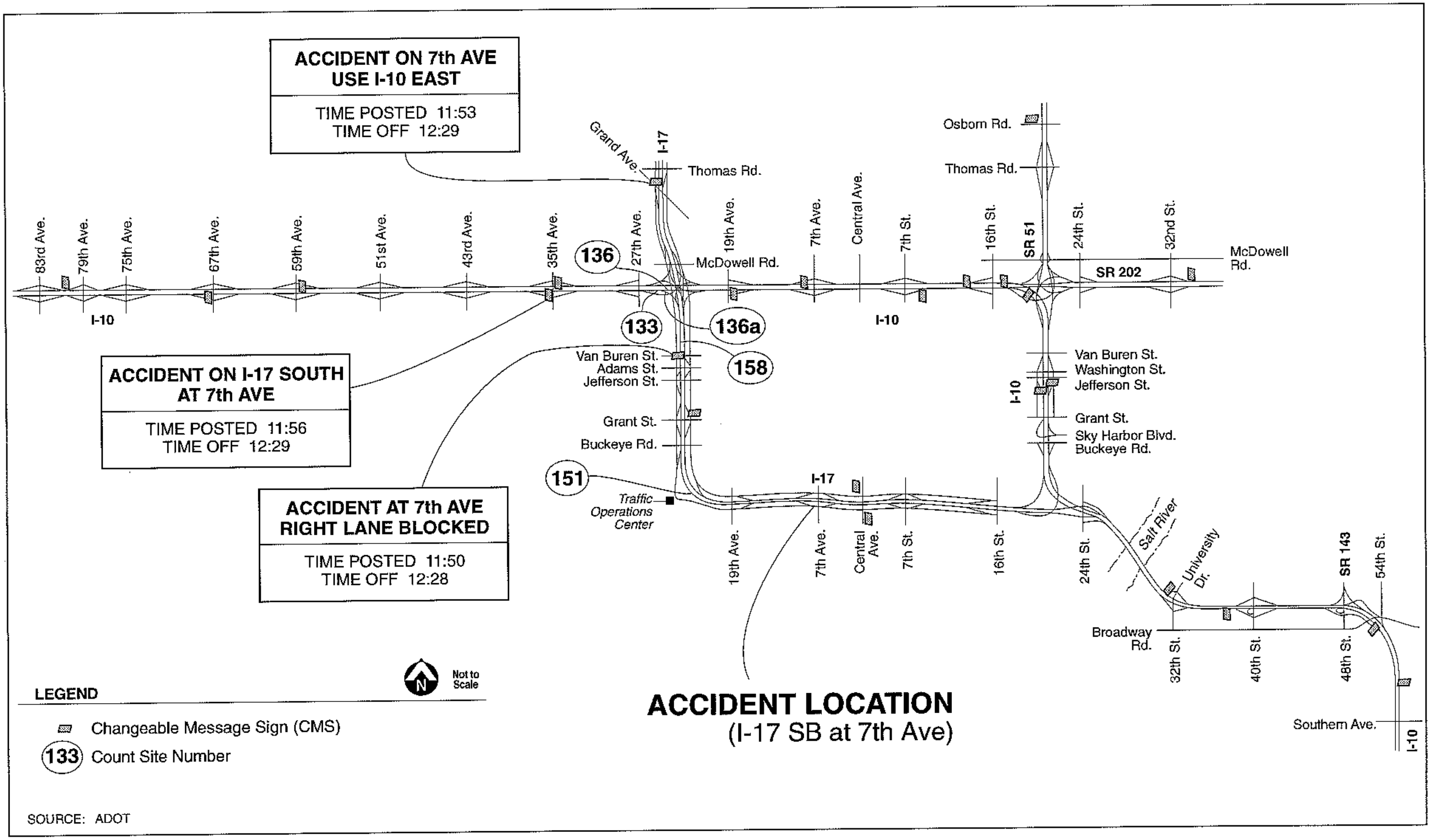


Figure 12
VARIABLE MESSAGE SIGNS (VMS) DISPLAYED DUE TO ACCIDENT ON SEPTEMBER 30, 1996 (CASE STUDY 3)

Two control measures were used in the evaluation process to assist in determining whether motorists had responded to the message displayed. One of the control measures was the distribution of traffic either by lane or by route during the half hour time period immediately before and after the message display on the same day as the accident. Another control measure was the distribution of traffic either by lane or by alternate route during the time period of the accident but on a typical day without the presence of an accident. These assessments were made at a specified point or points downstream of the message display where traffic volume data were available through one or more FMS traffic count sites. These control measures were used in a comparative analysis to the traffic distribution either by lane or by route during the time of the message display. Additional information on the analysis of each of the case studies is provided below.

Data were plotted in various ways to provide for visual interpretation of the results. In addition, statistical tests were conducted to assess the statistical significance of differences in the data. Detailed tabulations and results from the statistical tests are provided in the appendix to this chapter. Summary statements regarding conclusions based on the statistical tests can be found within the chapter text.

CASE STUDY EVALUATION

Case Study No. 1

Driver response to the VMS message posted on westbound I-10 at University Drive (Accident at 16th St. Use I-17 North) was evaluated based on the distribution of traffic between westbound I-10 and northbound I-17 downstream of the message. This evaluation was based on traffic volume information obtained for traffic count sites 39 and 144 located as shown in Figure 10. The sum of the traffic passing sites 39 and 144 represents the total traffic passing the VMS message at University Drive that remains on the freeway downstream of the sign. All vehicles passing sites 39 and 144 have had the opportunity to see the VMS message and respond. Driver response to this message was measured through the distribution of traffic passing traffic count sites 39 and 144.

The distribution of traffic passing count sites 39 and 144 for the half hour before, during, and for the half hour after the message display is provided in Figure 13. The data presented in Figure 13 indicates what appears to be a significant diversion of traffic from I-10 to I-17 as a result of the message display. Before the message display traffic is distributed approximately 58 percent to I-10 and 42 percent to I-17. During the message display the distribution is approximately 51/49. However, after the message display was terminated the percent distribution did not return to its pre-message condition, but rather remained at approximately 50 percent on each facility.

The distribution of traffic between sites 39 and 144 was also evaluated during the accident time period for two Mondays (April 22 and May 6, 1996) when there were no accidents or message displays. The five-minute traffic volume for these two days is plotted in Figures 14 and 15. These plots reveal that the distribution of traffic between

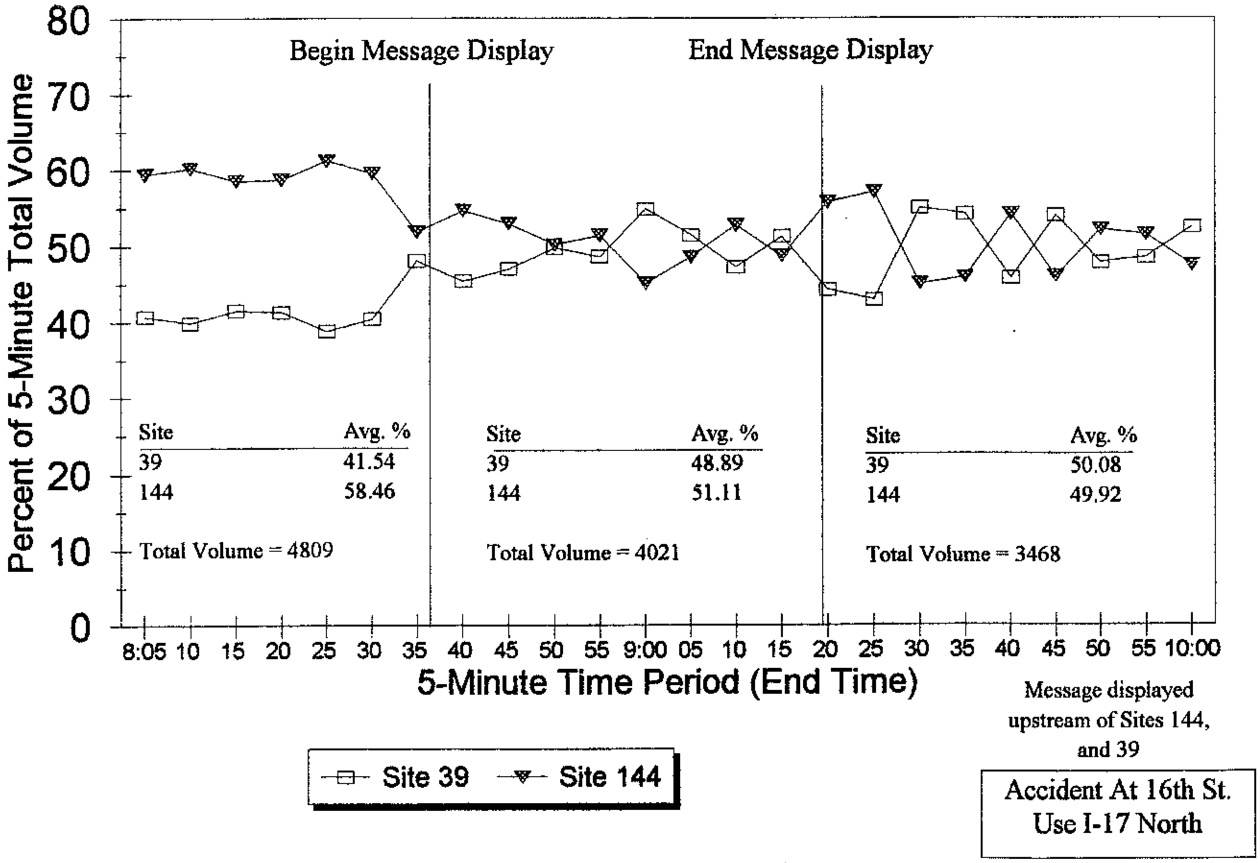


Figure 13
DISTRIBUTION OF TRAFFIC BETWEEN SITES 144 AND 39
DUE TO APRIL 29, 1996 ACCIDENT ON I-10

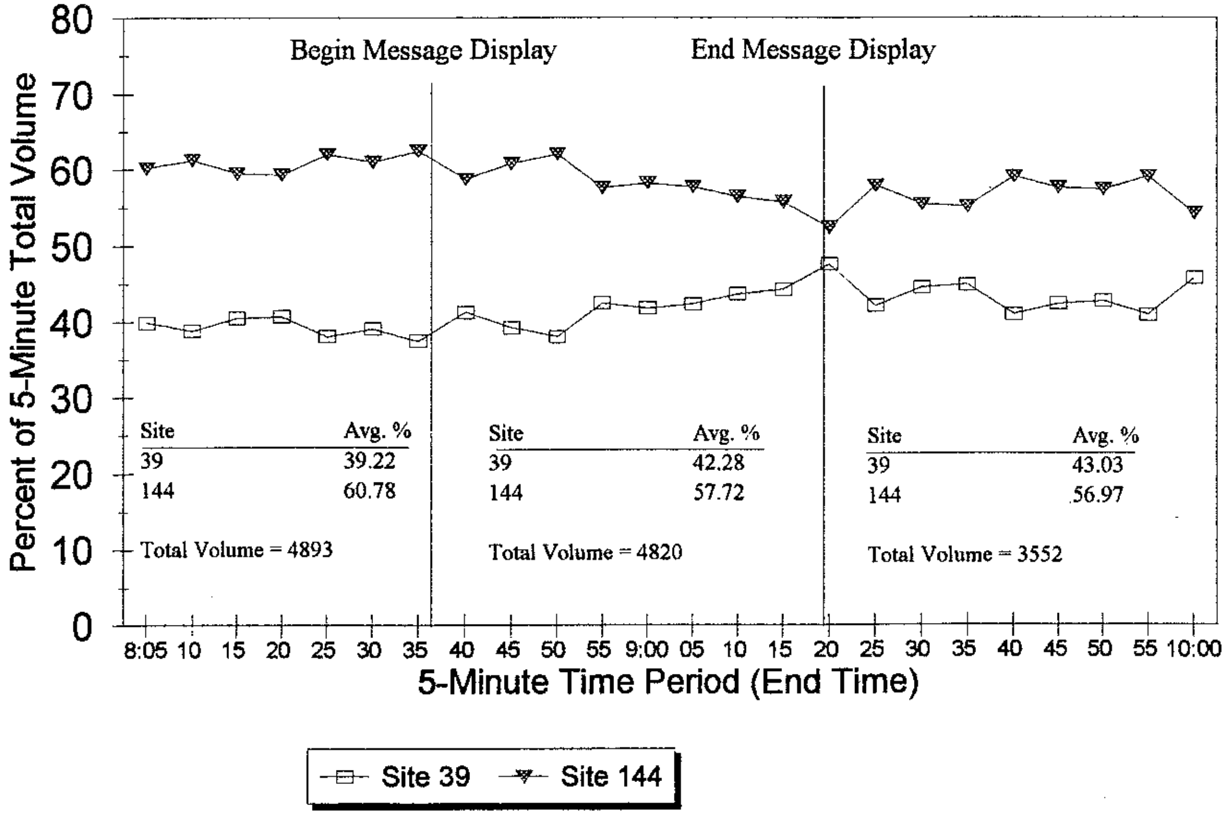


Figure 14
DISTRIBUTION OF TRAFFIC BETWEEN SITES 144 AND 39
ON APRIL 22, 1996

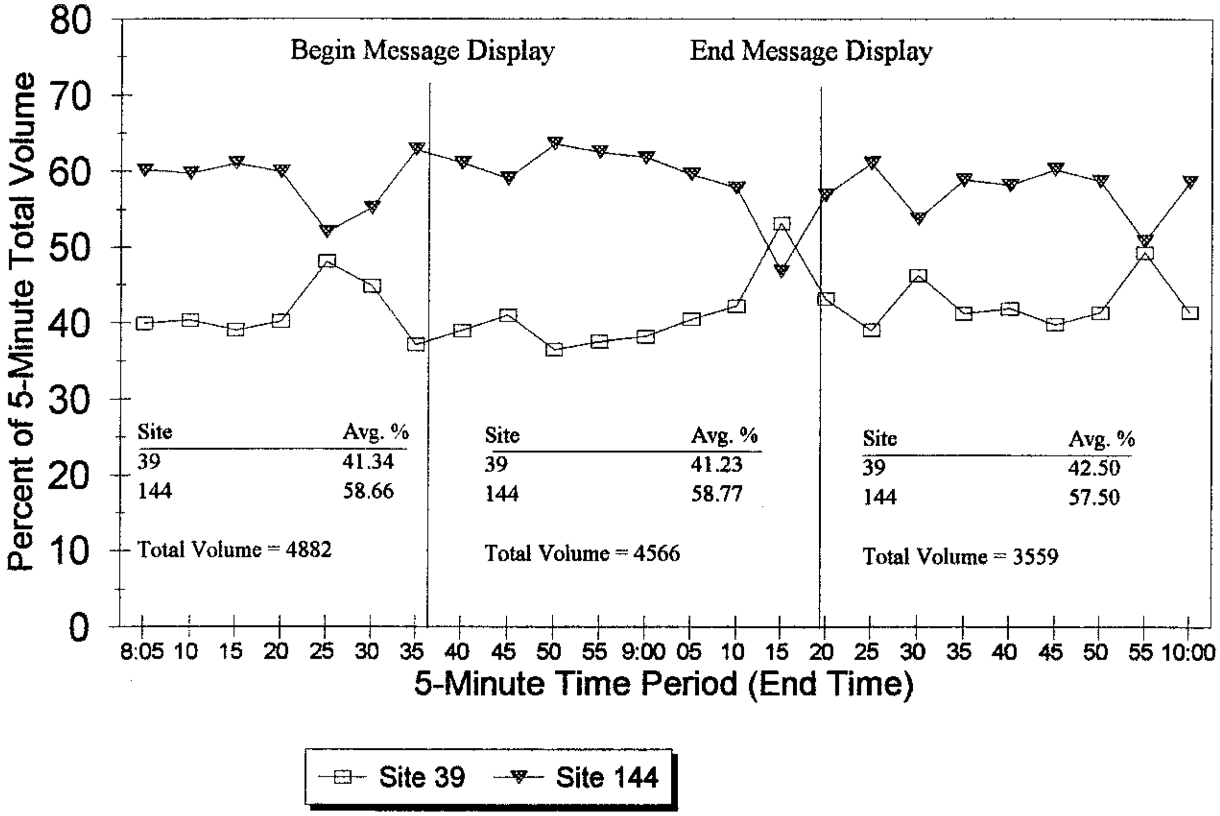


Figure 15
DISTRIBUTION OF TRAFFIC BETWEEN SITES 144 AND 39 ON MAY 6, 1996

sites 39 and 144 without the message display is very similar to the distribution on the day of the accident before the message display. Without the message display the distribution of traffic between I-10 and I-17 through sites 144 and 39 is fairly uniform throughout the 8:05 AM to 10:00 AM time period, with I-10 getting the higher percentage of the total volume.

A chi square analysis was conducted to compare the distribution of vehicles between sites 39 and 144 on the day of the accident with the distributions on the two non-accident days selected for the analysis (see Appendix A for detailed statistical analysis results). The results of the statistical tests indicate that before the message display the traffic distribution on the day of the accident is statistically consistent with the distributions on both of the non-accident days. During and after the message display there was a shift of traffic from site 144 to site 39 that is significantly different than the distributions on both of the non-accident days where the majority of traffic passes through site 144 on I-10. Therefore, it can be concluded that the message display has caused the diversion of traffic indicated in Figure 13. There also appears to have been some residual effect of the accident on the diversion of traffic from I-10 to I-17 even after the message was turned off. It is possible that this is a result of other information regarding the accident that was transmitted to motorists through other sources such as traffic advisory radio messages.

The total volume passing sites 39 and 144 during the message display was approximately 4000 vehicles (see Figure 16). If the number of vehicles passing site 144 was reduced from 58 percent of the total volume to 51 percent, the number of vehicles passing site 144 would be reduced by approximately 280 vehicles during the 43 minute message display, a 12 percent reduction in traffic on I-10 passing site 144. This represents a diversion of approximately 390 vehicles per hour, or about one-fifth of the capacity of a single freeway lane. It is logical to assume that all of these vehicles would have otherwise remained on I-10 and proceeded passed the accident site. The message appears to have contributed significantly to a reduction in congestion due to the accident by diverting traffic to an alternate route around the accident location.

The driver response to the message posted at Jefferson Street (Accident at 16th Street Right Lane Blocked) was evaluated by investigating the lane distribution of traffic at two traffic count sites downstream of the message, sites 141 and 88 (see Figure 10). Site 141 is located just upstream of the off-ramp from westbound I-10 to northbound SR51 and eastbound SR202. At the location of site 141 there are four mainline traffic lanes, one of which is an auxiliary lane (lane 4) which becomes one lane of the two-lane exit ramp, and an high-occupancy vehicle (HOV) lane. At the ramp junction, lane 3 is a choice lane where motorists can exit to SR51 or SR202, or proceed on I-10 if desired. Site 88 is downstream of the SR51/SR202 off-ramp and all traffic passing over this site must proceed on westbound I-10.

Figure 17 provides a look at the lane distribution of traffic passing site 141 the half hour before, during, and after the message display for the accident. The data in

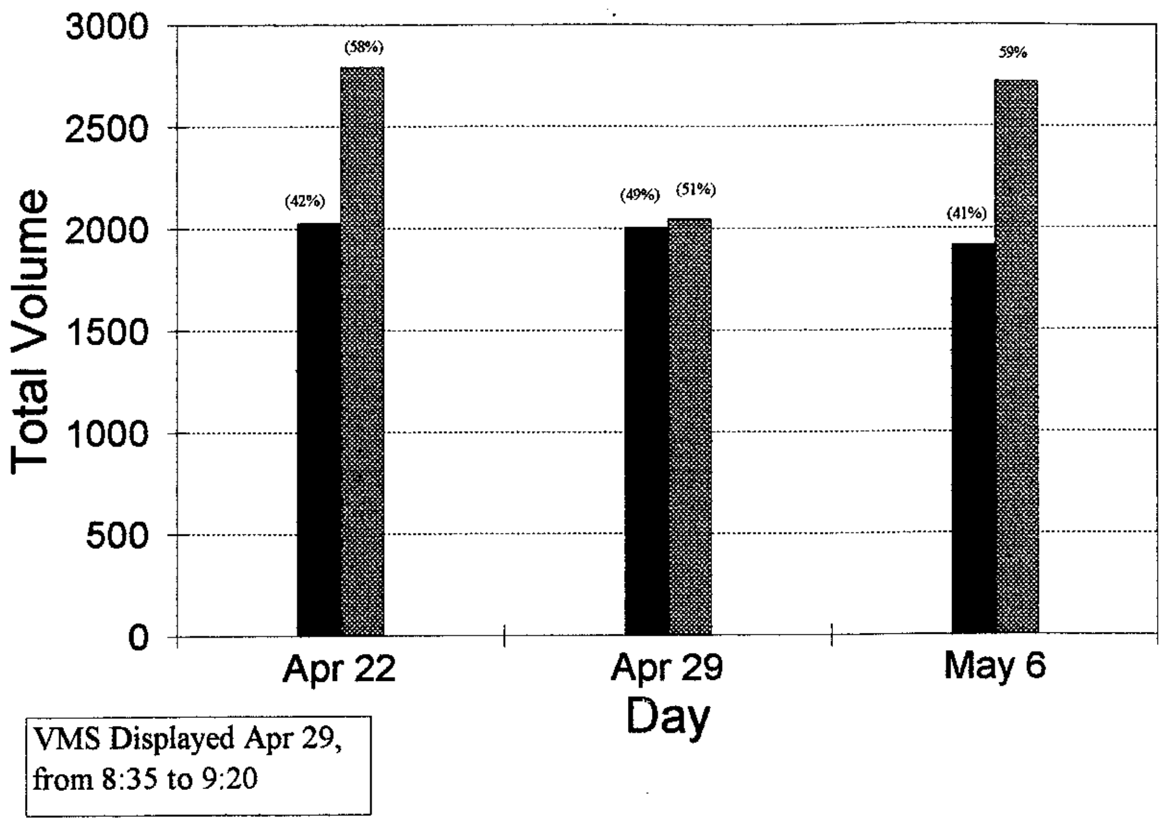


Figure 16
CASE 1 TOTAL STATION VOLUMES
SITES 39 AND 144 FROM 8:35 - 9:20 AM

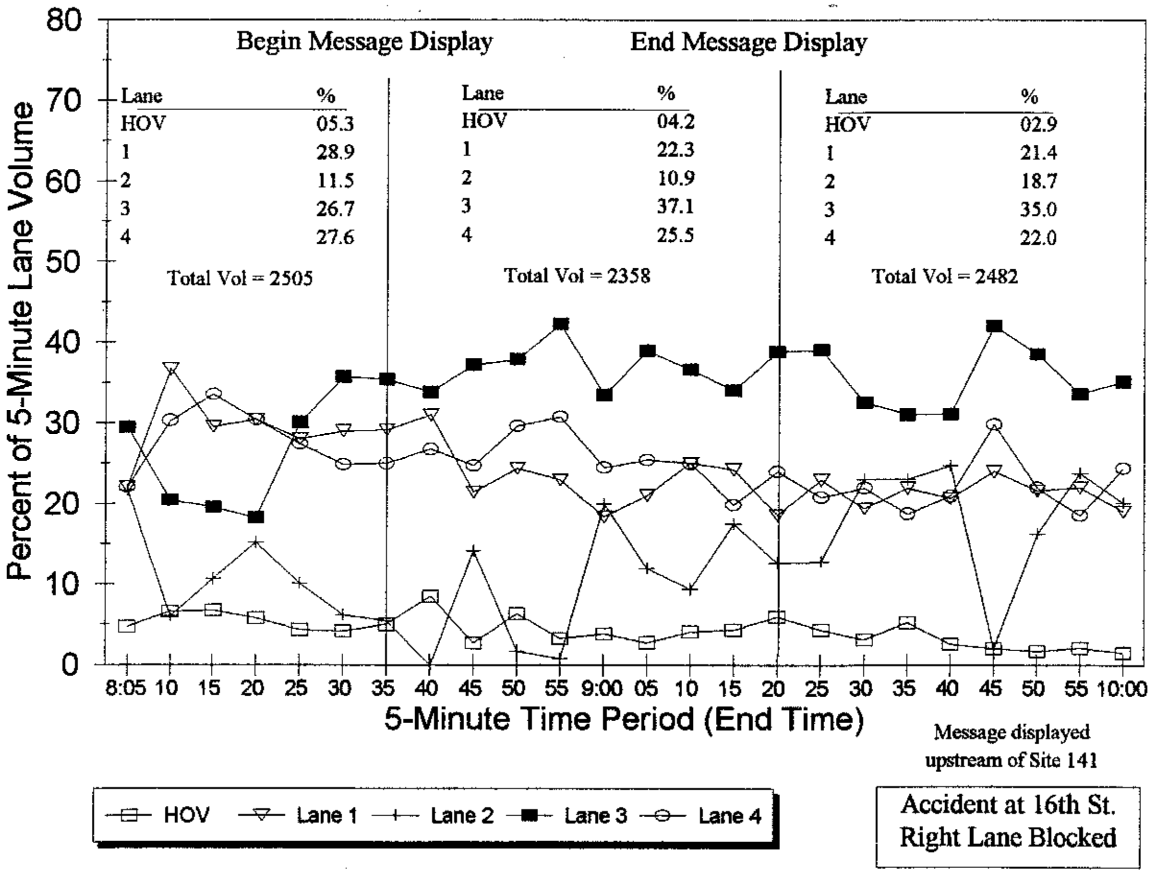


Figure 17
LANE DISTRIBUTION OF TRAFFIC AT SITE 141
ON APRIL 29, 1996 ACCIDENT ON I-10

Figure 17 reveals what could be a shift in traffic volume into lane 3 during the message display as the percent of the total volume in lane 3 increases from 26.7 percent before the message to 37.1 during the message. This increase in lane 3 percent of total volume is accompanied by a decrease in the percent of total volume in all other lanes at this site. However, review of lane distribution data during the same time period on the following day (Tuesday, April 30) as shown in Figure 18 indicates that the lane distribution without the accident is very similar to the condition with the accident. In both cases lane 3 has the highest percent of traffic passing site 141 during the time period of the message display and after the message display. Lane 4 has the second highest percent of traffic during and after the time of the message display on both days. Therefore, the lane distribution of traffic at site 141 on the day of the accident does not appear particularly unusual, and if there is any additional diversion of traffic to the SR51/SR202 off-ramp it is very slight and not readily detectable from these data.

Figures 19 and 20 present data on the percent of traffic passing site 141 that exits I-10 to either northbound SR51 or eastbound SR202 on Monday, April 29 and Tuesday, April 30 during the analysis time period. The plots of this information are fairly consistent between the two days, particularly during and after the time of the message display. The slight increase in the percent of traffic passing site 141 that exits to SR51/SR202 can be accounted for by the traffic that was diverted from I-10 to I-17 upstream of this location. When this estimated diversion (290 vehicles) is added to the total volume passing site 141 with the assumption that this traffic would have proceeded on I-10 past site 141, the percent of traffic that exits to SR51/SR202 is reduced to 38.5 percent. This is very consistent with the April 30th data, and further indicates that there was no additional diversion of traffic to the SR51/SR202 exit.

Looking downstream at site 88, Figures 21 and 22 provide data on the lane distribution of traffic on the day of the accident and the day after. The distributions are very similar between the two days with lane 3 consistently showing the smallest percent of the total volume passing site 88. The percent of the total volume in lanes 1 and 2 is also very similar on both days, and it is very consistent across the before, during, and after-message time periods. On the day of the accident there is a decrease in the percent of traffic volume occupying lane 3 from 22.8 percent before the message display to 17.7 percent during the message display. This is accompanied by an increase in the percent of total volume occupying lane 2 from 33.5 percent before the message display to 38.0 percent during the message display. On the day after the accident there is a similar decrease in the percent of traffic in lane 3 from 25.8 percent before the time of the message to 21.2 percent during the time of the message display. In both cases the percent of traffic in lane 3 after the time of the message display is approximately 20 percent.

A chi square analysis was conducted to compare the distribution of vehicles between lanes at site 88 before and during the message display on the day of the accident and on the following day, which was a non-accident day (see Appendix A for detailed statistical analysis results). The results of the statistical tests indicate that when using the day of the accident as the basis for comparison, there is significantly more traffic in lane 3

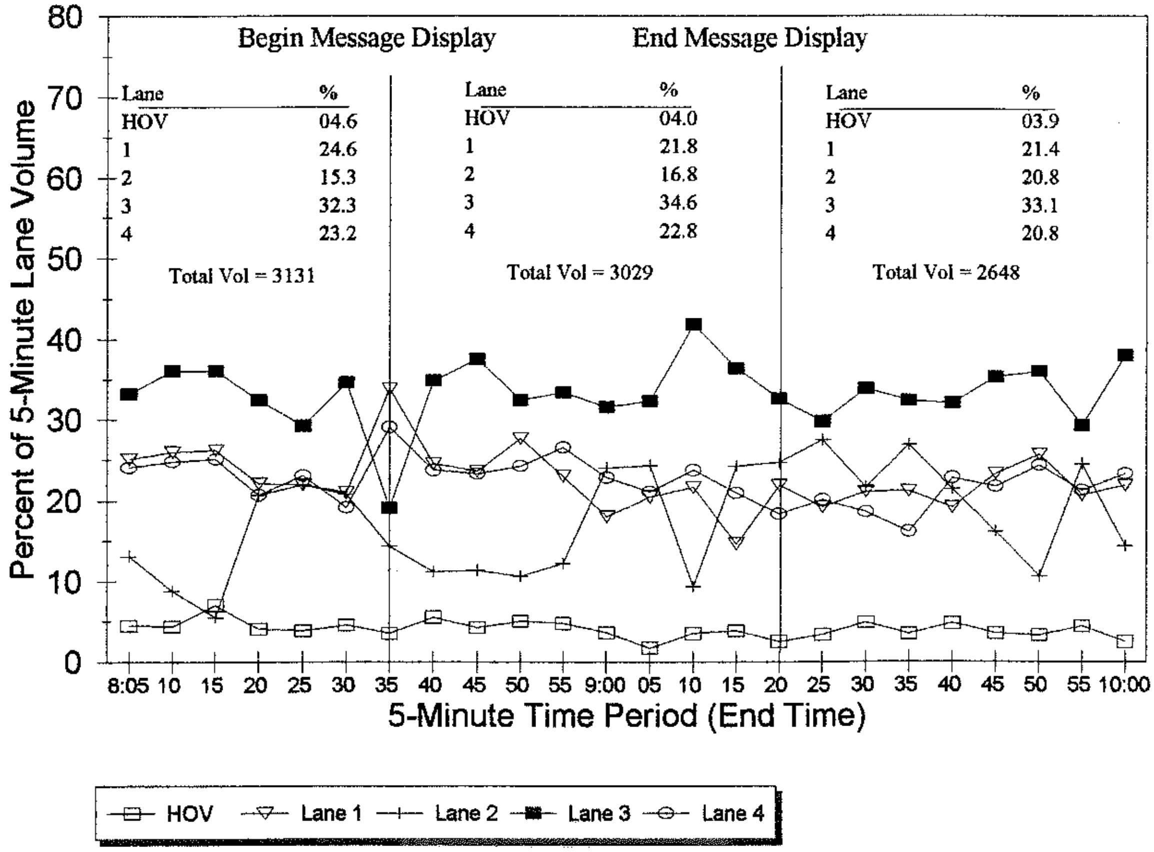


Figure 18
LANE DISTRIBUTION OF TRAFFIC AT SITE 141
ON APRIL 30, 1996

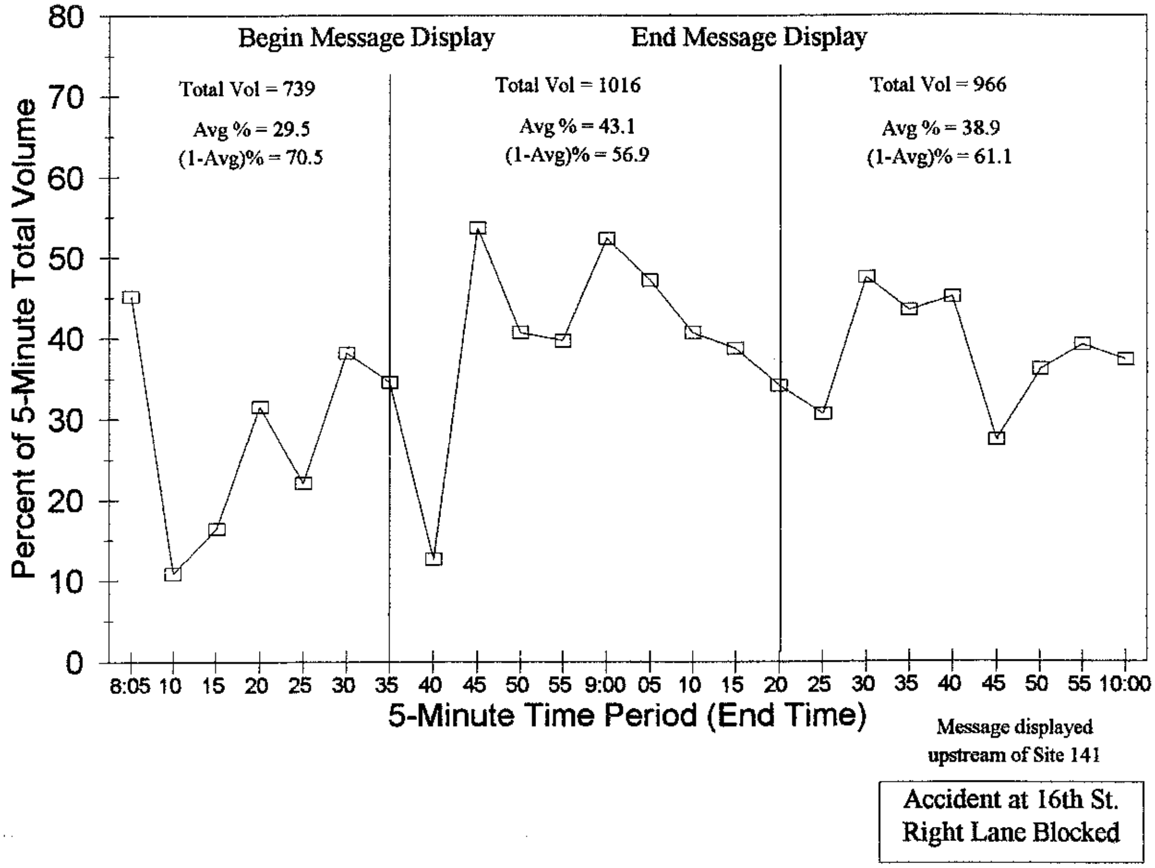


Figure 19
PERCENT OF 5-MINUTE VOLUME PASSING SITE 141
ON APRIL 29, 1996 PROCEEDING TO NB SR51 OR EB SR202

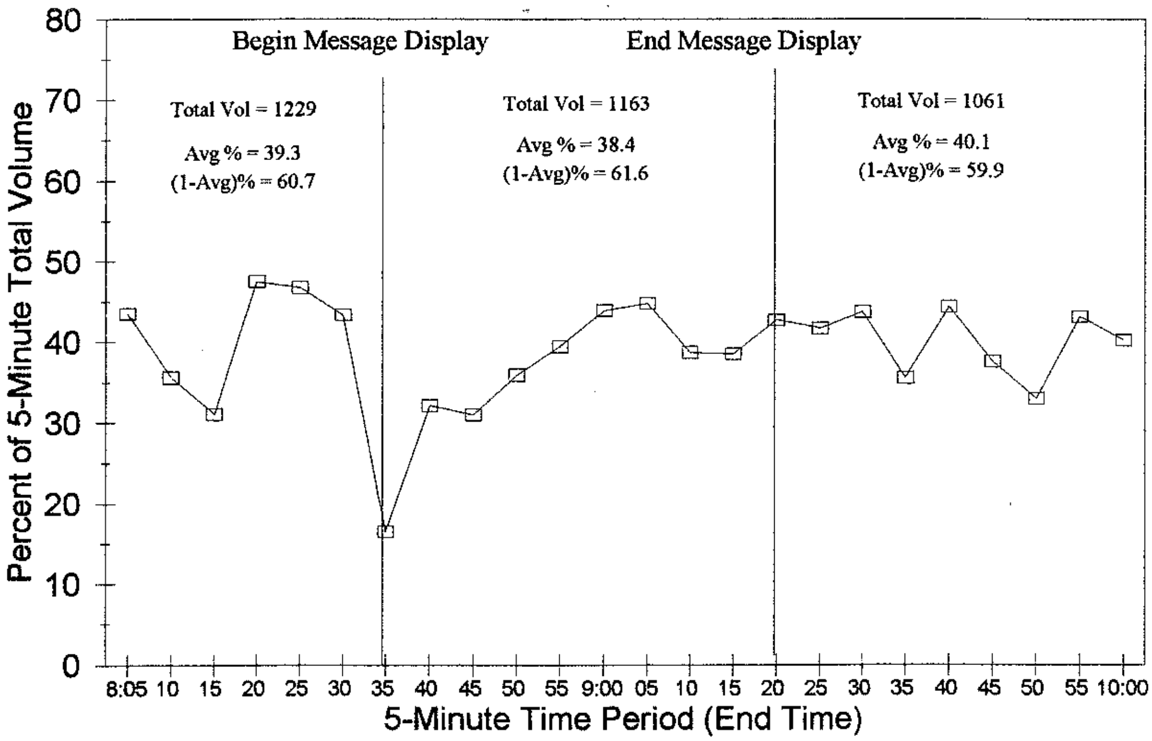


Figure 20
PERCENT OF 5-MINUTE VOLUME PASSING SITE 141
ON APRIL 30, 1996 PROCEEDING TO NB SR51 OR EB SR202

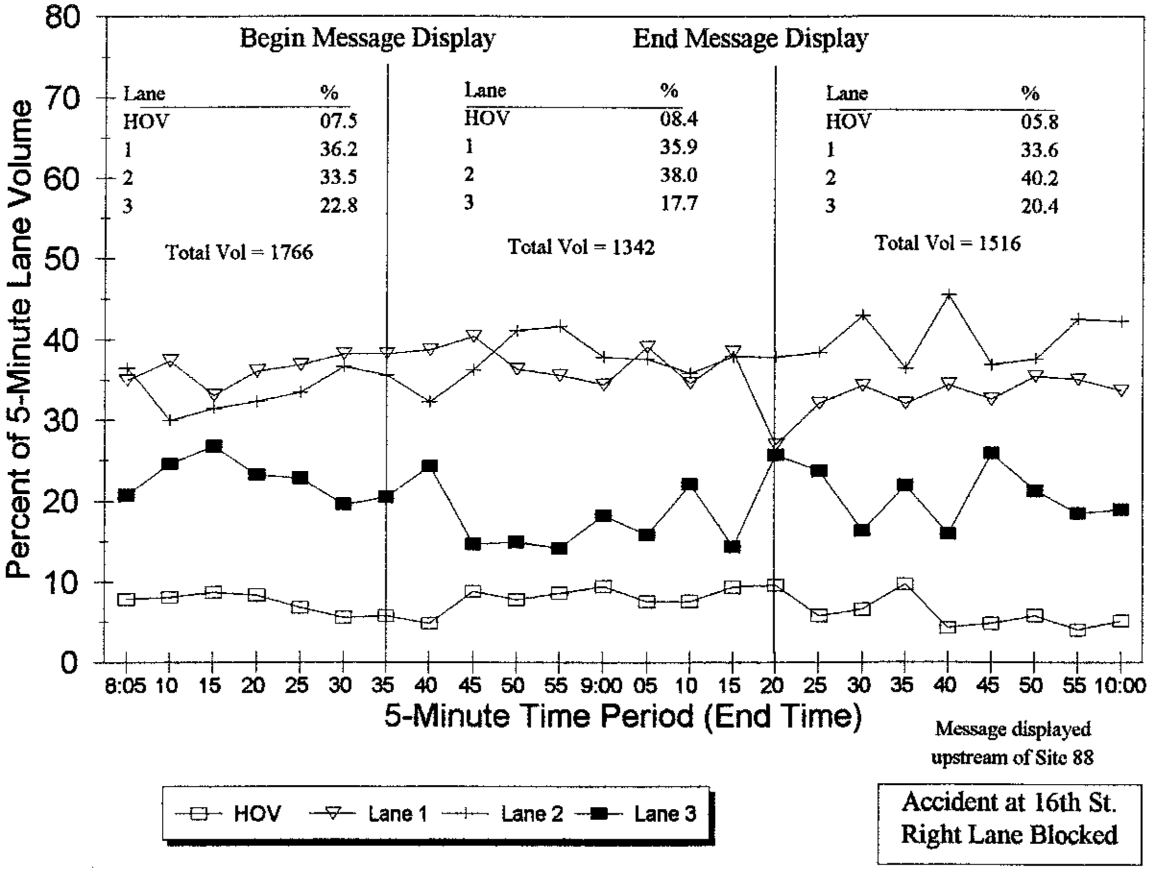


Figure 21
LANE DISTRIBUTION OF TRAFFIC AT SITE 88
DUE TO APRIL 29, 1996 ACCIDENT ON I-10

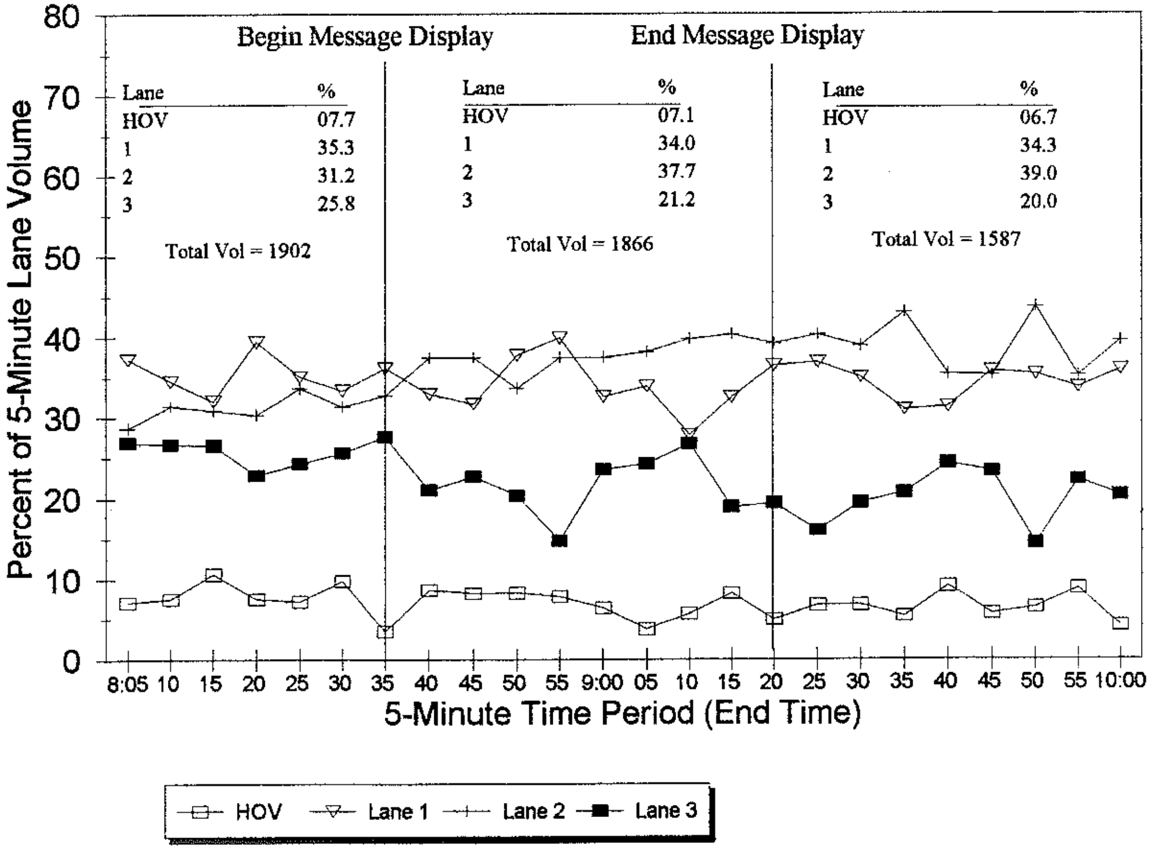


Figure 22
LANE DISTRIBUTION OF TRAFFIC AT SITE 88
ON APRIL 30, 1996

the day after the accident then would be expected. That is, on the day of the accident there was a significant shift in traffic out of lane 3 at site 88 during the period of the message display. Therefore, it can be concluded that on the day of the accident that the VMS message has achieved the desired result of moving traffic out of the blocked lane in advance of the accident site.

Case Study No. 2

Driver response to the VMS message posted on westbound I-10 at University Drive (Accident at 7th Ave. Use I-17 North) was evaluated based on the distribution of traffic between westbound I-10 and northbound I-17 downstream of the message. This evaluation was based on traffic volume information obtained for traffic count sites 39 and 144 located as shown in Figure 11. The sum of the traffic passing sites 39 and 144 represents the total traffic passing the VMS message at University Drive that remains on the freeway downstream of the sign. All vehicles passing sites 39 and 144 have had the opportunity to see the VMS message and respond. Driver response to this message was measured through the distribution of traffic passing traffic count sites 39 and 144. This is the same analysis that was performed for virtually the same message as part of Case Study No. 1.

The distribution of traffic passing count sites 39 and 144 for the half hour before, during, and for the half hour after the message display is provided in Figure 23. The data presented in Figure 23 indicates that there was an apparent diversion of traffic from I-10 to I-17 as a result of the message display. Before the message display traffic is distributed approximately 45 percent to I-10 and 55 percent to I-17. During the message display the distribution is approximately 47/53, with the higher percent on I-17. After the message display was terminated, the percent distribution returned to approximately the before-message condition with a higher percent of traffic on passing through site 144 on I-10 and a 54/46 split between I-10 and I-17. This is very similar to the results for Case Study No. 1.

The distribution of traffic between sites 39 and 144 was also evaluated during the accident time period for Monday July 29, 1997 when there was no accident or message display. The five-minute traffic volume for this day is plotted in Figure 24. This plot reveals that the distribution of traffic between sites 39 and 144 without the message display is very similar to the distribution on the day of the accident before the message display. Without the message display on the non-accident day, the distribution of traffic between I-10 and I-17 through sites 144 and 39 is fairly uniform throughout the 1:55 PM to 3:30 PM time period, with I-10 getting the higher percentage of the total volume. This is very similar to the data evaluated for Case Study No. 1.

A chi square analysis was conducted to compare the distribution of vehicles between sites 39 and 144 on the day of the accident and on the non-accident day (see Appendix A for detailed statistical analysis results). The results of the statistical tests indicate that before the time period of the message display the distribution of traffic

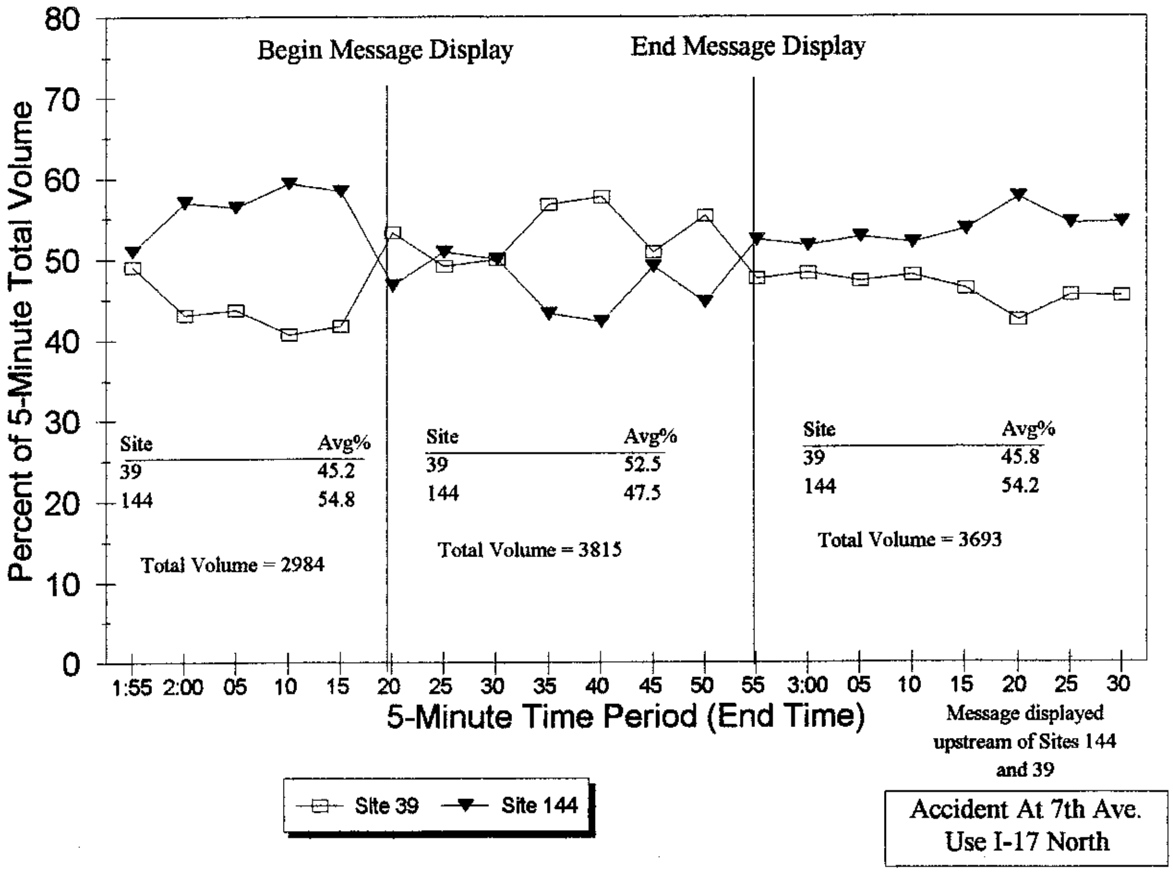


Figure 23
DISTRIBUTION OF TRAFFIC BETWEEN SITES 144 AND 39
DUE TO JULY 22, 1996 ACCIDENT ON I-10

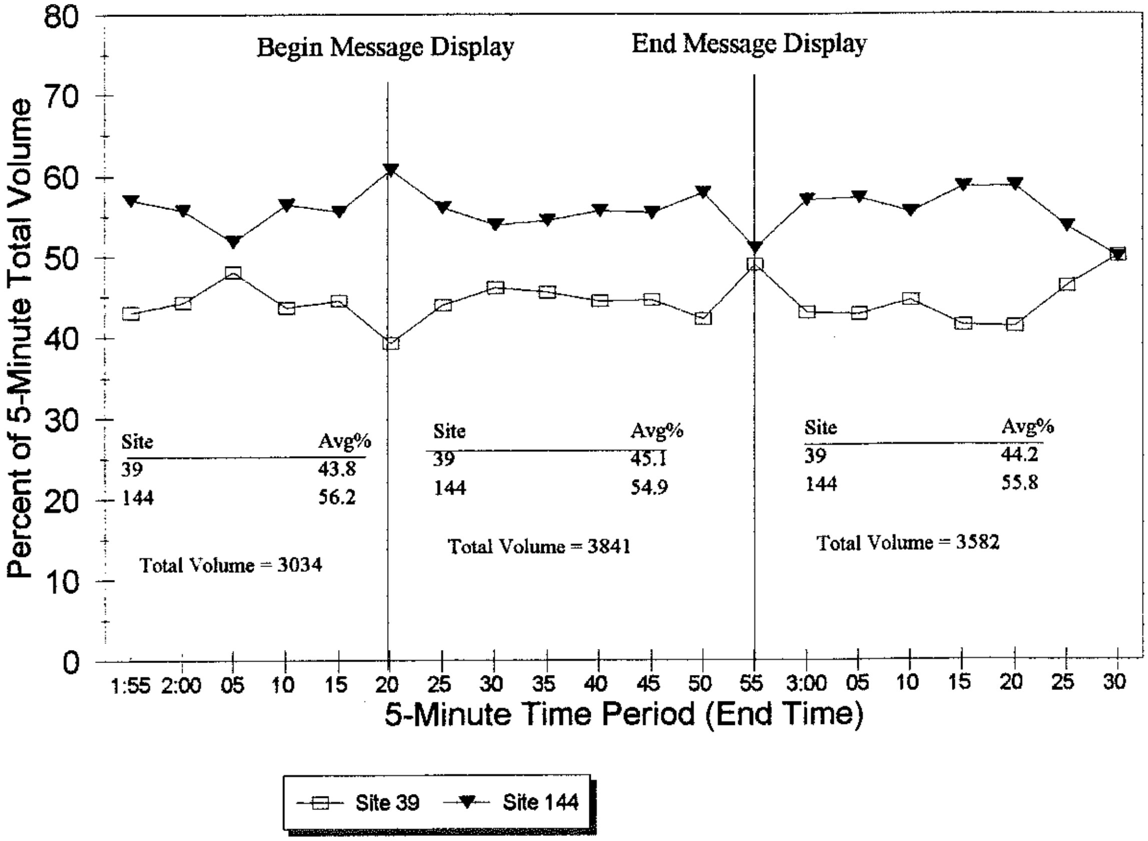


Figure 24
DISTRIBUTION OF TRAFFIC BETWEEN SITES 144 AND 39
ON JULY 29, 1996

between site 144 and site 39 is not significantly different between the accident and non-accident days. During the message display, there is a significant shift in traffic distribution from site 144 to site 39 with the traffic volume past site 144 being much lower than expected. There also appears to be some residual affect after the message was turned off in that on the accident day the traffic volume passing site 39 is higher than expected even though the distribution is similar to that before the message. It can be concluded that the message did cause a significant shift in traffic volume from I-10 to I-17.

The total volume passing sites 39 and 144 during the message display was approximately 3,250 vehicles (see Figure 25). If the number of vehicles passing site 144 was reduced from 55 percent of the total volume to 47 percent, the number of vehicles passing site 144 would be reduced by approximately 260 vehicles during the 35 minute message display, 14.5 percent reduction in I-10 traffic passing site 144. This represents a diversion of approximately 445 vehicles per hour, or about one-fourth of the capacity of a single freeway lane. It is logical to assume that all of these vehicles would have otherwise remained on I-10 and proceeded passed the accident site. The message appears to have contributed significantly to a reduction in congestion due to the accident by diverting traffic to an alternate route around the accident location.

Case Study No. 3

Driver response to the VMS message posted on eastbound I-10 35th Avenue (Accident on I-17 South at 7th Ave.) was evaluated based on the distribution of traffic between eastbound I-10 and southbound I-17 at the system interchange approximately one mile east and downstream of the message display. This evaluation was based on traffic volume information obtained for traffic count sites 133 and 136 located as shown in Figure 12. Traffic count site 133 is located just upstream of the off-ramp from eastbound I-10 to southbound I-17, and count site 136 is located just downstream of this off-ramp. Therefore, the difference in the traffic volume counts at these two sites is equal to the traffic volume proceeding southbound on I-17 from eastbound I-10 through location 136a shown in Figure 12. Location 136a is not an FMS traffic count site, and the volume data for this location were computed as described above. The total volume passing site 133 has the opportunity to respond to the VMS display by either exiting to southbound I-17 or remaining on I-10 eastbound and avoiding the accident location. Driver response to this message was measured through the distribution of traffic passing sites 136 and 136a.

The distribution of traffic passing sites 136 and 136a for the half hour before, during, and for the half hour after the message display is provided in Figure 26. The data presented in Figure 26 does not provide any evidence that the traffic volume through sites 136 and 136a either were or were not affected by the VMS message. Data are provided for these same two sites for the non-accident days of October 1, 1997 and October 7, 1997 in Figures 27 and 28 respectively. Note that there are negative values shown for volumes at site 136a in both Figures 27 and 28 that results from traffic counts that are

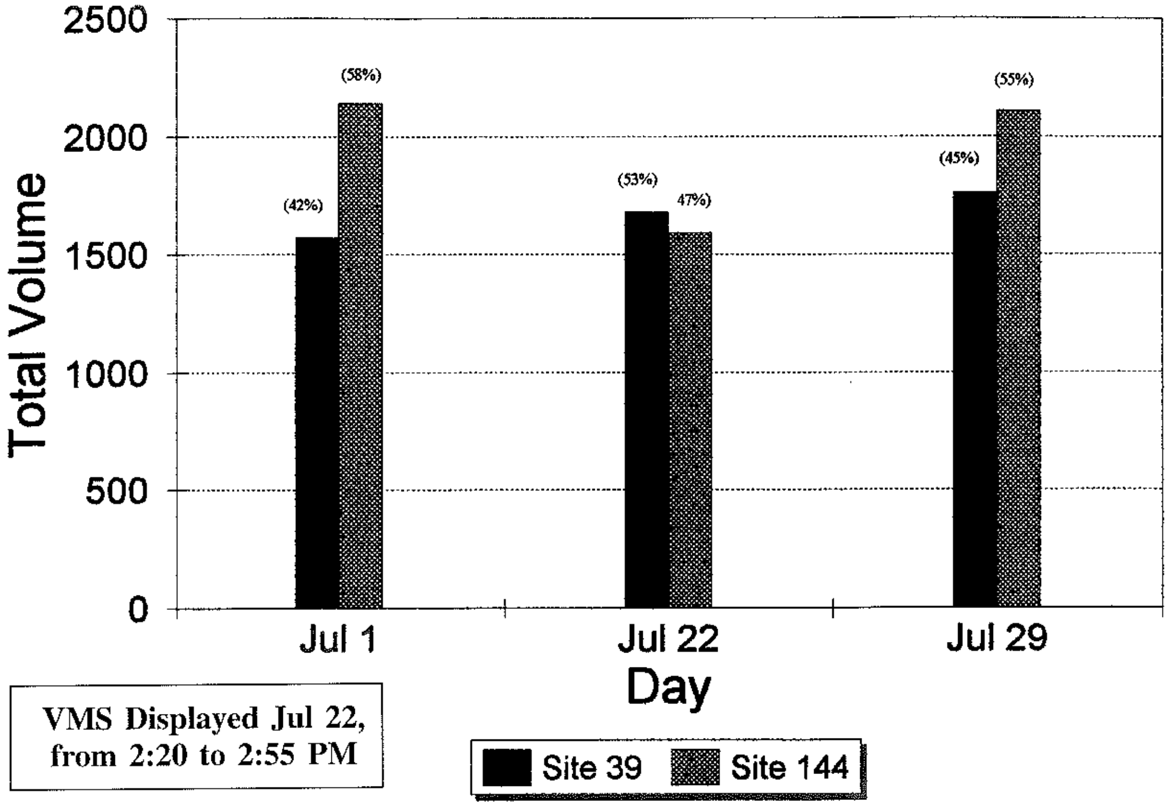


Figure 25
CASE 2 TOTAL STATION VOLUMES
SITES 39 AND 144 FROM 2:20 - 2:55 PM

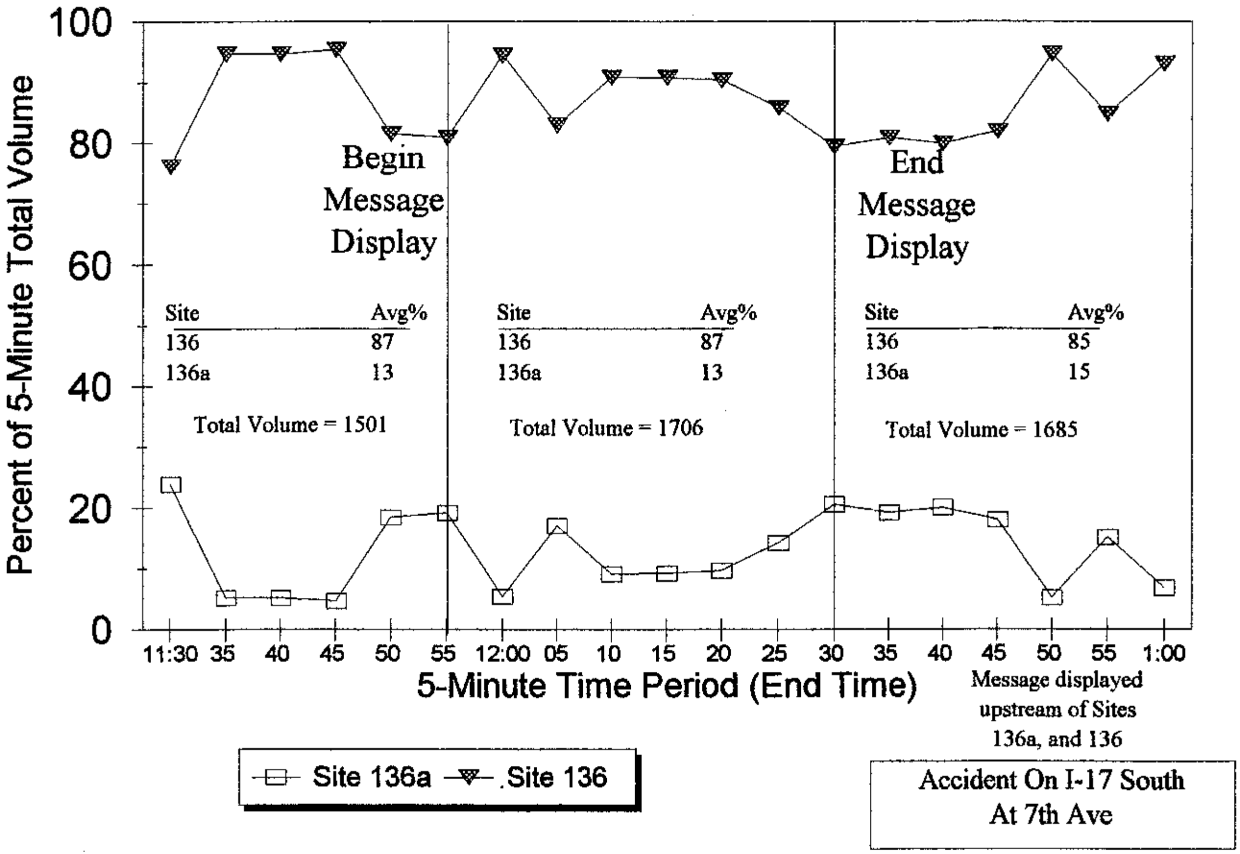


Figure 26
DISTRIBUTION OF TRAFFIC BETWEEN SITES 136/136A
DUE TO SEPTEMBER 30, 1996 ACCIDENT ON I-17

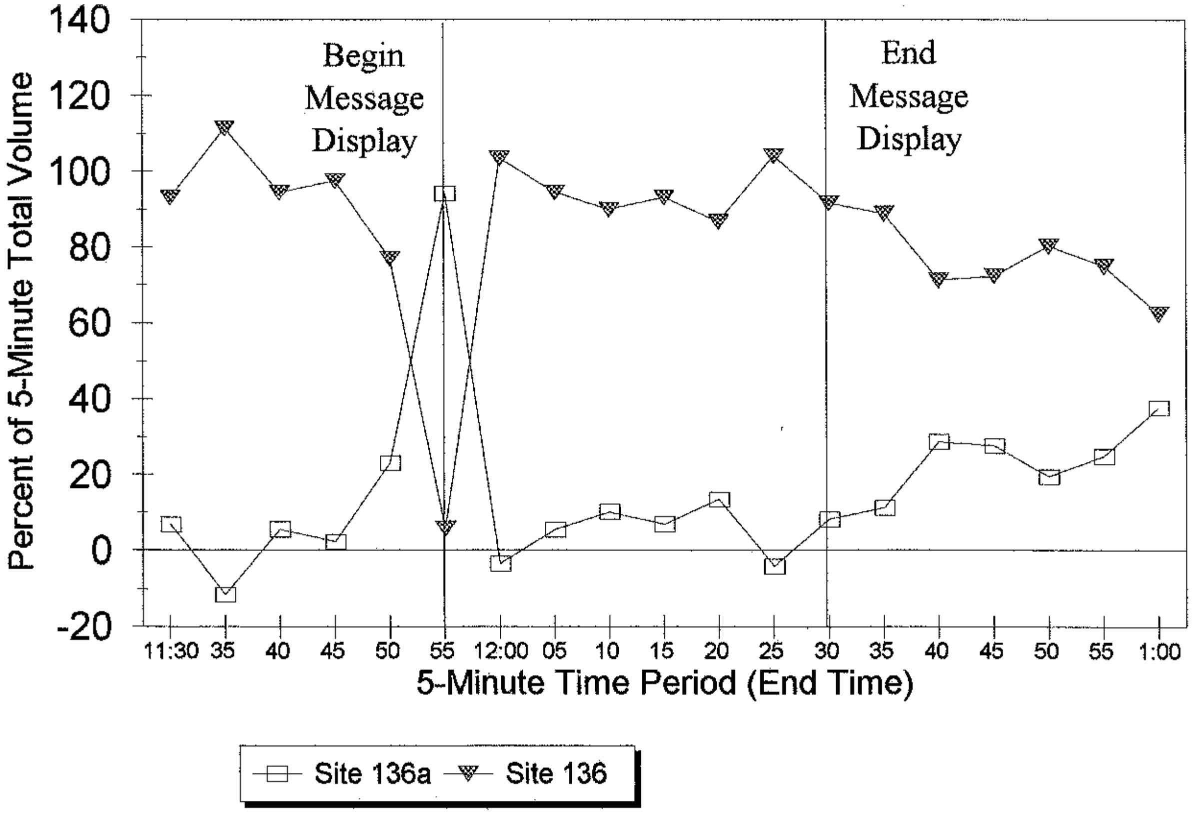


Figure 27
DISTRIBUTION OF TRAFFIC BETWEEN SITES 136/136A ON OCTOBER 1, 1996

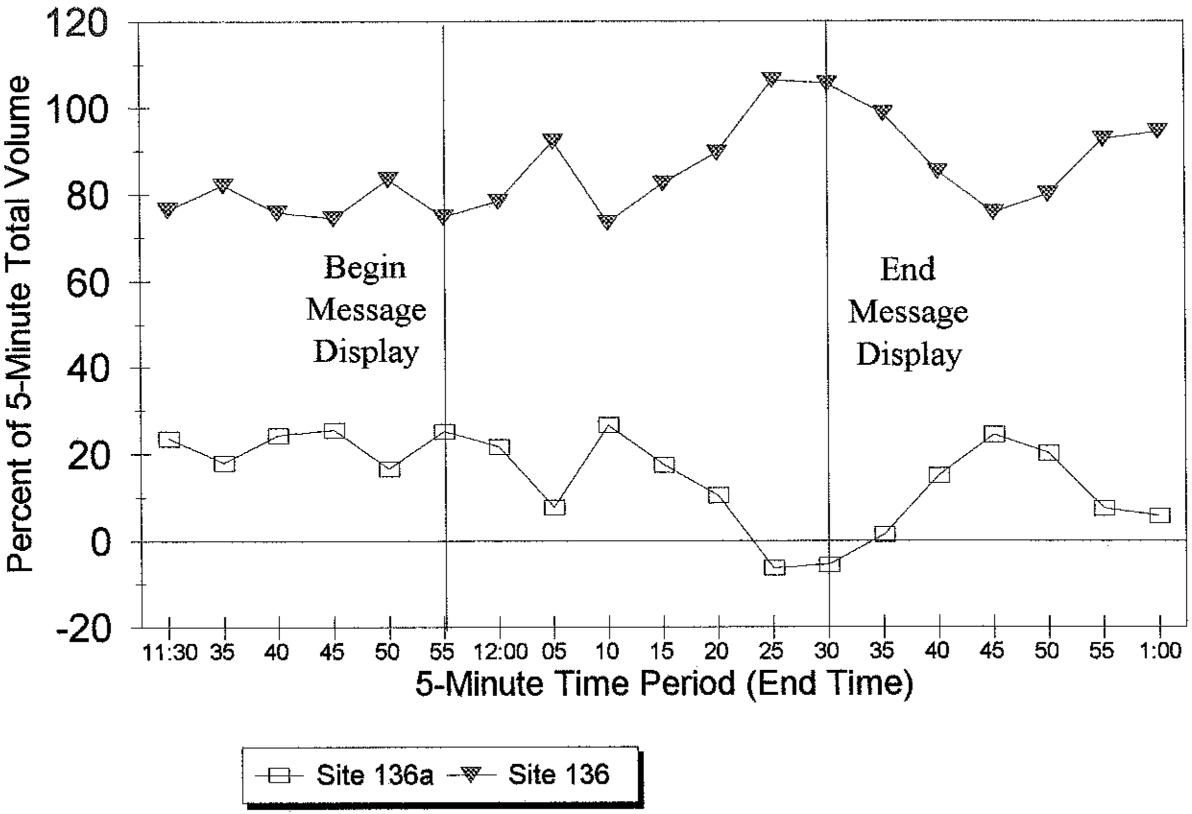


Figure 28
DISTRIBUTION OF TRAFFIC BETWEEN SITES 136/136A ON OCTOBER 7, 1996

larger at site 136 than at site 133. This indicates a problem with the data for the non-accident days which prohibited further analysis. Therefore, no conclusions can be drawn regarding traffic diversion at this location.

The impact of the VMS message on southbound I-17 at Van Buren Street (Accident at 7th Ave. Right Lane Blocked) was investigated through the evaluation of the lane distribution of traffic primarily at site 151 downstream of the sign. Data were evaluated on the day of the accident and compared to data for five non-accident days.

Figure 29 provides the lane distribution of traffic on the day of the accident for the half hour before, during, and for the half hour after the message display. The data in Figure 29 show a slight decrease in the lane 3 percent of total volume during the time of the message display in comparison to the percent either before or after the message display. Alone, this information does not provide conclusive evidence that the VMS message has caused traffic to move out of lane 3. The same data are plotted for five consecutive Mondays following the accident when there was no message display (see Figures 30 through 34). The lane distributions of traffic at site 151 plotted in Figures 30 through 34 are very similar to the that shown on the day of the accident.

A chi square analysis was conducted to compare the lane distribution of vehicles at site 151 for the five non-accident days to determine if these days could be considered homogeneous (see Appendix A for detailed statistical analysis results). The results of the statistical test indicate that the lane distribution for the non-accident days at site 151 can be considered homogeneous and that there are no significant differences between the non-accident days either before, during or after the time period of the message display on the accident day.

The expected values for the lane distributions on the non-accident days were used in a chi square analysis comparison with the data for the accident day (Appendix A for detailed statistical results). The results of this analysis indicate that there is no significant difference between the data for the accident day and the non-accident days. Therefore, there is no evidence of any lane displacement of traffic at site 151 on the day of the accident due to the message display.

SUMMARY

There is clear evidence that the VMS displays achieved the desired results in two of the three case studies. In both instances where the message to drivers advised the use on an alternative route there was a significant driver response exhibited through a traffic diversion to the alternative route. This diversion resulted in a significant reduction in the traffic volume passing the accident location, which resulted in a 12 and 14.5 percent diversion of I-10 traffic to I-17 for case studies No. 1 and 2, respectively. This is equivalent to approximately one-fifth to one-fourth the capacity of a single freeway traffic lane. The increase in the diversion of traffic from Case Study No. 1 to Case Study No. 2 may be indicative of an increased driver response as drivers become more familiar

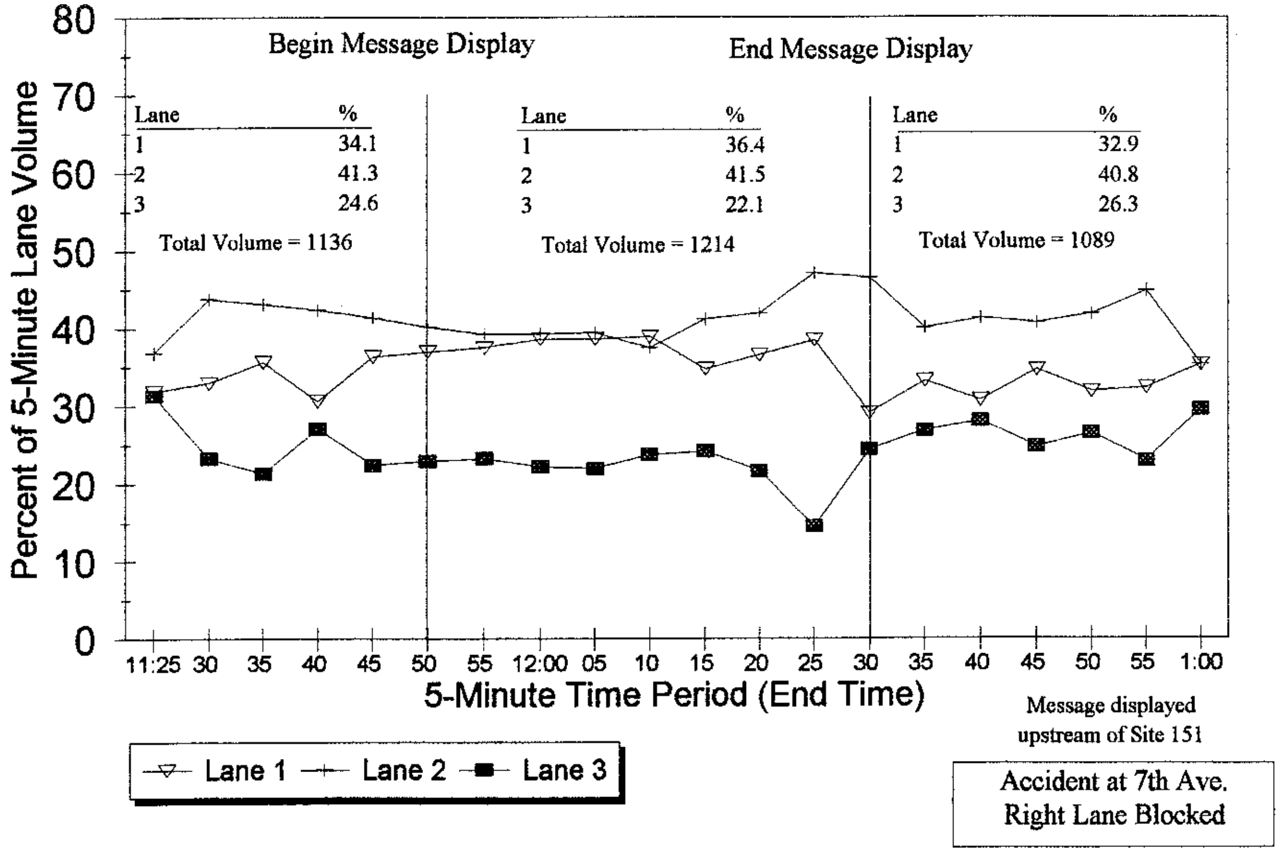


Figure 29
LANE DISTRIBUTION OF TRAFFIC AT SITE 151
DUE TO SEPTEMBER 30, 1996 ACCIDENT ON I-17

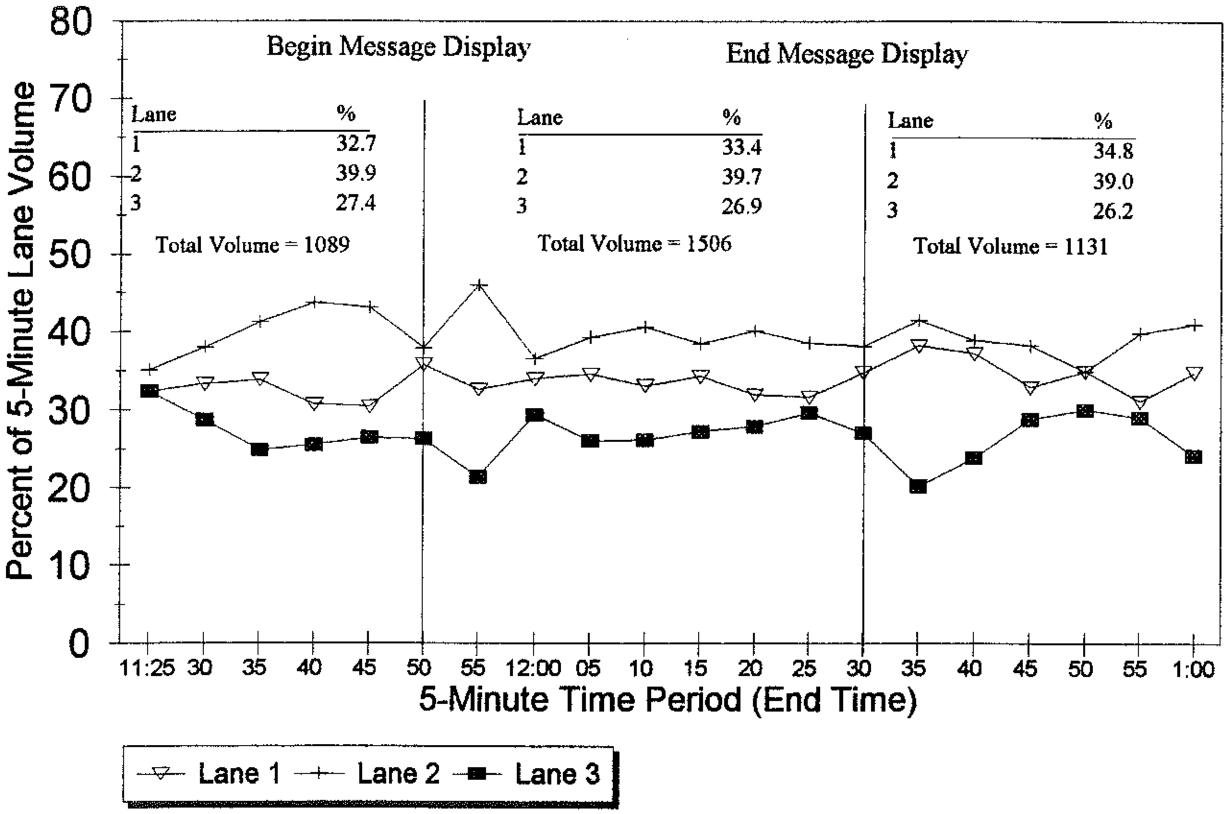


Figure 30
LANE DISTRIBUTION OF TRAFFIC AT SITE 151
ON OCTOBER 7, 1996

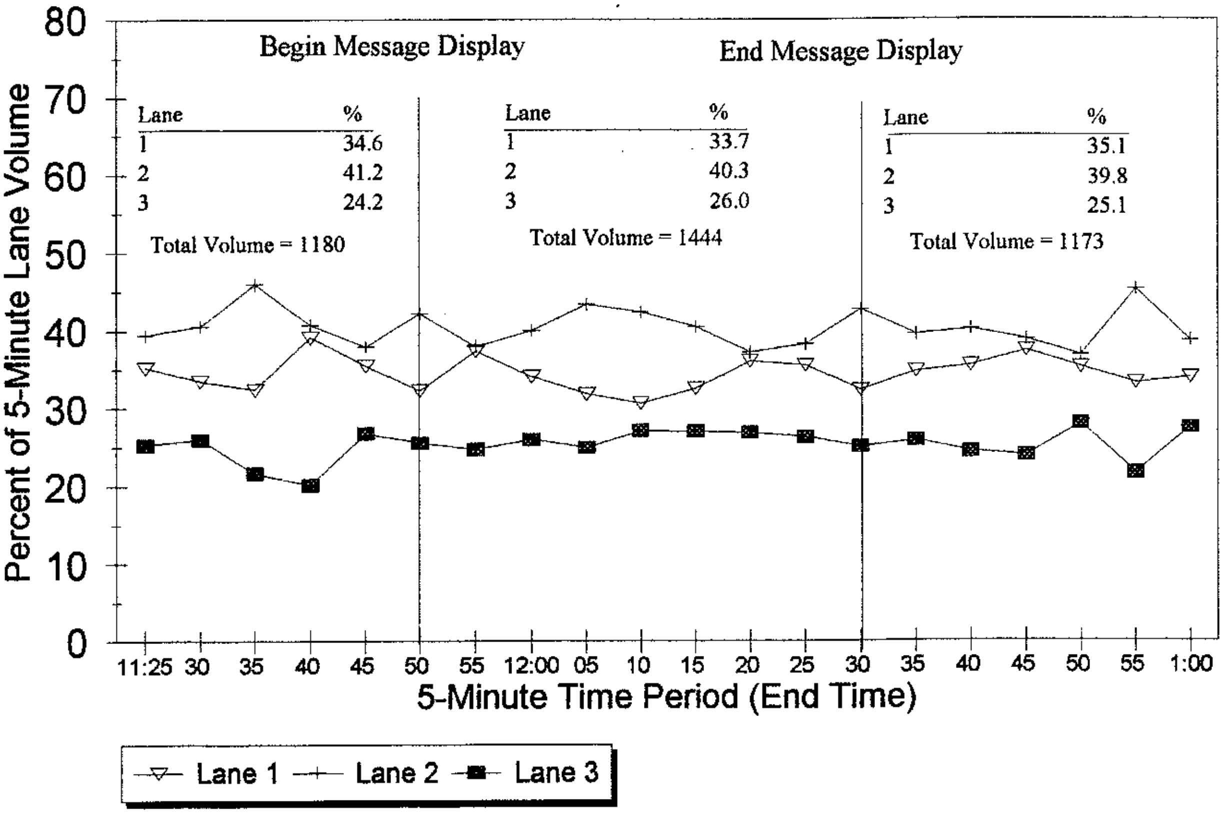


Figure 31
LANE DISTRIBUTION OF TRAFFIC AT SITE 151
ON OCTOBER 14, 1996

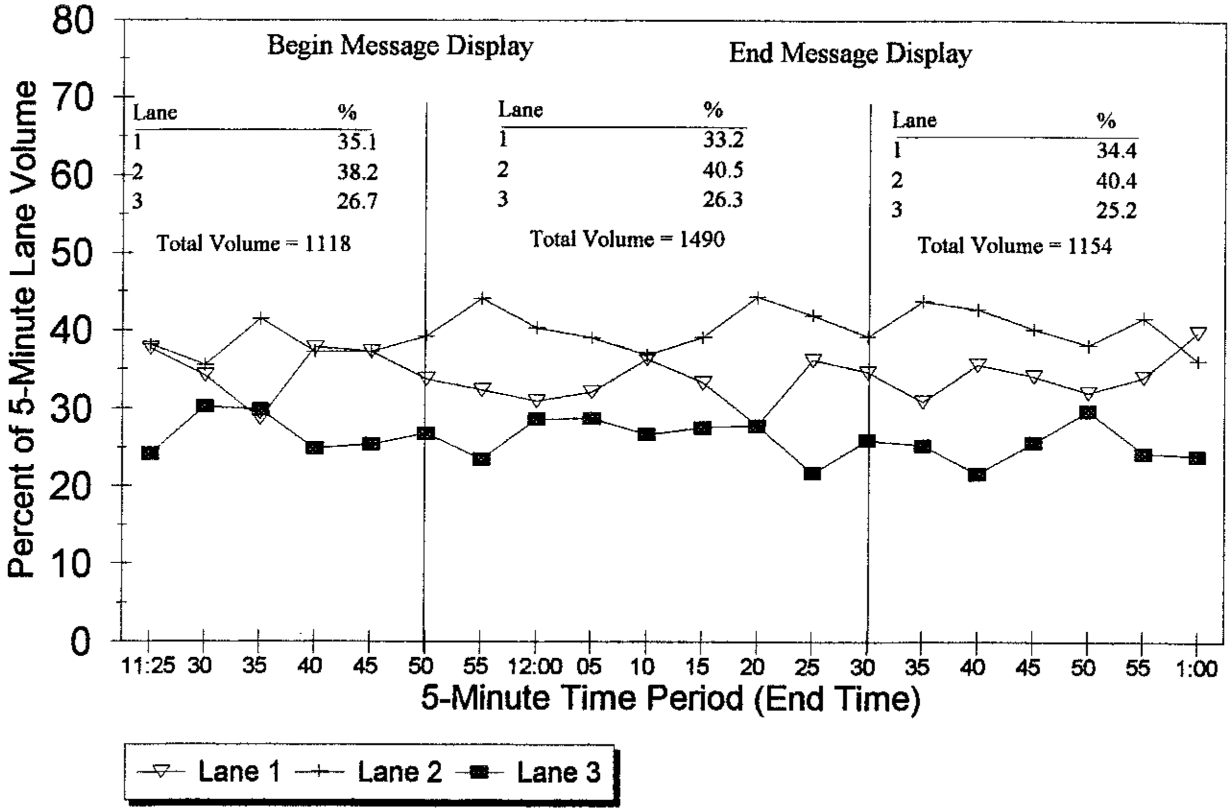


Figure 32
LANE DISTRIBUTION OF TRAFFIC AT SITE 151
ON OCTOBER 21, 1996

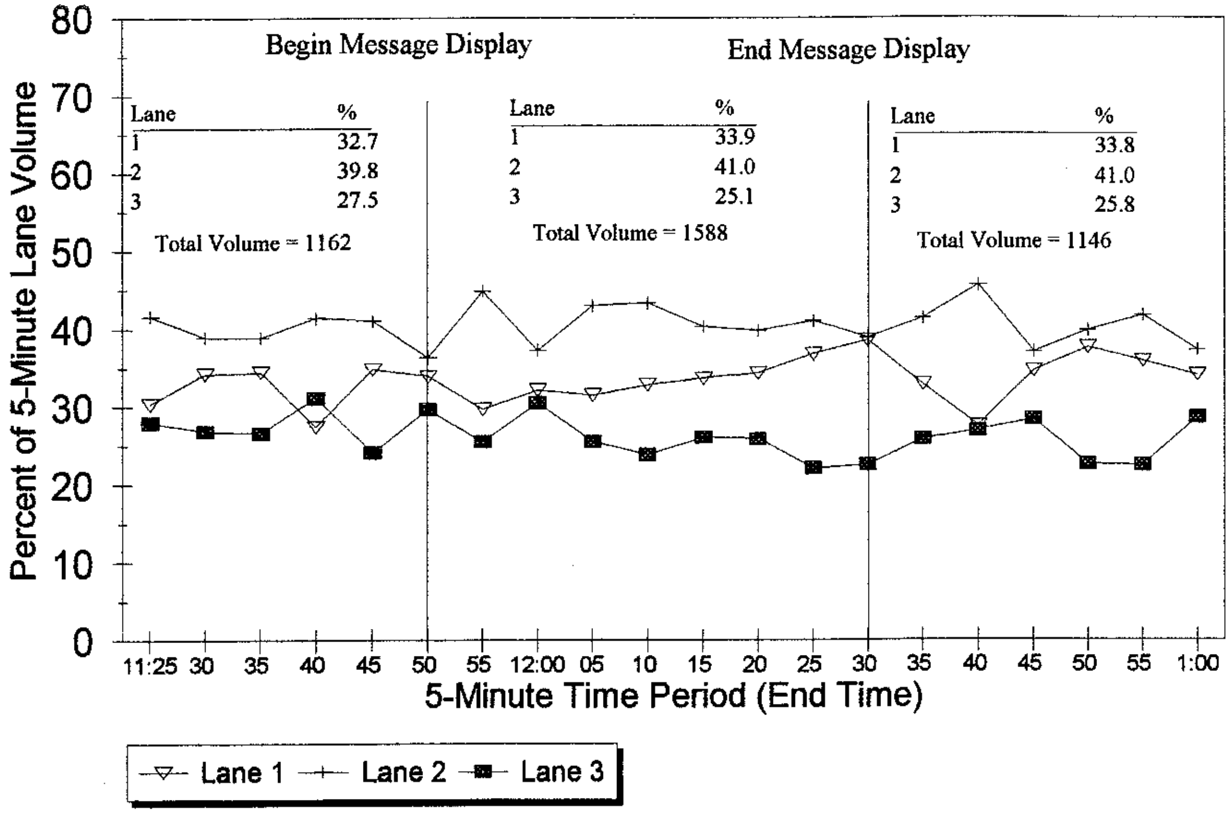


Figure 33
LANE DISTRIBUTION OF TRAFFIC AT SITE 151
ON OCTOBER 28, 1996

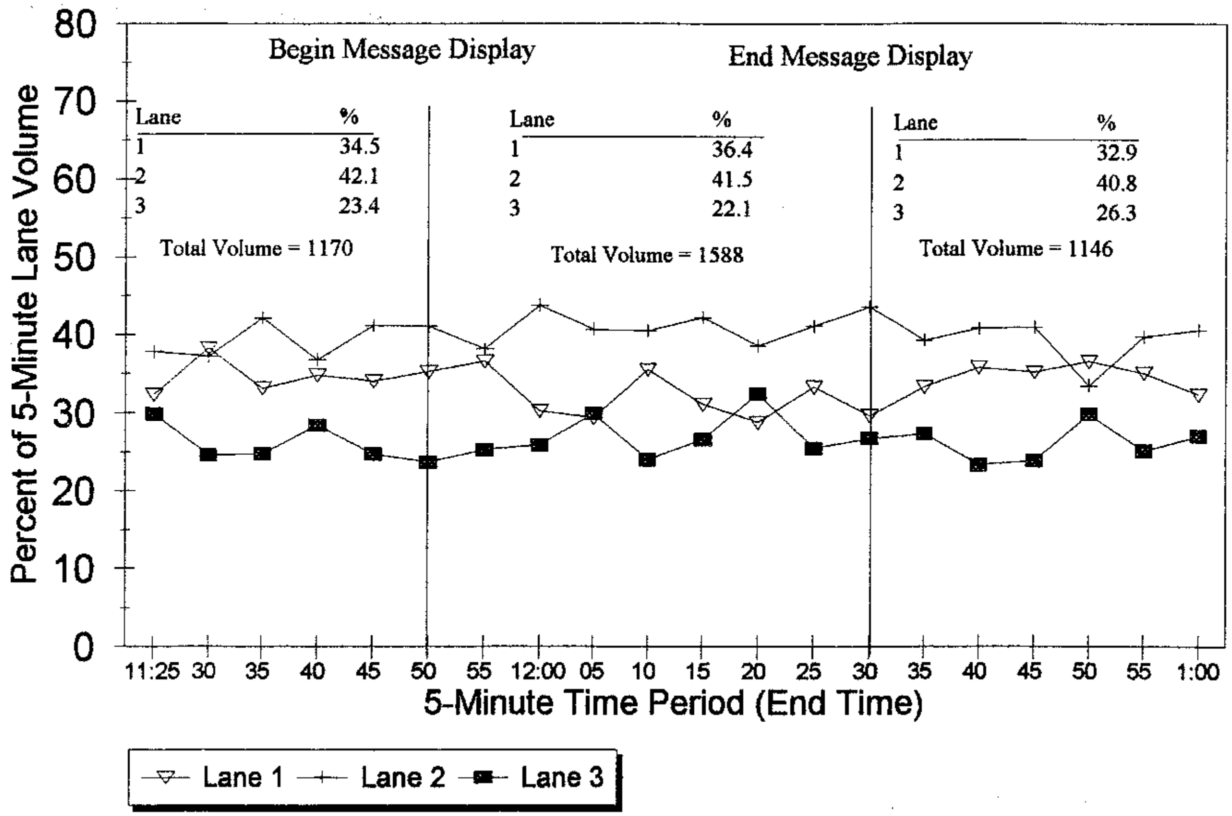


Figure 34
LANE DISTRIBUTION OF TRAFFIC AT SITE 151
ON NOVEMBER 4, 1996

with the VMS system. In one of the two case studies where drivers were advised of a lane blockage ahead, a significant lane shift away from the blocked lane was detected in advance of the accident location.

The VMS messages evaluated by the case studies provided information to motorists that either advised a specific action be taken (use an alternate route) or provided specific information regarding downstream roadway conditions (right lane blocked). In either case an appropriate response to the information provided could be determined by the motorists. In these cases the desired driver response is measurable and is significant, resulting in improved traffic control and reduced congestion at the accident location. Additional impacts could also include a reduction in secondary accidents resulting from congestion at the accident location. However, this latter hypothesis was not tested as part of this study.

SUGGESTIONS TO IMPROVE STUDY PROCEDURES

In general, the analysis of driver response to the VMS was reasonably successful. It may be of interest to evaluate the effects of the VMS on secondary accidents, that is, accidents that occur during the VMS message display and within the influence area of the primary accident. It is quite possible that the advanced warning of lane closures and accident location could reduce rear end or other types of accidents due to congestion in the area of the primary accident. However, it should be cautioned that turning off the VMS system in order to collect data on the nature of secondary traffic accidents without the advanced warning provided by the signs could create liability problems for ADOT if secondary accidents could have been avoided with the VMS in use.

The evaluation of travel time saved by those drivers that are diverted to an alternate route by the VMS would provide significant additional information on the benefits of the VMS. This could be accomplished by estimating the delay due to the incident based on the spot speed data gathered by the FMS.

It may be worthwhile to evaluate driver perceptions of the VMS through some sort of a survey procedure. Such factors as driver stress or frustration may be affected by the advanced warning information provided by the VMS. Simply knowing the cause of the congestion and the location of the accident may provide information that makes the condition more tolerable.

Messages that direct the driver to take a specific action were found to be effective in this study. It appears worthwhile to evaluate if there is a difference in driver response to specific message text, and which type of message provides the highest level of desired driver response.

VI. ANALYSIS OF INCIDENT RESPONSE TIME AND DURATION

STATISTICAL ANALYSIS OF RESPONSE TIME AND DURATION

During the before period 17 Arizona Local Emergency Response Team (ALERT) responses were reported for accidents within the study area. In the after period 28 ALERT unit responses were recorded by ADOT. Copies of the ADOT incident response log reports for each incident were provided by ADOT. These reports include a description of the incident, date and time of the incident, incident location, the incident response time (time from the first notification of the incident to arrival at the incident location), and duration of the incident (time from arrival at the incident location to the return to normal traffic operations). The time data were used in an assessment of the incident response time and incident duration before and after implementation of the FMS. Review of the after data revealed that five of the reports had either response time or duration listed as either zero or this information was missing. An investigation of why this occurred was not conducted, and these five cases were eliminated from the analysis data set, reducing the overall number of incidents in the after period to 23.

The analysis compared the incident response and duration times before and after using a rank sum test. A t-test of means was inappropriate because the range of the duration data was so great (minimum of 6 minutes to a maximum of 450 minutes in the before period) that no central tendency exists and the concept of a mean value is useless. In addition, the distributions of the response time and the duration time are relatively flat.

Response Time

Figure 35 provides frequency distributions of the response time before and after data. Table 12 provides the before and after data and the results of the rank sum test. The information in Table 12 indicates that there is no significant difference in the response time based on the data used in the analysis. The mean response time was 15.7 minutes in the before period and 15.1 minutes in the after period. The minimum response time was 7 minutes in the before period and 5 minutes after, with the maximum response time of 31 minutes before and 35 minutes after.

Incident Duration

Figure 36 provides frequency distributions of incident duration time before and after. Table 13 provides the before and after data and the results of the rank sum test. The information in Table 13 indicates that there is no significant difference in incident duration time based on the data used in the analysis. The mean duration time excluding outliers was 119 minutes before and 109 minutes after, an 8.4 percent difference. The minimum duration time was 6 minutes before and 10 minutes after, with the maximum duration time of 290 minutes before and 212 minutes after. Two points at the high end of the duration times were determined to be outliers and were eliminated from the analysis because of their unreasonable influence on the results.

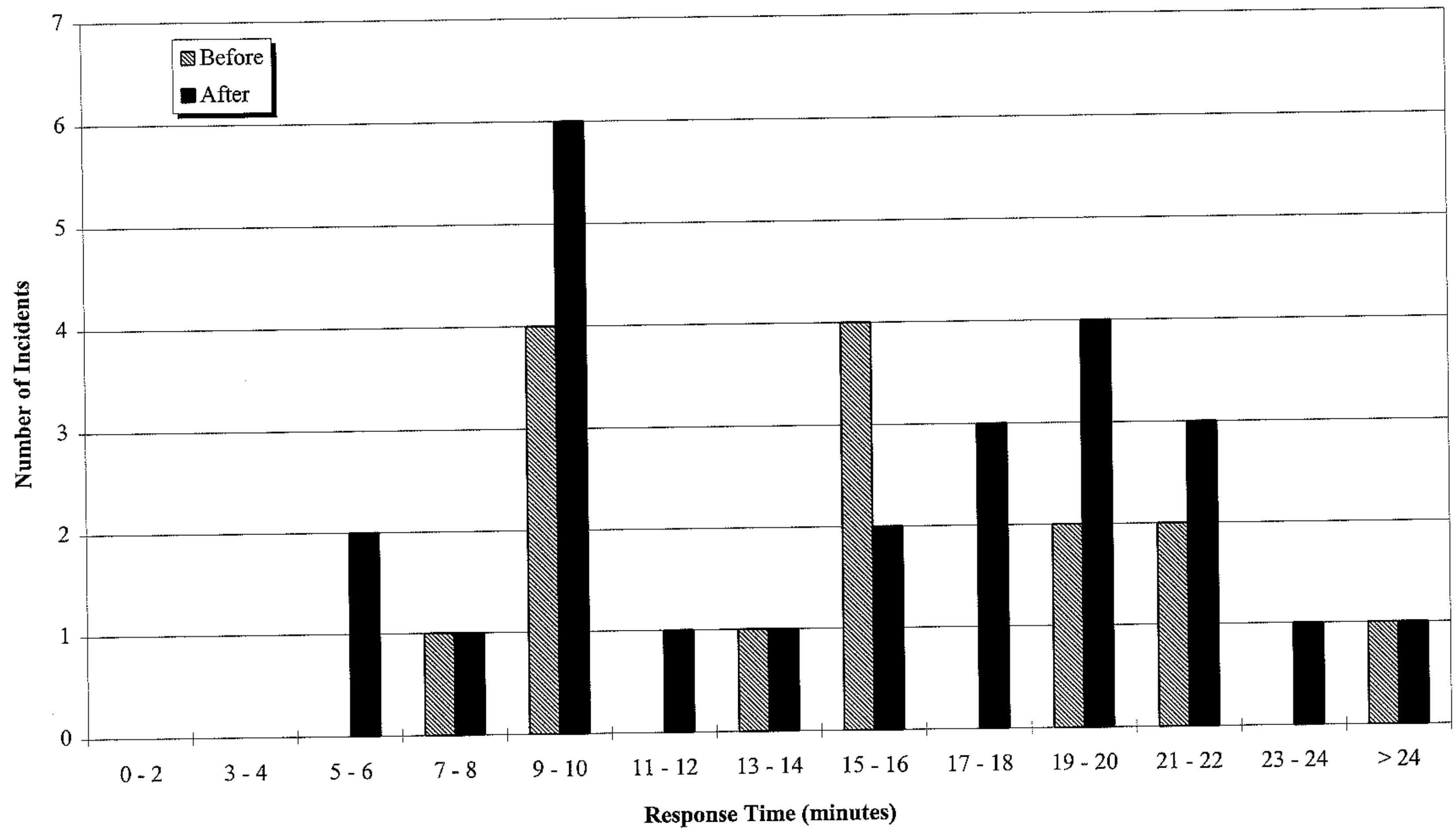


Figure 35
INCIDENT RESPONSE TIME FREQUENCY DISTRIBUTION

Table 12
INCIDENT RESPONSE TIMES
BEFORE AND AFTER COMPARISON OF MEANS

RESPONSE TIME (minutes) BEFORE	AFTER	SORT BEFORE	AFTER	Rank BEFORE	AFTER	Sort Combined	Rank Combined	Rank Adjusted
15	10	7	5	3.5	1.5	5	1	1.5
7	22	10	5	9.5	1.5	5	2	1.5
15	5	10	7	9.5	3.5	7	3	3.5
20	20	10	10	9.5	9.5	7	4	3.5
21	23	10	10	9.5	9.5	10	5	9.5
31	17	14	10	16.5	9.5	10	6	9.5
20	14	15	10	20.5	9.5	10	7	9.5
14	35	15	10	20.5	9.5	10	8	9.5
15	15	15	10	20.5	9.5	10	9	9.5
10	10	15	11	20.5	15	10	10	9.5
15	15	20	14	30	16.5	10	11	9.5
10	22	20	15	30	20.5	10	12	9.5
10	5	21	15	33.5	20.5	10	13	9.5
22	10	22	17	36	24.5	10	14	9.5
10	11	31	17	39	24.5	11	15	15
	21		18		26	14	16	16.5
	20		19		27	14	17	16.5
	20		20		30	15	18	20.5
	18		20		30	15	19	20.5
	10		20		30	15	20	20.5
	7		21		33.5	15	21	20.5
	10		22		36	15	22	20.5
	19		22		36	15	23	20.5
	17		23		38	17	24	24.5
	10		35		40	17	25	24.5
						18	26	26
						19	27	27
						20	28	30
						20	29	30
						20	30	30
						20	31	30
						20	32	30
						21	33	33.5
						21	34	33.5
						22	35	36
						22	36	36
						22	37	36
						23	38	38
						31	39	39
						35	40	40
					COUNT		40	40
					SUM		820	820

	BEFORE	AFTER
COUNT	15	25
MEAN	15.67	15.44

	BEFORE	AFTER
COUNT	15	25
SUM	308.5	511.5

W=308.5
N1=15
N2=25
MUW=307.5
SDW=35.79
ZW=0.03
NO SIG DIFF

RANK SUM TEST: NO SIG DIFF

Checked for Outliers: None in either series
Samples too small for T test on means

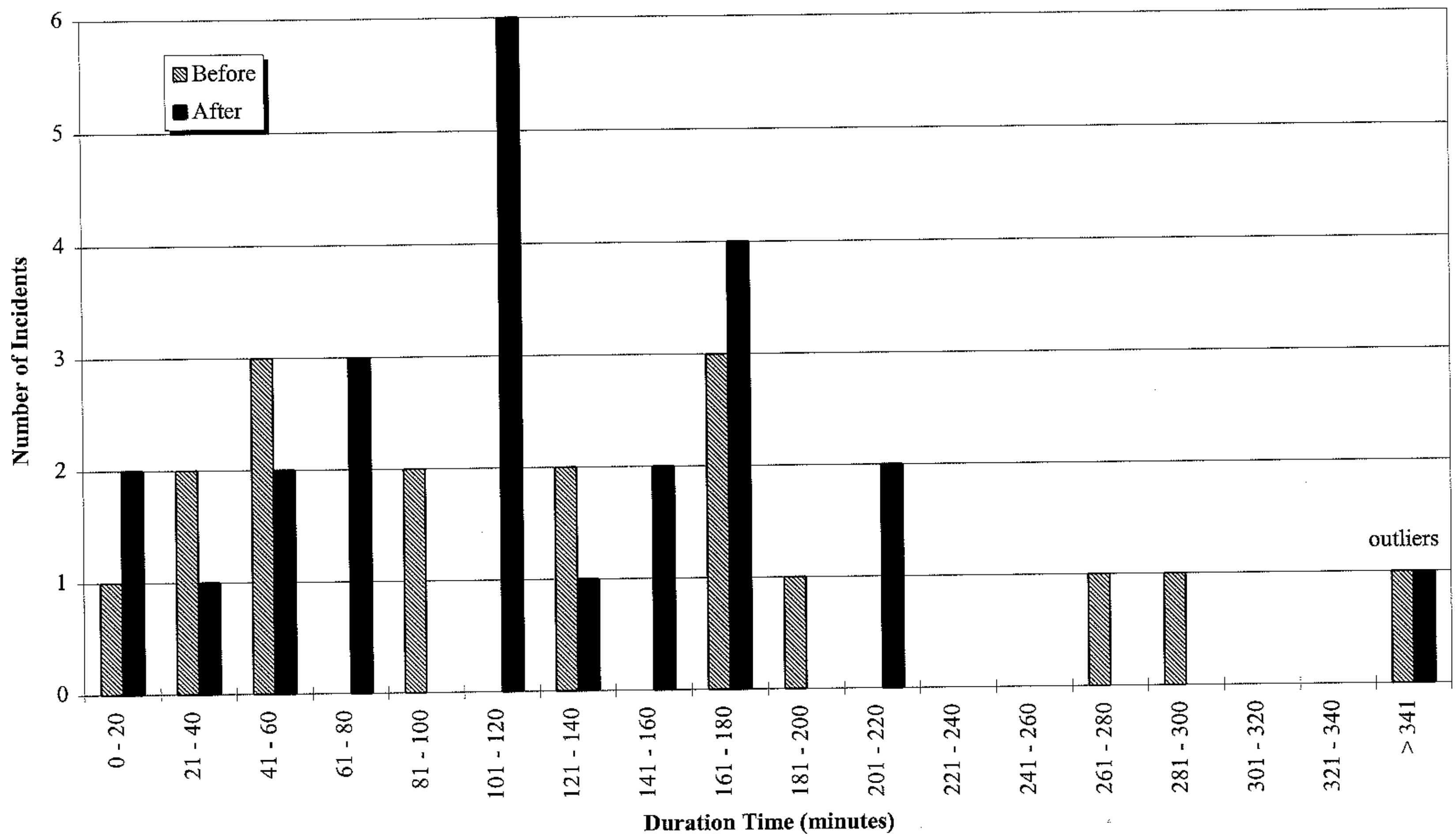


Figure 36
INCIDENT DURATION TIME FREQUENCY DISTRIBUTION

Table 13
INCIDENT DURATION TIMES
BEFORE/AFTER COMPARISON OF MEANS

DURATION TIME (minutes)		WITHOUT OUTLIERS									
BEFORE	AFTER	BEFORE	AFTER	SORT BEFORE	SORT AFTER	SORT COMBINED	RANK COMBINED	RANK ADJUSTED	RANK BEFORE	RANK AFTER	
95	170	95	170	6	10	6	1	1	1	2	
138	73	138	73	40	19	10	2	2	5.5	3	
262	117	262	117	40	30	19	3	3	5.5	4	
161	104	161	104	44	56	30	4	4	7	10	
450	60	40	60	54	60	40	5	5.5	8	11	
40	345	184	69	55	69	40	6	5.5	9	12	
184	69	290	165	82	70	44	7	7	15	13	
290	165	171	165	95	73	54	8	8	16	14	
171	165	55	10	122	104	55	9	9	23	17	
55	10	44	56	138	105	56	10	10	25	18	
44	56	40	212	161	110	60	11	11	28	19	
40	212	122	150	165	113	69	12	12	30	20	
122	150	6	105	171	117	70	13	13	33	21	
6	105	82	70	184	120	73	14	14	35	23	
82	70	54	113	262	129	82	15	15	38	24	
54	113	165	180	290	150	95	16	16	39	26	
165	180		120		158	104	17	17		27	
	120		158		165	105	18	18		30	
	158		19		165	110	19	19		30	
	19		30		170	113	20	20		32	
	30		129		180	117	21	21		34	
	129		204		204	120	22	22		36	
	204		110		212	122	23	23		37	
	110					129	24	24			
17	24	16	23	COUNT		138	25	25			
138.80	122.30	119.30	112.60	MEAN		150	26	26			
12808	5419	6801	3312	VARS		158	27	27			
						161	28	28			
						165	29	29			
						165	30	30	16	23	COUNT
						165	31	31			
						170	32	32	318	462	SUM
						171	33	33			
						180	34	34			
						184	35	35			
						204	36	36			
						212	37	37			
						262	38	38			
						290	39	39			
					COUNT	39	39	39			
					SUM	4498	780	780			

VARS ARE SIG DIFF
N'S ARE TOO SMALL FOR TEST ON MEANS

UNDERLINED VALUES ARE OUTLIERS

RANK SUM TEST: NO SIG DIFF IN LOCATION

Because ranges are so great for such small samples, the mean is not very appropriate. A test for location such as the rank-sum test is more meaningful.

W=318
N1=16
N2=23
MUW=320
SDW=35.02
ZW=0.06
NO SIG DIFF

SUMMARY

There are three primary variables that may be affected by incident management procedures; incident detection time, incident response time, and incident duration. There does not appear to be anything inherent in the FMS that would affect incident response time. The ALERT units were in place and ready to respond to incidents in the same manner in the before and after conditions. The FMS did not affect ALERT response policies or procedures. Incident duration could conceivably be affected by the FMS since more specific information regarding the nature of the incident and the type of response required can be obtained through the CCTV cameras that provide 100 percent surveillance of the study area. Through improvement in the type of the initial response, it is possible that incident duration could be reduced. The mean incident duration including outliers was reduced from before to after by 19.11 minutes (138.76 minutes to 119.65 minutes). The mean incident duration excluding outliers was reduced from before to after by 10.24 minutes (119.31 minutes to 109.41 minutes). However, even though the mean duration time in the after period is less than in the before period, this was determined not to be statistically significant primarily because of the large range in the data.

This analysis did not take into consideration the characteristics of the incidents that occurred in the before and after conditions. Factors such as the number and type of vehicles involved, the extent of injuries, and presence of rolled-over commercial vehicles, just to name a few, can seriously affect the time required to clear the incident. The sample sizes were not large enough to control for the many factors that could affect incident duration, and the recorded difference in the mean duration from before to after may be a result of differences in key incident characteristics rather than the presence of the FMS.

The remaining variable is incident detection time. It is quite possible that the incident detection elements of the FMS have reduced incident detection time (i.e., the time from the moment the incident occurs to the notification of ADOT that the incident has occurred). However, these data did not exist for the before condition, and it is difficult to precisely establish the time an incident occurred after it has been detected. Therefore, the change in detection time was not an element of this study.

SUGGESTIONS TO IMPROVE STUDY PROCEDURES

With the FMS now in place it may be possible to determine the difference in detection time with and without the FMS by establishing a mechanism to record the time an incident is detected by the FMS and the time the TOC is notified of the incident through some other means. This difference would be the change in the detection time resulting from the FMS even though the actual time the incident occurred is not known. Other means of notification could be made by DPS or through motorist call-in, for example.

VII. NOISE AND AIR QUALITY ASSESSMENT

INTRODUCTION

The evaluation of the noise and air quality measures of effectiveness was conducted through the use of modeling procedures. The noise levels and vehicle emissions before and after the implementation of the FMS were estimated based on the measured traffic volumes and travel speeds in the before and after periods. Noise levels and vehicle emissions were not measured directly due to the problems associated with controlling for outside influences and background noise and pollutant levels.

The noise and air quality analysis was conducted on a systemwide basis by estimating noise levels and vehicle emissions at five locations within the study area for both directions of travel. Both the noise and air evaluations were conducted for typical summer and winter days to account for seasonal variations. This is particularly important for the air analysis where the pollutant of primary concern changes from winter to summer. The following sections provide the details of how the noise and air quality evaluations were conducted and summarizes the results of the analyses.

NOISE ANALYSIS

Methodology and Assumptions

FHWA's traffic noise prediction model, STAMINA 2.0, was used to predict traffic noise levels adjacent to specified freeway links. Both the eastbound and westbound directions of travel were considered at each site. Roadway geometry at each site assumed an approximate median width separating the two directions of travel. Noise receivers were assumed at 100 feet from the edge of the nearest travel lane on both sides of the freeway.

Traffic data used in the noise analysis were provided through the before and after data collection for the FMS evaluation. Traffic data for each model run included peak hour traffic volumes and speed for each direction of travel. The location for traffic data collection and noise analysis are provided in Figure 37. Noise modeling was conducted for both morning and evening peak traffic hours, and for both summer and winter seasons. For each model run, 5 percent heavy trucks and 3 percent medium trucks were assumed for both directions of travel. Table 14 provides a summary of the volumes and speeds used in both the noise and air analyses.

Noise Modeling Results

Results of the STAMINA modeling analysis are shown in Tables 15 and 16. Modeled noise levels represent one hour average, or equivalent, noise levels in A-weighted decibels (abbreviated Leq dBA). Comparisons of modeled noise levels for a

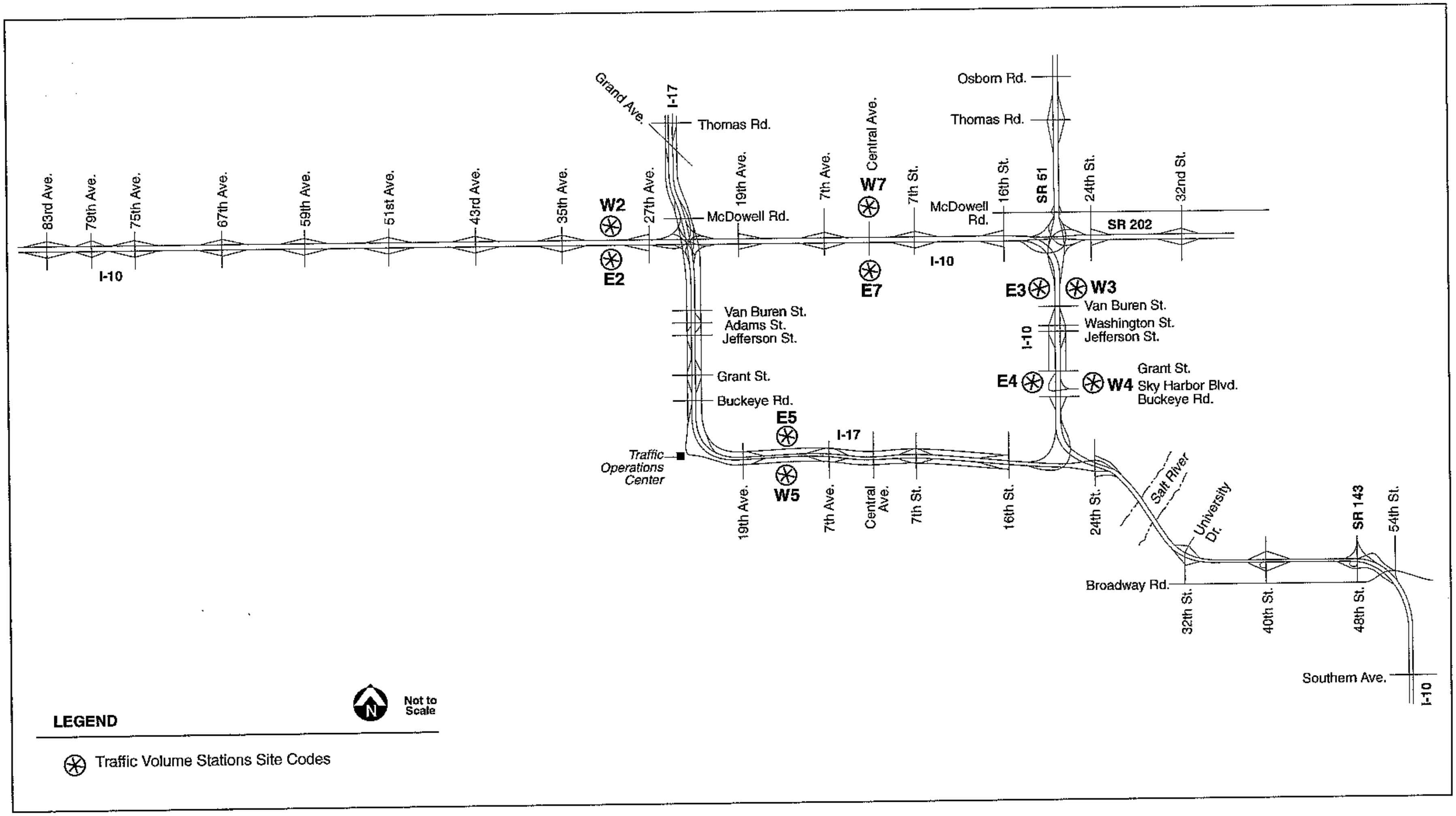


Figure 37
LOCATIONS FOR VOLUME AND SPEED DATA USED IN NOISE AND AIR ANALYSES

Table 14
TRAFFIC VOLUME (VPH) AND SPEED (MPH) SUMMARY

AM Peak Hour Summer Day

	Eastbound				Westbound			
	Before		After		Before		After	
Site	vph	mph	vph	mph	vph	mph	vph	mph
2	8257	54	5515	33	3688	62	3327	65
3	5309	58	6055	56	5977	53	5345	57
4	4590	42	4190	51	6049	38	3958	46
5	3334	56	3513	58	4123	59	4493	55
7	7473	54	5208	55	6344	52	8365	54

PM Peak Hour Summer Day

	Eastbound				Westbound			
	Before		After		Before		After	
Site	vph	mph	vph	mph	vph	mph	vph	mph
2	4864	59	3822	47	7249	63	6876	25
3	4914	62	5573	58	6085	61	5960	52
4	4590	42	5231	57	4861	49	3361	46
5	4027	58	4531	61	3380	61	3852	51
7	5950	52	5942	62	7150	55	7108	50

AM Peak Hour Winter Day

	Eastbound				Westbound			
	Before		After		Before		After	
Site	vph	mph	vph	mph	vph	mph	vph	mph
2	5975	57	7285	48	4690	60	3696	65
3	6197	53	6015	62	6352	61	5941	57
4	5277	49	4314	54	5941	40	5896	46
5	3731	51	4025	61	4643	59	4805	55
7	7693	57	5609	54	6965	55	8113	52

PM Peak Hour Winter Day

	Eastbound				Westbound			
	Before		After		Before		After	
Site	vph	mph	vph	mph	vph	mph	vph	mph
2	5404	65	5584	62	8850	63	7169	59
3	5485	58	5999	66	6693	48	6061	53
4	5818	54	5497	49	5207	34	5379	49
5	4498	58	5147	58	3601	60	3953	63
7	7017	62	6399	54	8090	42	7819	55

Note that speeds are presented here in miles-per-hour because these are the units required by the air and noise models for input data.

Table 15
COMPARISON OF BEFORE AND AFTER TRAFFIC NOISE LEVELS
IN Leq dB(A)
TYPICAL SUMMER DAY

	AM Peak Hour			PM Peak Hour		
Site/ Receiver	Before	After	Change	Before	After	Change
2/ EB 100'	76.1	71.8	-4.3	75.7	71.4	-4.3
2/ WB 100'	75.0	73.5	-1.5	76.8	70.2	-6.6
3/ EB 100'	74.9	75.3	0.4	75.6	75.2	-0.4
3/ WB 100'	74.9	75.1	0.2	76.0	74.8	-1.2
4/ EB 100'	71.8	72.7	0.9	72.1	74.2	2.1
4/ WB 100'	72.0	72.1	0.1	72.9	72.4	-0.5
5/ EB 100'	74.4	74.7	0.3	74.9	75.3	0.4
5/ WB 100'	74.8	74.9	0.1	74.8	74.7	-0.1
7/ EB 100'	76.3	75.9	-0.4	75.8	75.4	-0.4
7/ WB 100'	76.0	76.5	0.5	76.2	75.6	-0.6

Table 16
COMPARISON OF BEFORE AND AFTER TRAFFIC NOISE LEVELS
IN Leq dB(A)
TYPICAL WINTER DAY

	AM Peak Hour			PM Peak Hour		
Site/ Receiver	Before	After	Change	Before	After	Change
2/ EB 100'	75.4	74.8	-0.6	76.9	76.5	-0.4
2/ WB 100'	75.1	74.7	-0.4	77.8	77.2	-0.6
3/ EB 100'	75.4	76.1	0.7	75.1	76.3	1.2
3/ WB 100'	76.1	75.7	-0.4	74.7	75.4	0.7
4/ EB 100'	73.3	73.6	0.3	74.2	73.8	-0.4
4/ WB 100'	72.7	73.6	0.9	72.0	73.7	1.7
5/ EB 100'	74.5	75.4	0.9	75.3	75.9	0.6
5/ WB 100'	75.1	75.4	0.3	75.1	75.8	0.7
7/ EB 100'	77.0	75.8	-1.2	76.8	76.3	-0.5
7/ WB 100'	76.7	76.2	-0.5	76.0	76.6	0.6

typical summer day are provided in Table 15. Comparisons of modeled noise levels for a typical winter day are provided in Table 16. Comparisons for both morning and evening peak hours are provided in each table.

Differences in noise shown in Tables 15 and 16 are the result of differences in traffic volumes and travel speeds assumed in the before and after conditions. As shown in Tables 15 and 16, differences between before and after noise levels are generally minor (less than 1 decibel). Human hearing can begin to distinguish noise level differences of approximately 2-3 decibels. Therefore, the FMS project did not likely produce a perceivable difference in noise for most of the periods that were evaluated.

For certain locations/periods, noise level differences of greater than 2-3 decibels were predicted after implementation of the FMS (sites 2, 3, 4). In one case, a decrease of 6.6 decibels was predicted in the after period (site 2, summer PM period). In another case, an increase of 2.6 decibels was predicted in the after period (site 3, AM winter period). These changes in noise would be perceivable. The more substantial differences modeled for these locations are directly related to the differences in travel speeds and traffic volumes assumed in the before and after periods. The noise level reduction of 6.6 dB(A) at site 2 is attributed to a reduction in speed at that location from 63 miles per hour in the before period to 25 miles per hour in the after period. Conversely, the 2.6 dB(A) increase in noise predicted for site 3 is attributed to an increase in eastbound traffic volume from 3,170 vehicles in the before condition to 6,015 in the after condition.

AIR QUALITY ANALYSIS

Methodology and Assumptions

Peak hour vehicle emissions were estimated for the before and after periods and the results were compared. For summer conditions, emissions were estimated for ozone precursors, hydrocarbons (HC) and oxides of Nitrogen (NOx). For winter conditions, emissions were estimated for carbon monoxide (CO).

Vehicle emission rates specific to Maricopa County were generated using EPA's mobile source emissions model MOBILE 5a. The Maricopa Association of Governments (MAG) provided current MOBILE 5a input parameters for use in the analysis. MOBILE 5a was then used to generate vehicle emission rates for the range of freeway speeds provided by the FMS traffic analysis. Both the summer and winter emission rates were then weighted based on MAG's current recommendations for the inspection/maintenance (IM) program and non-IM composition of the vehicle fleet (89.6 percent IM and 10.4 percent non-IM). Table 14 provides a summary of the volumes and speeds used in the air and noise analyses.

Peak hour VMT was calculated for each freeway link by multiplying the peak hour volume by the link's length. Link emissions were then calculated by multiplying the appropriate MOBILE 5a emission rate for the link's travel speed by the link's peak hour

VMT. Worksheets used to calculate the emissions for each site, and for each period, are provided in Appendix B. Also provided in Appendix B is a table showing the emission factors for each pollutant used for the various travel speeds included in the analysis.

Emissions Estimate Results

Table 17 provides a comparison of before and after emissions for HC, NOx, and CO. The table provides the percent change in emissions for each site, and the total change for each pollutant for all of the sites combined.

As with the noise analysis, emissions differences in the before and after periods are the result of differences in traffic volume and travel speeds assumed for each freeway link. Differences in traffic volume would affect emissions in a linear fashion (increasing volume would increase emissions proportionally). However, changes in travel speeds produce more variable effects on emissions, depending on the given travel speed and the pollutant being considered. The table showing the relationship between travel speed and emission rates shows the effects of relative travel speed on the emission rates for the three different pollutants that were considered.

As shown in Table 17, varying results were predicted for emissions in the before and after conditions. In some cases, emissions were lower in the after period. In other cases, emissions were higher in the after period. As noted earlier, the emissions estimates are the direct result of traffic volume and speed assumptions in the before and after periods for each specific link. As shown in Table 17, the difference in before and after traffic assumptions produced rather significant differences in emissions for certain links (up to 30-40 percent in some cases). However, as shown in the total values for the various sites combined, after emissions tended to be nearly equal to or slightly lower than the before period emissions.

SUMMARY

The air and noise analysis was conducted using models (STAMINA 2.0 for the noise analysis, and Mobile 5a for the air analysis) specifically designed and approved by FHWA for use in the evaluation of traffic noise levels and vehicle emissions. Traffic volume and speed data from the before and after periods were used as model input to estimate traffic noise and vehicle emissions for a typical summer day and typical winter day from the before and after periods. Model runs were made with data from five locations within the study area for both the AM and PM peak periods. Estimated changes in the traffic noise levels and vehicle emissions are primarily a result of the differences in the traffic volume and speed between the before and after periods.

Table 17
COMPARISON OF BEFORE AND AFTER EMISSIONS

HC Emissions (typical summer day)

Site		AM Peak Hour Emissions (gr) Before	After	Percent Change	PM Peak Hour Emissions (gr) Before	After	Percent Change
2		12,317	10,544	-14%	13,192	13,640	3%
3		8,616	8,717	1%	9,260	8,829	-5%
4		3,878	2,791	-28%	3,320	3,102	-7%
5		6,226	6,403	3%	6,001	6,475	8%
7		11,066	10,838	-2%	10,480	10,514	0%
	total	42,104	39,294	-7%	42,253	42,381	0%

NOx Emissions (typical summer day)

Site		AM Peak Hour Emissions (gr) Before	After	Percent Change	PM Peak Hour Emissions (gr) Before	After	Percent Change
2		23,862	16,012	-33%	26,890	15,417	-43%
3		16,407	17,080	4%	18,861	16,300	-14%
4		5,245	4,561	-13%	4,946	5,658	14%
5		12,355	12,499	1%	12,068	11,917	-1%
7		19,928	20,657	4%	19,201	17,695	-8%
	total	77,797	70,809	-9%	81,965	66,985	-18%

CO Emissions (typical winter day)

Site		AM Peak Hour Emissions (gr) Before	After	Percent Change	PM Peak Hour Emissions (gr) Before	After	Percent Change
2		96,359	99,250	3%	192,134	136,031	-29%
3		84,334	93,309	11%	69,717	102,525	47%
4		25,883	22,127	-15%	27,605	23,786	-14%
5		59,261	55,539	-6%	60,042	77,225	29%
7		87,803	72,123	-18%	117,236	75,001	-36%
	total	353,640	342,347	-3%	466,734	414,567	-11%

The result of the noise analysis vary by analysis location within the study area, but in general there were no perceptible changes in estimated noise levels. The results of analysis of vehicle emissions also varied by analysis location, but overall there was a general decline in the estimate of vehicle emissions from the before and after periods. Table 18 provides a summary of the overall change in the estimated vehicle emission levels from all five locations.

SUGGESTIONS TO IMPROVE STUDY PROCEDURES

There are two suggestions for improving this element of the study. The first suggestion is to include some type of comparative assessment to evaluate the proportion of vehicle emissions generated by freeway traffic within the study area in comparison to emission levels within the remainder of the metropolitan area. The idea is to attempt to determine whether or not there has been some broader impact from the development of the freeway system in the region that might account for the results estimated for the study area. In addition, a second suggestion is made to include regional air quality station data near the freeway to determine whether or not the modeled results are supported by measured air quality information before and after the implementation of the FMS.

Table 18

ESTIMATED CHANGE IN TOTAL VEHICLE EMISSIONS (ALL 5 SITES)

HC Summer Day	-7% AM	0% PM
NO_x Summer Day	-9% AM	-18% PM
CO Winter Day	-3% AM	-11% PM

VIII. ACCIDENT ANALYSIS

STATISTICAL ANALYSIS OF ACCIDENTS

Accident records were provided by the Arizona Department of Public Safety (DPS) for the 10-month before period (May 1993 through February 1994) and for the 10-month after period (November 1995 through February 1996, and May 1996 through October 1996). The data were stratified by roadway segment based on the reference points shown in Figure 38, with the segments defined as A-C (I-10, from 67th Avenue to SR51/SR202), C-D (I-10, from SR51/SR202 to I-17), D-E (I-17, from I-10 to 19th Avenue), and E-F (I-17, from 19th Avenue to McDowell Road). This referencing scheme for the freeway segments was used to correspond to the segments established for traffic volume and travel time data collection.

The accident data provided by DPS included all accidents associated with the freeway and the ramps. DPS could not facilitate sorting the data between mainline and ramp accidents. Data from the ADOT ALISS system were not used because of the time lag between accident occurrence in the after period and entry of the data into the ALISS system.

Traffic volume data for the analysis were provided through the ADOT permanent count stations that existed in the before condition and through the FMS loop detectors in the after condition. The loop detector sites for the after condition were selected to correspond to the locations of the permanent count stations from the before condition. The locations used for traffic volume data collection are shown in Figure 39. Total monthly traffic volume count data for each of the locations were used in the computation of accident rates before and after. As discussed earlier in this report, the permanent count station between 67th Avenue and 59th Avenue (site E1) in the before period did not function and no data were reported from this location.

The analysis of the accident data consisted of the computation and comparison of the accident rates by segment before and after, and a chi square statistical analysis of the accident data to determine if there were significant differences before and after. In addition, historical accident rate information was obtained from ADOT for urban freeways as a comparative statistic.

Accident Rate Analysis

Accident rates were computed for each of the freeway segments based on the total accidents for the 10-month period before and after. The total volume for each of the segments was determined from the sum of the monthly volume data provided by ADOT. On freeway segments with two traffic count sites, the volume from both sites was averaged to estimate the volume for the entire segment. The 10-month accidents, traffic volumes, and segment length in kilometers were used to compute the segment accident rate in terms of accidents per million vehicle kilometers. The results along with other

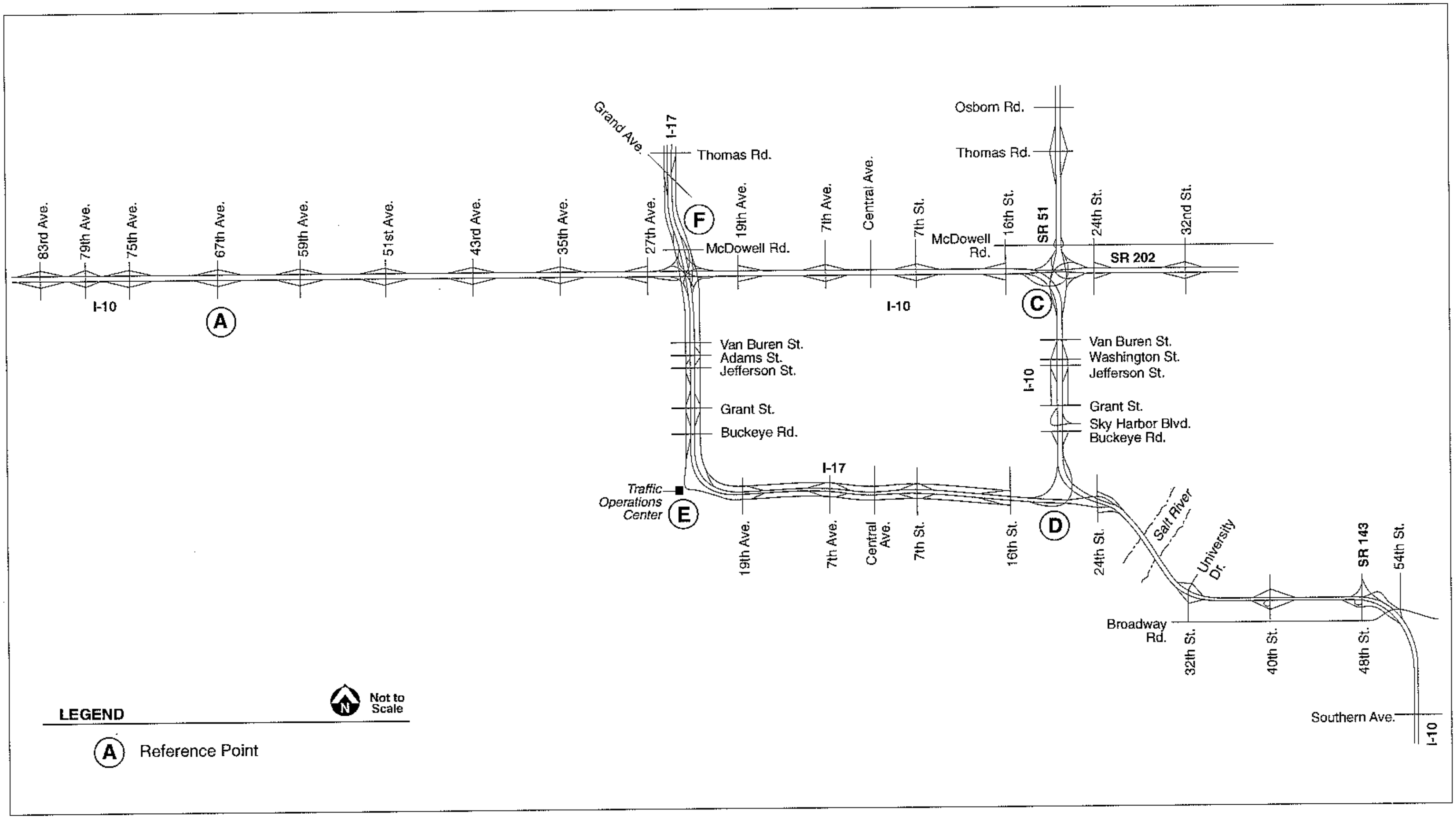


Figure 38
SEGMENT REFERENCE POINTS FOR ACCIDENT DATA

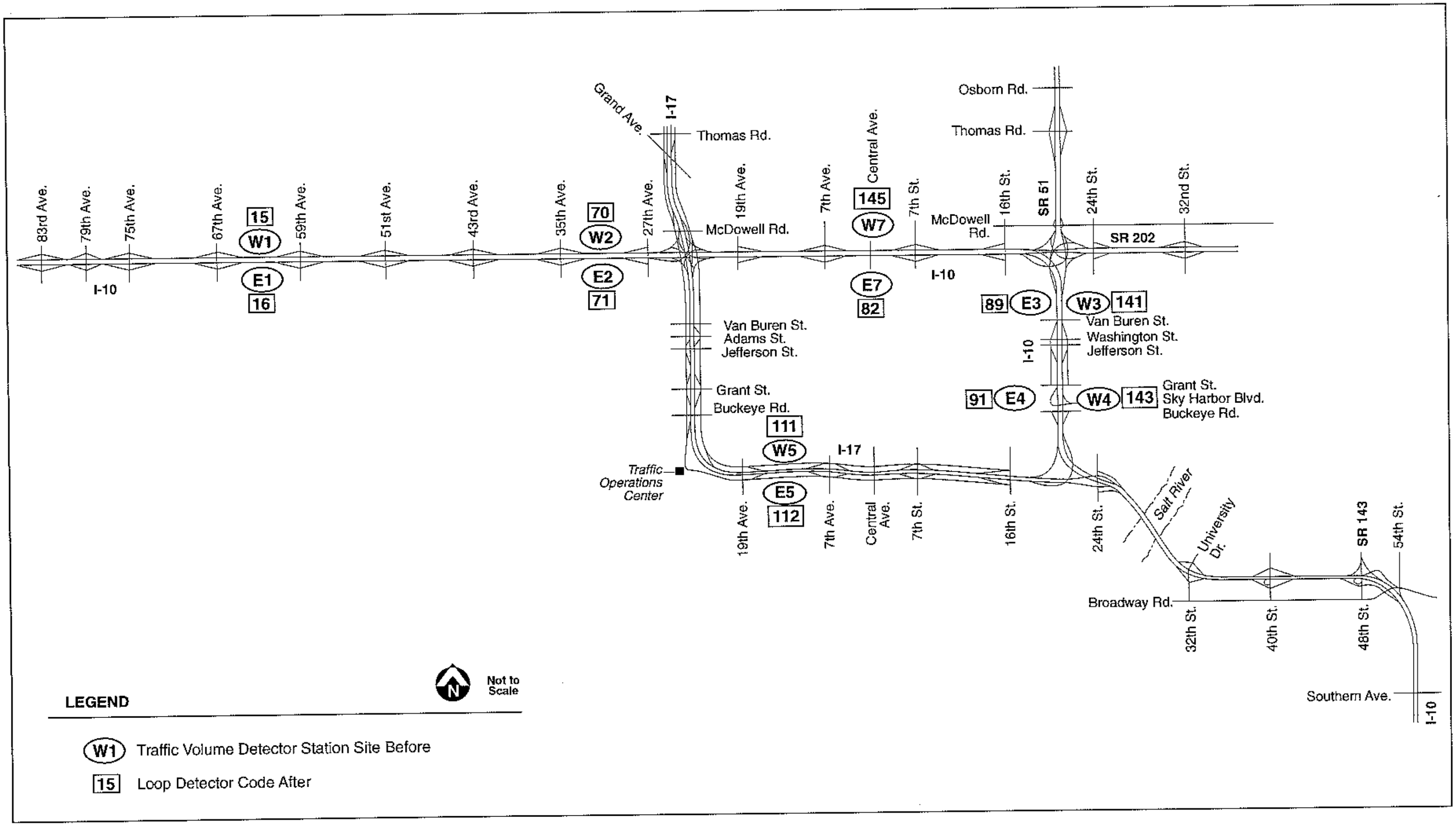


Figure 39
TRAFFIC VOLUME DATA COLLECTION SITES FOR THE ACCIDENT ANALYSIS

pertinent data are provided in Table 19. Note that for segment E-F no accident rate computation is available because there was no traffic count station on this segment to provide traffic data in the before period.

The number of accidents increased on three of the four segments from the before to the after period. Accidents increased most dramatically on segment A-C showing an increase of 56 percent. At the same time traffic volume was reported as lower on the three segments where accidents increased. Therefore, the accident rate increased on each of these three segments. Information obtained from ADOT indicates that on a statewide basis the accident rate on urban freeways has been approximately 0.81 to 0.86 accidents per million vehicle kilometers of travel for 1994 and 1995. The data available for this analysis indicate a rate in the before condition substantially less than the reported statewide rate. The after period rate was higher than the statewide rate on one segment and lower on two of the segments. Overall the after period rate is more consistent with the statewide data.

Statistical Analysis of the Accident Data

The computation of the accident rates does not, in itself, provide a mechanism to determine whether the before and after conditions are significantly different in a statistical sense. The statistical significance of the difference in the accident rate from before to after cannot be determined. A chi square analysis was conducted to determine if there were significant differences before and after in the number of accidents taking into consideration the traffic volumes. In this analysis the null hypothesis was that accidents are proportional to traffic volumes, and traffic volume was used as the basis for the computation of the expected number of accidents before and after by month. The results of the analysis are provided below by freeway segment.

I-10, 67th Avenue to SR202/SR51

The results of the chi square analysis for this segment are provided in Table 20. It is apparent that accidents uniformly increased over the study period while traffic volume did not. The chi square table, by displaying large values when small ones would be consistent with the null hypothesis, supports the conclusion that accident patterns and traffic patterns are significantly different. Accidents in the before period are significantly less than expected, and accidents in the after period are significantly more than expected based on the traffic volumes.

I-10, SR202/SR51 to I-17

The results of the chi square analysis for this segment are provided in Table 21. While the mean number of accidents increased slightly, the mean traffic volume declined. The large value of chi square for the entire table (32.85) means that the difference in overall patterns is highly significant. Accidents in the after period generally are significantly greater than expected.

Table 19
ACCIDENT RATE ANALYSIS BY SEGMENT

SEGMENT	FREEWAY	LENGTH (kilometers both directions)	VEHICLES (millions in both directions)		ACCIDENTS (total for both directions)		ACCIDENT RATE (Accidents per mvk)	
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
A-C	I-10	29	55.56	50.14	879	1368	0.55	0.94
C-D	I-10	7.6	43.99	31.07	156	182	0.47	0.77
D-E	I-17	11.7	32.74	26.66	126	157	0.33	0.50
E-F	I-17	8.5	N/A	N/A	232	169	N/A	N/A

Traffic volumes for segment E-F were not available in the before period and not collected in the after period.

Table 20
I-10, 67TH AVENUE TO SR202/SR51
NUMBER OF ACCIDENTS AND TRAFFIC VOLUME BOTH DIRECTIONS

NULL HYPOTHESIS: BY MONTH, ACCIDENTS ARE PROPORTIONAL TO TRAFFIC VOLUMES.

ACCIDENTS

MONTH	BEFORE	AFTER	TOTAL
MAY	99	136	235
JUN	96	118	214
JUL	78	125	203
AUG	93	137	230
SEP	119	130	249
OCT	90	165	255
NOV	75	151	226
DEC	80	114	194
JAN	71	150	221
FEB	77	142	219
MEAN	87.8	136.8	

TRAFFIC VOLUME*

MONTH	BEFORE	AFTER	TOTAL
MAY	52.840	44.403	97.243
JUN	49.372	52.174	101.546
JUL	49.762	36.200	85.962
AUG	53.200	58.000	111.200
SEP	68.008	52.447	120.455
OCT	61.070	57.687	118.757
NOV	62.068	44.968	107.036
DEC	55.185	51.644	106.829
JAN	54.194	52.931	107.125
FEB	49.921	50.909	100.830
	55.562	50.136	

* DIVIDED BY 100,000

EXPECTED NUMBER OF ACCIDENTS BASED ON TRAFFIC VOLUME

MONTH	BEFORE	AFTER	TOTAL
MAY	127.7	107.3	235
JUN	104.0	110.0	214
JUL	117.5	85.5	203
AUG	110.0	120.0	230
SEP	140.6	108.4	249
OCT	131.1	123.9	255
NOV	131.1	94.9	226
DEC	100.2	93.8	194
JAN	111.8	109.2	221
FEB	108.4	110.6	219

CHI SQUARE TABLE

MONTH	BEFORE	AFTER	TOTAL	PROB
MAY	6.45	7.67	14.12	0.00
JUN	0.62	0.59	1.21	0.27
JUL	13.29	18.26	31.55	0.00
AUG	2.64	2.42	5.06	0.02
SEP	3.31	4.30	7.61	0.01
OCT	12.90	13.66	26.56	0.00
NOV	23.97	33.09	57.07	0.00
DEC	4.08	4.36	8.44	0.00
JAN	14.89	15.25	30.14	0.00
FEB	9.11	8.93	18.04	0.00
TOTAL	91.26	108.53	199.79	
PROB	0.00	0.00	0.00	

Table 21
I-10, SR 202/SR 51 to I-17
NUMBER OF ACCIDENTS AND TRAFFIC VOLUME BOTH DIRECTIONS

NULL HYPOTHESIS: BY MONTH, ACCIDENTS ARE PROPORTIONAL TO TRAFFIC VOLUMES.

ACCIDENTS			
MONTH	BEFORE	AFTER	TOTAL
MAY	19	22	41
JUN	14	13	27
JUL	16	14	30
AUG	15	19	34
SEP	18	16	34
OCT	9	18	27
NOV	21	22	43
DEC	12	18	30
JAN	13	26	39
FEB	19	14	33
MEAN	15.6	18.2	

TRAFFIC VOLUME*			
MONTH	BEFORE	AFTER	TOTAL
MAY	46.107	23.090	69.197
JUN	43.151	30.743	73.894
JUL	45.839	20.032	65.871
AUG	45.214	30.317	75.531
SEP	43.583	32.604	76.187
OCT	42.045	35.392	77.437
NOV	42.849	30.588	73.437
DEC	44.634	35.785	80.419
JAN	45.839	36.774	82.613
FEB	40.597	35.414	76.011
	43.986	31.074	

* DIVIDED BY 100,000

EXPECTED NUMBER OF ACCIDENTS BASED ON TRAFFIC VOLUME			
MONTH	BEFORE	AFTER	TOTAL
MAY	27.3	13.7	41
JUN	15.8	11.2	27
JUL	20.9	9.1	30
AUG	20.4	13.6	34
SEP	19.4	14.6	34
OCT	14.7	12.3	27
NOV	25.1	17.9	43
DEC	16.7	13.3	30
JAN	21.6	17.4	39
FEB	17.6	15.4	33

CHI SQUARE TABLE				
MONTH	BEFORE	AFTER	TOTAL	PROB
MAY	2.53	5.06	7.59	0.01
JUN	0.20	0.28	0.48	0.49
JUL	1.14	2.61	3.75	0.05
AUG	1.41	2.10	3.51	0.06
SEP	0.11	0.14	0.25	0.62
OCT	2.19	2.60	4.78	0.03
NOV	0.67	0.93	1.60	0.21
DEC	1.30	1.62	2.92	0.09
JAN	3.45	4.30	7.75	0.01
FEB	0.11	0.12	0.23	0.63
TOTAL	13.09	19.76	32.85	
PROB	0.16	0.02	0.00	

I-17, I-10 to 19th Avenue

The results of the chi square analysis for this segment are provided in Table 22. While the mean number of accidents increased slightly, the mean traffic volume declined. The large value of chi square for the entire table (31.25) means that the difference in overall patterns is highly significant. Accidents in the before period generally are less than expected and accidents in the after period are significantly greater than expected.

SUMMARY

The results of the accident analysis indicate that not only have the number of accidents increased significantly in the after period but the traffic volumes have decreased. This yields an increase in the accident rate from before to after. There is no way or relating this increase in the accident rate to the implementation of the FMS. There is no means of determining whether or not the accident rate would have increased more or less without the implementation of the FMS. This latter point could only be assessed through a study design that included an analysis of control sections of the freeway where the FMS had not been implemented.

Several factors confounded the accident analysis that could not be addressed through the study design employed. First, the accident data provided by DPS could not be sorted by mainline and ramp accidents. The section of I-10 from 67th Avenue to SR202/SR51 is where the number of accidents and the resulting accident rate increased most dramatically in the after period. This is the same section of the freeway where the ramp meters were turned on in the after period. It may be that the presence of the ramp meters has contributed to an increase in ramp accidents in the after period which has subsequently caused an increase in both the number of accidents and the accident rate on this segment.

Second, sections of the freeway within the study area were restriped during the study period to increase the number of basic lanes. I-10 from I-17 to SR51 was restriped from two to three basic lanes during June and July of 1993, which would have affected seven out of ten months of the before period and the entire after period. This restriping could have affected the accident characteristics more in the after period than in the before period.

Third, the speed limits on the rural portions of the Arizona interstate system were increased from 55 mph to 75 mph during the time between the before and after periods. It is possible that the increase of the speed limits on the rural portions of the interstate system may have contributed to changes in travel speed within the study area and an increase in accidents. However, at this juncture this is speculation.

Table 22
I-17, I-10 TO 19TH AVENUE
NUMBER OF ACCIDENTS AND TRAFFIC VOLUME BOTH DIRECTIONS

NULL HYPOTHESIS: BY MONTH, ACCIDENTS ARE PROPORTIONAL TO TRAFFIC VOLUMES.

ACCIDENTS

MONTH	BEFORE	AFTER	TOTAL
MAY	11	15	26
JUN	15	24	39
JUL	11	24	35
AUG	16	17	33
SEP	10	15	25
OCT	16	7	23
NOV	15	19	34
DEC	10	8	18
JAN	10	8	18
FEB	12	20	32
MEAN	12.6	15.7	

TRAFFIC VOLUME*

MONTH	BEFORE	AFTER	TOTAL
MAY	34.316	26.548	60.864
JUN	32.116	27.762	59.878
JUL	34.116	19.980	54.096
AUG	33.651	29.094	62.745
SEP	32.437	28.044	60.481
OCT	31.293	31.648	62.941
NOV	31.891	24.917	56.808
DEC	33.219	28.921	62.140
JAN	34.116	20.324	54.440
FEB	30.215	29.324	59.539
	32.737	26.656	

* DIVIDED BY 100,000

EXPECTED NUMBER OF ACCIDENTS
BASED ON TRAFFIC VOLUME

MONTH	BEFORE	AFTER	TOTAL
MAY	14.7	11.3	26
JUN	20.9	18.1	39
JUL	22.1	12.9	35
AUG	17.7	15.3	33
SEP	13.4	11.6	25
OCT	11.4	11.6	23
NOV	19.1	14.9	34
DEC	9.6	8.4	18
JAN	11.3	6.7	18
FEB	16.2	15.8	32
MEAN	15.6	12.7	

CHI SQUARE TABLE

MONTH	BEFORE	AFTER	TOTAL	PROB
MAY	0.91	1.18	2.09	0.15
JUN	1.67	1.94	3.61	0.06
JUL	5.55	9.48	15.04	0.00
AUG	0.16	0.19	0.35	0.55
SEP	0.87	1.00	1.87	0.17
OCT	1.82	1.80	3.62	0.06
NOV	0.88	1.12	2.00	0.16
DEC	0.01	0.02	0.03	0.86
JAN	0.15	0.24	0.39	0.53
FEB	1.11	1.14	2.25	0.13
TOTAL	13.14	18.12	31.25	
PROB	0.16	0.03	0.00	

SUGGESTIONS TO IMPROVE STUDY PROCEDURES

The analysis of whether or not the FMS has affected the accident rate on the freeway system could be improved somewhat by including the evaluation of control sections. This could be done by defining sections of the freeway system in the Phoenix metropolitan area as control sections, provided traffic volume data are available, and reviewing historical accident records for the same before and after time periods as used in this study. The major question is whether historical traffic volume data are available. In the absence of historical traffic data for control sections, specifically during the period before the FMS was implemented there is no way of estimating what the background change in the accident rate would have been without the FMS.

Other factors could also be addressed in the accident analysis. These factors include the analysis of the change in mainline versus ramp accidents in the area where the ramp meters were turned on, an analysis of the severity of the accidents in the before and after period (the implication being that on-ramp accidents would tend to be less severe than mainline accidents), and an analysis of mainline and ramp accidents by direction of travel and time of day and by freeway segment (metered versus non-metered). The analysis of these additional factors could lend additional insight into the impacts of the FMS on accidents on the freeway system.

APPENDIX A

VMS STATISTICAL EVALUATIONS

Table A1
VMS EFFECTS ON TRAFFIC PATTERNS
APRIL 29 ACCIDENT: APRIL 22 COMPARED TO APRIL 29
NULL HYPOTHESIS: HOMOGENEOUS IN ACCORDANCE WITH BEFORE PATTERN

	TRAFFIC VOLUMES BEFORE MESSAGE				
	4/22/96	4/22/96	4/29/96	4/29/96	
AM	SITE 39	SITE 144	SITE 39	SITE 144	TOTAL
8:05	297	448	310	452	1507
:10	298	467	299	451	1515
:15	309	454	319	450	1532
:20	301	438	291	413	1443
:25	234	381	258	406	1279
:30	261	407	278	406	1352
:35	225	375	230	248	1078
TOTAL	1925	2970	1985	2826	9706
	TRAFFIC VOLUMES DURING MESSAGE				
8:40	259	369	74	89	791
:45	253	392	285	321	1251
:50	222	362	266	268	1118
:55	236	320	247	261	1064
9:00	208	290	243	200	941
:05	193	263	230	217	903
:10	216	279	205	229	929
:15	202	254	239	227	922
TOTAL	1789	2529	1789	1812	7919
	TRAFFIC VOLUMES AFTER MESSAGE				
9:20	239	263	186	234	922
:25	184	253	206	274	917
:30	180	224	216	177	797
:35	229	281	249	211	970
:40	197	284	214	253	948
:45	189	257	244	208	898
:50	199	267	189	206	861
:55	167	241	195	207	810
10:00	183	217	220	199	819
TOTAL	1767	2287	1919	1969	7942

	EXPECTED VALUES				
	4/22/96	4/22/96	4/29/96	4/29/96	
AM	SITE 39	SITE 144	SITE 39	SITE 144	TOTAL
8:05	298.9	461.1	308.2	438.8	1507
:10	300.5	463.6	309.8	441.1	1515
:15	303.8	468.8	313.3	446.1	1532
:20	286.2	441.6	295.1	420.1	1443
:25	253.7	391.4	261.6	372.4	1279
:30	268.1	413.7	276.5	393.6	1352
:35	213.8	329.9	220.5	313.9	1078
TOTAL	1925	2970	1985	2826	9706
	EXPECTED VALUES BASED ON BEFORE TIMES				
8:40	156.9	242.0	161.8	230.3	791
:45	248.1	382.8	255.8	364.2	1251
:50	221.7	342.1	228.6	325.5	1118
:55	211.0	325.6	217.6	309.8	1064
9:00	186.6	287.9	192.4	274.0	941
:05	179.1	276.3	184.7	262.9	903
:10	184.2	284.3	190.0	270.5	929
:15	182.9	282.1	188.6	268.4	922
TOTAL	1570.6	2423.2	1619.5	2305.7	7919
	EXPECTED VALUES BASED ON BEFORE TIMES				
9:20	182.9	282.1	188.6	268.4	922
:25	181.9	280.6	187.5	267.0	917
:30	158.1	243.9	163.0	232.1	797
:35	192.4	296.8	198.4	282.4	970
:40	188.0	290.1	193.9	276.0	948
:45	178.1	274.8	183.7	261.5	898
:50	170.8	263.5	176.1	250.7	861
:55	160.6	247.9	165.7	235.8	810
10:00	162.4	250.6	167.5	238.5	819
TOTAL	1575.1	2430.2	1624.2	2312.4	7942

Table A1 (cont.)

VMS EFFECTS ON TRAFFIC PATTERNS

APRIL 29 ACCIDENT: APRIL 22 COMPARED TO APRIL 29

NULL HYPOTHESIS: HOMOGENEOUS IN ACCORDANCE WITH BEFORE PATTERN

BEFORE MESSAGE CHI SQUARE TABLE

AM	4/22/96 SITE 39	4/22/96 SITE 144	4/29/96 SITE 39	4/29/96 SITE 144	TOTAL
8:05	0.0	0.4	0.0	0.4	0.8
:10	0.0	0.0	0.4	0.2	0.6
:15	0.1	0.5	0.1	0.0	0.7
:20	0.8	0.0	0.1	0.1	1.0
:25	1.5	0.3	0.0	3.0	4.9
:30	0.2	0.1	0.0	0.4	0.7
:35	0.6	6.2	0.4	13.8	21.0
TOTAL	3.2	7.5	1.0	18.0	29.7
PROB					0.04

AFTER MESSAGE CHI SQUARE TABLE

AM	4/22/96 SITE 39	4/22/96 SITE 144	4/29/96 SITE 39	4/29/96 SITE 144	TOTAL
9:20	17.2	1.3	0.0	4.4	23.0
:25	0.0	2.7	1.8	0.2	4.7
:30	3.0	1.6	17.2	13.1	35.0
:35	7.0	0.8	12.9	18.1	38.8
:40	0.4	0.1	2.1	1.9	4.6
:45	0.7	1.2	19.8	10.9	32.6
:50	4.7	0.0	0.9	8.0	13.6
:55	0.3	0.2	5.2	3.5	9.2
10:00	2.6	4.5	16.5	6.5	30.1
TOTAL	35.9	12.5	76.5	66.6	191.5
PROB					0.00

DURING MESSAGE CHI SQUARE TABLE

AM	4/22/96 SITE 39	4/22/96 SITE 144	4/29/96 SITE 39	4/29/96 SITE 144	TOTAL
8:40	66.5	66.6	47.6	86.7	267.4
:45	0.1	0.2	3.3	5.1	8.8
:50	0.0	1.2	6.1	10.2	17.4
:55	3.0	0.1	4.0	7.7	14.7
9:00	2.4	0.0	13.3	20.0	35.7
:05	1.1	0.6	11.1	8.0	20.9
:10	5.5	0.1	1.2	6.4	13.1
:15	2.0	2.8	13.5	6.4	24.7
TOTAL	80.5	71.6	100.1	150.4	402.7
PROB					0.00
L 7 RWS	14.1	5.0	52.5	63.7	135.3
PROB					0.00

CONCLUSIONS:

THE 8:05 - 8:35 TABLE IS HOMOGENEOUS, EXCEPT FOR 8:35 AT SITE 144 ON BOTH DAYS.

IN THE 8:40 - 9:15 TABLE , THE TOP ROW IS DISCARDED BECAUSE OF THE ANOMALOUS 74 AND 89 COUNTS. THE 4/22/96 COLUMNS ARE REASONABLY CONSISTENT WITH BEFORE MESSAGE PATTERNS. ON 4/29/96 TRAFFIC SHIFTS FROM SITE 144 TO SITE 39.

IN THE 9:20 - 10:00 TABLE, THE 8:40 - 9:15, DURING MESSAGE, PATTERN IS REPEATED. THE SHIFT TO SITE 39 FROM 144 CONTINUES.

Table A2
VMS EFFECTS ON TRAFFIC PATTERNS
APRIL 29 ACCIDENT: APRIL 22 COMPARED TO MAY 6
NULL HYPOTHESIS: HOMOGENEOUS ACROSS BOTH DATES AND ALL TIMES

TRAFFIC VOLUMES BEFORE MESSAGE TIMES

AM	4/22/96 SITE 39	4/22/96 SITE 144	5/6/96 SITE 39	5/6/96 SITE 144	TOTAL
8:05	297	448	304	458	1507
:10	298	467	317	469	1551
:15	309	454	307	480	1550
:20	301	438	285	425	1449
:25	234	381	322	348	1285
:30	261	407	208	258	1134
:35	225	375	261	442	1303
8:40	259	369	277	434	1339
:45	253	392	220	317	1182
:50	222	362	227	396	1207
:55	236	320	194	323	1073
9:00	208	290	211	341	1050
:05	193	263	165	243	864
:10	216	279	192	263	950
:15	202	254	185	163	804
9:20	239	263	179	236	917
:25	184	253	172	269	878
:30	180	224	222	258	884
:35	229	281	201	287	998
:40	197	284	177	246	904
:45	189	257	179	271	896
:50	199	267	181	257	904
:55	167	241	205	211	824
10:00	183	217	175	248	823
TOTAL	5481	7786	5366	7643	26276

EXPECTED VALUES FROM MARGINAL TOTALS

AM	4/22/96 SITE 39	4/22/96 SITE 144	5/6/96 SITE 39	5/6/96 SITE 144	TOTAL
8:05	314.4	446.5	307.8	438.3	1507
:10	323.5	459.6	316.7	451.1	1551
:15	323.3	459.3	316.5	450.9	1550
:20	302.3	429.4	295.9	421.5	1449
:25	268.0	380.8	262.4	373.8	1285
:30	236.5	336.0	231.6	329.9	1134
:35	271.8	386.1	266.1	379.0	1303
8:40	279.3	396.8	273.4	389.5	1339
:45	246.6	350.2	241.4	343.8	1182
:50	251.8	357.7	246.5	351.1	1207
:55	223.8	317.9	219.1	312.1	1073
9:00	219.0	311.1	214.4	305.4	1050
:05	180.2	256.0	176.4	251.3	864
:10	198.2	281.5	194.0	276.3	950
:15	167.7	238.2	164.2	233.9	804
9:20	191.3	271.7	187.3	266.7	917
:25	183.1	260.2	179.3	255.4	878
:30	184.4	261.9	180.5	257.1	884
:35	208.2	295.7	203.8	290.3	998
:40	188.6	267.9	184.6	262.9	904
:45	186.9	265.5	183.0	260.6	896
:50	188.6	267.9	184.6	262.9	904
:55	171.9	244.2	168.3	239.7	824
10:00	171.7	243.9	168.1	239.4	823
TOTAL	5481	7786	5366	7643	26276

Table A2 (cont.)
CHI SQUARE TABLE FOR VMS EFFECTS ON TRAFFIC PATTERNS
APRIL 29 ACCIDENT: APRIL 22 COMPARED TO MAY 6
NULL HYPOTHESIS: HOMOGENEOUS ACROSS BOTH DATES AND ALL TIMES

AM	4/22/96 SITE 39	4/22/96 SITE 144	5/6/96 SITE 39	5/6/96 SITE 144	TOTAL
8:05	1.0	0.0	0.0	0.9	1.9
:10	2.0	0.1	0.0	0.7	2.8
:15	0.6	0.1	0.3	1.9	2.9
:20	0.0	0.2	0.4	0.0	0.6
:25	4.3	0.0	13.5	1.8	19.6
:30	2.5	15.0	2.4	15.7	35.6
:35	8.1	0.3	0.1	10.5	18.9
8:40	1.5	1.9	0.0	5.1	8.6
:45	0.2	5.0	1.9	2.1	9.1
:50	3.5	0.1	1.5	5.7	10.9
:55	0.7	0.0	2.9	0.4	3.9
9:00	0.6	1.4	0.1	4.1	6.2
:05	0.9	0.2	0.7	0.3	2.1
:10	1.6	0.0	0.0	0.6	2.3
:15	7.0	1.0	2.6	21.5	32.2
9:20	11.9	0.3	0.4	3.5	16.1
:25	0.0	0.2	0.3	0.7	1.2
:30	0.1	5.5	9.5	0.0	15.1
:35	2.1	0.7	0.0	0.0	2.9
:40	0.4	1.0	0.3	1.1	2.8
:45	0.0	0.3	0.1	0.4	0.8
:50	0.6	0.0	0.1	0.1	0.8
:55	0.1	0.0	8.0	3.4	11.6
10:00	0.7	3.0	0.3	0.3	4.3
TOTAL	50.4	36.3	45.6	80.9	213.2
PROB					0.000

CONCLUSION:
CHI SQUARE FOR THE ENTIRE TABLE (213.2) IS SIGNIFICANT. CELLS ARE NOT HOMOGENEOUS.
LARGE VALUES OF CHI SQUARE APPEAR THROUGHOUT THE TABLE WITH NO APPARENT PATTERN.

Table A3

VMS EFFECTS ON TRAFFIC PATTERNS

APRIL 29 ACCIDENT: APRIL 29 COMPARED TO MAY 6

NULL HYPOTHESIS: HOMOGENEOUS IN ACCORDANCE WITH BEFORE PATTERN

	TRAFFIC VOLUMES BEFORE MESSAGE						EXPECTED VALUES				
	4/29/96	4/29/96	5/6/96	5/6/96			4/29/96	4/29/96	5/6/96	5/6/96	
AM	SITE 39	SITE 144	SITE 39	SITE 144	TOTAL	AM	SITE 39	SITE 144	SITE 39	SITE 144	TOTAL
8:05	310	452	304	458	1524	8:05	312.0	444.2	315.0	452.7	1524
:10	299	451	317	469	1536	:10	314.5	447.7	317.5	456.3	1536
:15	319	450	307	480	1556	:15	318.6	453.6	321.6	462.2	1556
:20	291	413	285	425	1414	:20	289.5	412.2	292.3	420.0	1414
:25	258	406	322	348	1334	:25	273.1	388.8	275.7	396.3	1334
:30	278	406	208	258	1150	:30	235.5	335.2	237.7	341.6	1150
:35	230	248	261	442	1181	:35	241.8	344.3	244.1	350.8	1181
TOTAL	1985	2826	2004	2880	9695	TOTAL	1985	2826	2004	2880	9695
	TRAFFIC VOLUMES DURING MESSAGE TIMES						EXPECTED VALUES BASED ON BEFORE TIMES				
8:40	74	89	277	434	874	8:40	178.9	254.8	180.7	259.6	874
:45	285	321	220	317	1143	:45	234.0	333.2	236.3	339.5	1143
:50	266	268	227	396	1157	:50	236.9	337.3	239.2	343.7	1157
:55	247	261	194	323	1025	:55	209.9	298.8	211.9	304.5	1025
9:00	243	200	211	341	995	9:00	203.7	290.0	205.7	295.6	995
:05	230	217	165	243	855	:05	175.1	249.2	176.7	254.0	855
:10	205	229	192	263	889	:10	182.0	259.1	183.8	264.1	889
:15	239	227	185	163	814	:15	166.7	237.3	168.3	241.8	814
TOTAL	1789	1812	1671	2480	7752	TOTAL	1587.2	2259.6	1602.4	2302.8	7752
	TRAFFIC VOLUMES AFTER MESSAGE						EXPECTED VALUES BASED ON BEFORE TIMES				
9:20	186	234	179	236	835	9:20	171.0	243.4	172.6	248.0	835
:25	206	274	172	269	921	:25	188.6	268.5	190.4	273.6	921
:30	216	177	222	258	873	:30	178.7	254.5	180.5	259.3	873
:35	249	211	201	287	948	:35	194.1	276.3	196.0	281.6	948
:40	214	253	177	246	890	:40	182.2	259.4	184.0	264.4	890
:45	244	208	179	271	902	:45	184.7	262.9	186.4	267.9	902
:50	189	206	181	257	833	:50	170.6	242.8	172.2	247.5	833
:55	195	207	205	211	818	:55	167.5	238.4	169.1	243.0	818
10:00	220	199	175	248	842	10:00	172.4	245.4	174.0	250.1	842
TOTAL	1919	1969	1691	2283	7862	TOTAL	1609.7	2291.7	1625.1	2335.5	7862

Table A3 (cont.)

VMS EFFECTS ON TRAFFIC PATTERNS

APRIL 29 ACCIDENT: APRIL 29 COMPARED TO MAY 6

NULL HYPOTHESIS: HOMOGENEOUS IN ACCORDANCE WITH BEFORE PATTERN

BEFORE MESSAGE CHI SQUARE TABLE

AM	4/29/96 SITE 39	4/29/96 SITE 144	5/6/96 SITE 39	5/6/96 SITE 144	TOTAL
8:05	0.0	0.1	0.4	0.1	0.6
:10	0.8	0.0	0.0	0.4	1.1
:15	0.0	0.0	0.7	0.7	1.4
:20	0.0	0.0	0.2	0.1	0.2
:25	0.8	0.8	7.8	5.9	15.2
:30	7.7	14.9	3.7	20.5	46.8
:35	0.6	26.9	1.2	23.7	52.3
TOTAL	9.9	42.8	13.9	51.2	117.8
PROB					0.000

DURING MESSAGE CHI SQUARE TABLE

AM	4/29/96 SITE 39	4/29/96 SITE 144	5/6/96 SITE 39	5/6/96 SITE 144	TOTAL
8:40	61.5	107.9	51.4	117.1	337.9
:45	11.1	0.4	1.1	1.5	14.2
:50	3.6	14.2	0.6	8.0	26.4
:55	6.6	4.8	1.5	1.1	14.0
9:00	7.6	27.9	0.1	7.0	42.6
:05	17.2	4.2	0.8	0.5	22.7
:10	2.9	3.5	0.4	0.0	6.8
:15	31.4	0.4	1.7	25.7	59.2
TOTAL	141.9	163.4	57.6	160.8	523.7
PROB					0.000
L. 7 ROW	80.4	55.5	6.2	43.7	185.8
PROB					0.000

AFTER MESSAGE CHI SQUARE TABLE

AM	SITE 39	SITE 144	SITE 39	SITE 144	TOTAL
9:20	1.3	0.4	0.2	0.6	2.5
:25	1.6	0.1	1.8	0.1	3.6
:30	7.8	23.6	9.6	0.0	40.9
:35	15.5	15.4	0.1	0.1	31.2
:40	5.5	0.2	0.3	1.3	7.2
:45	19.1	11.5	0.3	0.0	30.9
:50	2.0	5.6	0.5	0.4	8.4
:55	4.5	4.1	7.6	4.2	20.5
10:00	13.1	8.8	0.0	0.0	22.0
TOTAL	70.5	69.7	20.4	6.7	167.2
PROB					0.000

CONCLUSIONS:

THE 'BEFORE MESSAGE' CRITERION TABLE IS NOT AS GOOD AS THE ONE WITH 4/22/96 REPLACING 5/6/96.

NEVERTHELESS, THE SHIFT FROM SITE 144 TO SITE 39 ON 4/49/96 APPEARS AGAIN IN BOTH THE 'DURING' AND 'AFTER' MESSAGE TABLES.

Table A4

VMS ANALYSIS

LANE DISTRIBUTION OF TRAFFIC AT SITE 88

APRIL 29, 1996

NULL HYPOTHESIS: HOMOGENEOUS IN ACCORDANCE WITH BEFORE PATTERN

LANES ORDERED FROM HOV TO OUTSIDE (3)

BEFORE MESSAGE

AM	HOV	LANE 1	LANE 2	LANE 3	TOTAL
8:05	21	93	97	55	266
:10	24	111	89	73	297
:15	26	99	94	80	299
:20	22	95	85	61	263
:25	16	56	78	53	203
:30	14	96	92	49	251
:35	9	60	58	32	159
SUM	132	610	593	403	1738

EXPECTED VALUES

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:05	20.2	93.4	90.8	61.7	266
:10	22.6	104.2	101.3	68.9	297
:15	22.7	104.9	102.0	69.3	299
:20	20.0	92.3	89.7	61.0	263
:25	15.4	71.2	69.3	47.1	203
:30	19.1	88.1	85.6	58.2	251
:35	12.1	55.8	54.3	36.9	159
SUM	132	610	593	403	1738

MESSAGE DISPLAY PERIOD

AM	HOV	LANE 1	LANE 2	LANE 3	TOTAL
8:40	3	24	20	15	62
:45	15	69	62	25	171
:50	13	61	69	25	168
:55	14	58	68	23	163
9:00	14	51	58	27	150
:05	10	52	50	21	133
:10	12	55	67	35	169
:15	17	70	69	26	182
SUM	98	440	463	197	1198

EXPECTED VALUES FROM BEFORE PERIOD

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:40	4.7	21.8	21.2	14.4	62
:45	13.0	60.0	58.3	39.7	171
:50	12.8	59.0	57.3	39.0	168
:55	12.4	57.2	55.6	37.8	163
9:00	11.4	52.6	51.2	34.8	150
:05	10.1	46.7	45.4	30.8	133
:10	12.8	59.3	57.7	39.2	169
:15	13.8	63.9	62.1	42.2	182
SUM	91.0	420.5	408.8	277.8	1198

CHI SQUARE TABLE FOR 8:05 - 8:35

AM	HOV	LANE 1	LANE 2	LANE 3	TOTAL
8:05	0.03	0.00	0.43	0.72	1.19
:10	0.09	0.44	1.50	0.25	2.28
:15	0.48	0.34	0.63	1.64	3.09
:20	0.21	0.08	0.25	0.00	0.53
:25	0.02	3.26	1.10	0.75	5.13
:30	1.34	0.71	0.47	1.45	3.98
:35	0.78	0.32	0.26	0.64	2.00
SUM	2.96	5.14	4.64	5.46	18.20
PROB					0.44

CHI SQUARE TABLE FOR 8:40 - 9:15

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:40	0.62	0.23	0.06	0.03	0.94
:45	0.31	1.34	0.23	5.41	7.30
:50	0.00	0.07	2.38	5.00	7.45
:55	0.21	0.01	2.76	5.79	8.77
9:00	0.60	0.05	0.91	1.74	3.30
:05	0.00	0.61	0.47	3.14	4.22
:10	0.05	0.31	1.51	0.45	2.33
:15	0.73	0.59	0.77	6.22	8.30
SUM	2.53	3.21	9.09	27.78	42.61
PROB					0.00

CONCLUSIONS:

THE 8:05 - 8:35 TABLE IS HOMOGENEOUS WITH RESPECT TO MARGINAL TOTALS.

IN THE 8:40 - 9:15 TABLE, THERE IS A SIGNIFICANT SHIFT OF TRAFFIC AWAY FROM LANE 3.

Table A5

VMS ANALYSES

LANE DISTRIBUTION OF TRAFFIC AT SITE 88

APRIL 29 AND APRIL 30, 1996

NULL HYPOTHESIS: HOMOGENEOUS IN ACCORDANCE WITH 4/29/96 PATTERN

LANES ORDERED FROM HOV TO OUTSIDE (3)

APRIL 29 BEFORE MESSAGE

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:	21	93	97	55	266
:1	24	111	89	73	297
:1	26	99	94	80	299
:2	22	95	85	61	263
:2	16	56	78	53	203
:3	14	96	92	49	251
:3	9	60	58	32	159
SUM	132	610	593	403	1738

EXPECTED VALUES

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:0	20.2	93.4	90.8	61.7	266
:10	22.6	104.2	101.3	68.9	297
:15	22.7	104.9	102.0	69.3	299
:20	20.0	92.3	89.7	61.0	263
:25	15.4	71.2	69.3	47.1	203
:30	19.1	88.1	85.6	58.2	251
:35	12.1	55.8	54.3	36.9	159
SUM	132	610	593	403	1738

APRIL 30 BEFORE MESSAGE

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:	20	104	60	75	259
:1	22	101	92	78	293
:1	34	103	99	85	321
:2	19	100	77	58	254
:2	20	97	93	67	277
:3	24	52	77	63	216
:3	8	84	76	64	232
SUM	147	641	574	490	1852

EXPECTED VALUES BASED ON APRIL 29

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:0	19.7	90.9	88.4	60.1	259
:10	22.3	102.8	100.0	67.9	293
:15	24.4	112.7	109.5	74.4	321
:20	19.3	89.1	86.7	58.9	254
:25	21.0	97.2	94.5	64.2	277
:30	16.4	75.8	73.7	50.1	216
:35	17.6	81.4	79.2	53.8	232
SUM	140.7	650.0	631.9	429.4	1852

CHI SQUARE TABLE FOR APRIL 29

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:	0.0	0.0	0.4	0.7	1.2
:1	0.1	0.4	1.5	0.2	2.3
:1	0.5	0.3	0.6	1.6	3.1
:2	0.2	0.1	0.2	0.0	0.5
:2	0.0	3.3	1.1	0.7	5.1
:3	1.3	0.7	0.5	1.5	4.0
:3	0.8	0.3	0.3	0.6	2.0
SUM	3.0	5.1	4.6	5.5	18.2
PROB					0.44

CHI SQUARE TABLE FOR APRIL 30

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:0	0.0	1.9	9.1	3.7	14.7
:10	0.0	0.0	0.6	1.5	2.2
:15	3.8	0.8	1.0	1.5	7.1
:20	0.0	1.3	1.1	0.0	2.4
:25	0.1	0.0	0.0	0.1	0.2
:30	3.5	7.5	0.1	3.3	14.5
:35	5.3	0.1	0.1	1.9	7.4
SUM	12.6	11.6	12.1	12.1	48.5
PROB					0.00

CONCLUSIONS:

THE APRIL 29 CHI SQUARE (18.2) IS NOT SIGNIFICANT. THE TABLE IS HOMOGENEOUS.
THE APRIL 30 CHI SQUARE (48.5) IS SIGNIFICANT. THE TABLE IS NOT HOMOGENEOUS.
ONE TO 3 LARGE VALUES OF CHI SQUARE OCCUR IN EVERY LANE, BUT THERE IS NO PATTERN.

Table A6
VMS ANALYSIS
LANE DISTRIBUTION OF TRAFFIC AT SITE 88
APRIL 29 AND APRIL 30, 1996
NULL HYPOTHESIS: HOMOGENEOUS IN ACCORDANCE WITH APRIL 29 PATTERN
LANES ORDERED FROM HOV TO OUTSIDE (3)

APRIL 29 MESSAGE DISPLAY PERIOD

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:40	3	24	20	15	62
:45	15	69	62	25	171
:50	13	61	69	25	168
:55	14	58	68	23	163
9:00	14	51	58	27	150
:05	10	52	50	21	133
:10	12	55	67	35	169
:15	17	70	69	26	182
SUM	98	440	463	197	1198

APRIL 29 EXPECTED VALUES

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:40	5.1	22.8	24.0	10.2	62
:45	14.0	62.8	66.1	28.1	171
:50	13.7	61.7	64.9	27.6	168
:55	13.3	59.9	63.0	26.8	163
9:00	12.3	55.1	58.0	24.7	150
:05	10.9	48.8	51.4	21.9	133
:10	13.8	62.1	65.3	27.8	169
:15	14.9	66.8	70.3	29.9	182
SUM	98	440	463	197	1198

APRIL 30 MESSAGE DISPLAY PERIOD

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:40	3	80	91	51	225
:45	15	77	91	55	238
:50	13	91	81	49	234
:55	14	81	76	30	201
9:00	14	61	70	44	189
:05	10	63	71	45	189
:10	12	49	70	47	178
:15	17	67	83	39	206
SUM	98	569	633	360	1660

EXPECTED VALUES BASED ON APRIL 29

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:40	18.4	82.6	87.0	37.0	225
:45	19.5	87.4	92.0	39.1	238
:50	19.1	85.9	90.4	38.5	234
:55	16.4	73.8	77.7	33.1	201
9:00	15.5	69.4	73.0	31.1	189
:05	15.5	69.4	73.0	31.1	189
:10	14.6	65.4	68.8	29.3	178
:15	16.9	75.7	79.6	33.9	206
SUM	136	610	642	273	1660

APRIL 29 CHI SQUARE TABLE

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:40	0.8	0.1	0.7	2.3	3.8
:45	0.1	0.6	0.3	0.3	1.3
:50	0.0	0.0	0.3	0.2	0.6
:55	0.0	0.1	0.4	0.5	1.0
9:00	0.2	0.3	0.0	0.2	0.8
:05	0.1	0.2	0.0	0.0	0.3
:10	0.2	0.8	0.0	1.9	3.0
:15	0.3	0.1	0.0	0.5	1.0
SUM	1.8	2.2	1.7	6.0	11.8
PROB					0.95

APRIL 30 CHI SQUARE TABLE

AM	HOV	LANE 1	LANE 2	LANE 3	SUM
8:40	12.9	0.1	0.2	5.3	18.5
:45	1.0	1.2	0.0	6.4	8.7
:50	2.0	0.3	1.0	2.9	6.1
:55	0.4	0.7	0.0	0.3	1.4
9:00	0.1	1.0	0.1	5.4	6.7
:05	1.9	0.6	0.1	6.2	8.8
:10	0.5	4.1	0.0	10.7	15.3
:15	0.0	1.0	0.1	0.8	1.9
SUM	18.8	9.0	1.6	38.0	67.4
PROB					0.00

CONCLUSIONS:
THE APRIL 29 CHI SQUARE (11.8) IS NOT SIGNIFICANT. THE TABLE IS HOMOGENEOUS.
THE APRIL 30 CHI SQUARE (67.4) IS SIGNIFICANT. THE TABLE IS NOT HOMOGENEOUS.
THERE IS SIGNIFICANTLY MORE TRAFFIC IN LANE 3 THAN EXPECTED.
THE HOV VALUE AT 8:40 (3) IS SIGNIFICANTLY SMALLER THAN EXPECTED.

Table A7

VMS EFFECTS ON TRAFFIC PATTERNS

JULY 22 ACCIDENT: JULY 22 COMPARED TO JULY 29

NULL HYPOTHESIS: HOMOGENEOUS IN ACCORDANCE WITH BEFORE PATTERN

TRAFFIC VOLUMES BEFORE MESSAGE TIMES

	7/22/96	7/22/96	7/29/96	7/29/96	
PM	SITE 39	SITE 144	SITE 39	SITE 144	TOTAL
1:55	231	240	209	277	957
2:00	215	284	213	268	980
:05	211	272	244	263	990
:10	212	309	250	323	1094
:15	215	301	225	281	1022
TOTAL	1084	1406	1141	1412	5043

EXPECTED VALUES

	7/22/96	7/22/96	7/29/96	7/29/96	
PM	SITE 39	SITE 144	SITE 39	SITE 144	TOTAL
1:55	205.7	266.8	216.5	268.0	957
2:00	210.7	273.2	221.7	274.4	980
:05	212.8	276.0	224.0	277.2	990
:10	235.2	305.0	247.5	306.3	1094
:15	219.7	284.9	231.2	286.2	1022
TOTAL	1084	1406	1141	1412	5043

TRAFFIC VOLUMES DURING MESSAGE TIMES

PM	SITE 39	SITE 144	SITE 39	SITE 144	
2:20	263	231	189	292	975
:25	222	230	225	287	964
:30	243	243	243	284	1013
:35	315	240	259	310	1124
:40	330	242	254	316	1142
:45	310	299	274	340	1223
:50	327	264	215	295	1101
TOTAL	2010	1749	1659	2124	7542

EXPECTED VALUES BASED ON BEFORE TIMES

PM	SITE 39	SITE 144	SITE 39	SITE 144	
2:20	209.6	271.8	220.6	273.0	975
:25	207.2	268.8	218.1	269.9	964
:30	217.7	282.4	229.2	283.6	1013
:35	241.6	313.4	254.3	314.7	1124
:40	245.5	318.4	258.4	319.8	1142
:45	262.9	341.0	276.7	342.4	1223
:50	236.7	307.0	249.1	308.3	1101
TOTAL	1621.2	2102.7	1706.4	2111.7	7542

TRAFFIC VOLUMES AFTER MESSAGE TIMES

PM	SITE 39	SITE 144	SITE 39	SITE 144	
2:55	262	288	263	274	1087
3:00	241	258	202	268	969
:05	270	301	228	305	1104
:10	276	299	270	337	1182
:15	249	288	205	290	1032
:20	201	273	216	307	997
:25	237	283	219	254	993
:30	235	282	241	240	998
TOTAL	1971	2272	1844	2275	8362

EXPECTED VALUES BASED ON BEFORE TIMES

PM	SITE 39	SITE 144	SITE 39	SITE 144	
2:55	233.7	303.1	245.9	304.4	1087
3:00	208.3	270.2	219.2	271.3	969
:05	237.3	307.8	249.8	309.1	1104
:10	254.1	329.5	267.4	331.0	1182
:15	221.8	287.7	233.5	289.0	1032
:20	214.3	278.0	225.6	279.2	997
:25	213.4	276.9	224.7	278.0	993
:30	214.5	278.2	225.8	279.4	998
TOTAL	1797.4	2331.3	1891.9	2341.3	8362

Table A7 (cont.)

VMS EFFECTS ON TRAFFIC PATTERNS

JULY 22 ACCIDENT: JULY 22 COMPARED TO JULY 29

NULL HYPOTHESIS: HOMOGENEOUS IN ACCORDANCE WITH BEFORE PATTERN

BEFORE MESSAGE TIMES CHI SQUARE TABLE

	7/22/96	7/22/96	7/29/96	7/29/96	
PM	SITE 39	SITE 144	SITE 39	SITE 144	TOTAL
1:55	3.1	2.7	0.3	0.3	6.4
2:00	0.1	0.4	0.3	0.1	1.0
:05	0.0	0.1	1.8	0.7	2.6
:10	2.3	0.1	0.0	0.9	3.3
:15	0.1	0.9	0.2	0.1	1.3
TOTAL	5.6	4.1	2.6	2.2	14.5
PROB					0.27

DURING MESSAGE TIMES CHI SQUARE TABLE

	7/22/96	7/22/96	7/29/96	7/29/96	
PM	SITE 39	SITE 144	SITE 39	SITE 144	TOTAL
2:20	13.6	6.1	4.5	1.3	25.6
:25	1.1	5.6	0.2	1.1	7.9
:30	2.9	5.5	0.8	0.0	9.3
:35	22.3	17.2	0.1	0.1	39.6
:40	29.1	18.3	0.1	0.0	47.6
:45	8.4	5.2	0.0	0.0	13.7
:50	34.5	6.0	4.7	0.6	45.7
TOTAL	111.9	63.9	10.4	3.1	189.4
PROB					0.00

AFTER MESSAGE TIMES CHI SQUARE TABLE

PM	SITE 39	SITE 144	SITE 39	SITE 144	TOTAL
2:55	3.4	0.7	1.2	3.0	8.4
3:00	5.1	0.5	1.4	0.0	7.1
:05	4.5	0.2	1.9	0.1	6.6
:10	1.9	2.8	0.0	0.1	4.9
:15	3.3	0.0	3.5	0.0	6.8
:20	0.8	0.1	0.4	2.8	4.1
:25	2.6	0.1	0.1	2.1	5.0
:30	2.0	0.1	1.0	5.6	8.6
TOTAL	23.7	4.6	9.5	13.7	51.4
PROB					0.00

CONCLUSIONS:

THE 1:55 - 2:15 TABLE IS HOMOGENEOUS OVERALL, ALTHOUGH THERE ARE TWO MISFITS IN THE UPPER LEFT CORNER.

CHI SQUARE FOR THE 2:20 - -2:50 TABLE (189.4) IS SIGNIFICANT. ON 7/22/96 SITE 39 VALUES ARE GREATER AND SITE 144 VALUES ARE LESS THAN EXPECTED.

CHI SQUARE IN THE 2:55 - 3:30 TABLE (51.4) IS SIGNIFICANT. ON 7/22/96 SITE 39 VALUES ARE GREATER THAN EXPECTED. LARGE CELL VALUES IN THE REST OF THE TABLE FORM NO PATTERN.

Table A8

LANE DISTRIBUTION OF TRAFFIC AT SITE151

ACCIDENT 3 ON SEPTEMBER 30,1996

NULL HYPOTHESIS: POST-ACCIDENT DATA ARE HOMOGENEOUS

DATA TABLE

	OCTOBER 7, 1996			OCTOBER 14, 1996			OCTOBER 21, 1996			OCTOBER 28, 1996			NOVEMBER 4, 1996			
AM/PM	LANE 1	LANE 2	LANE 3	LANE 1	LANE 2	LANE 3	LANE 1	LANE 2	LANE 3	LANE 1	LANE 2	LANE 3	LANE 1	LANE 2	LANE 3	TOTAL
11:25	60	65	60	67	75	48	78	79	50	62	85	57	65	76	60	987
:30	57	65	49	66	80	51	52	54	46	79	90	62	73	71	47	942
:35	60	73	44	69	98	46	47	68	49	70	79	54	67	85	50	959
:40	59	84	49	76	79	39	73	72	48	45	68	51	71	75	58	947
:45	53	75	46	73	78	55	75	75	51	68	80	47	62	75	45	958
:50	68	72	50	58	76	46	68	79	54	56	60	49	67	78	45	926
:55	61	86	40	59	60	39	58	79	42	49	74	42	68	71	47	875
12:00	66	71	57	63	74	48	53	69	49	57	66	54	56	81	48	912
:05	65	74	49	55	75	43	56	68	50	63	86	51	55	76	56	922
:10	62	76	49	52	72	46	79	80	58	69	91	50	71	81	48	984
:15	58	65	46	65	61	54	69	81	57	66	79	51	56	76	48	932
:20	55	69	48	66	68	49	49	78	49	69	80	52	47	63	53	895
:25	64	78	60	65	70	48	70	81	42	70	78	42	60	74	46	948
:30	72	79	56	62	82	48	60	68	45	96	97	56	51	75	46	993
:35	70	76	37	66	75	49	60	85	49	65	82	51	56	66	46	933
:40	67	70	43	67	76	46	66	79	40	50	83	49	72	82	47	937
:45	63	73	55	80	83	51	68	80	51	72	77	59	62	72	42	988
:50	72	72	62	72	75	57	69	82	64	70	74	42	71	65	56	1003
:55	60	77	56	63	86	41	59	72	42	67	78	42	60	68	43	914
1:00	62	73	43	63	72	51	75	68	45	63	69	53	55	69	46	907
TOTAL	1254	1473	999	1307	1515	955	1284	1497	981	1306	1576	1014	1245	1479	977	18862

Table A8 (cont.)

LANE DISTRIBUTION OF TRAFFIC AT SITE151

ACCIDENT 3 ON SEPTEMBER 30,1996

NULL HYPOTHESIS: POST-ACCIDENT DATA ARE HOMOGENEOUS

EXPECTED VALUES FROM MARGINAL TOTALS

	OCTOBER 7, 1996			OCTOBER 14, 1996			OCTOBER 21, 1996			OCTOBER 28, 1996			NOVEMBER 4, 1996			
AM/PM	LANE 1	LANE 2	LANE 3	LANE 1	LANE 2	LANE 3	LANE 1	LANE 2	LANE 3	LANE 1	LANE 2	LANE 3	LANE 1	LANE 2	LANE 3	TOTAL
11:25	65.6	77.1	52.3	68.4	79.3	50.0	67.2	78.3	51.3	68.3	82.5	53.1	65.1	77.4	51.1	987
:30	62.6	73.6	49.9	65.3	75.7	47.7	64.1	74.8	49.0	65.2	78.7	50.6	62.2	73.9	48.8	942
:35	63.8	74.9	50.8	66.5	77.0	48.6	65.3	76.1	49.9	66.4	80.1	51.6	63.3	75.2	49.7	959
:40	63.0	74.0	50.2	65.6	76.1	47.9	64.5	75.2	49.3	65.6	79.1	50.9	62.5	74.3	49.1	947
:45	63.7	74.8	50.7	66.4	76.9	48.5	65.2	76.0	49.8	66.3	80.0	51.5	63.2	75.1	49.6	958
:50	61.6	72.3	49.0	64.2	74.4	46.9	63.0	73.5	48.2	64.1	77.4	49.8	61.1	72.6	48.0	926
:55	58.2	68.3	46.3	60.6	70.3	44.3	59.6	69.4	45.5	60.6	73.1	47.0	57.8	68.6	45.3	875
12:00	60.6	71.2	48.3	63.2	73.3	46.2	62.1	72.4	47.4	63.1	76.2	49.0	60.2	71.5	47.2	912
:05	61.3	72.0	48.8	63.9	74.1	46.7	62.8	73.2	48.0	63.8	77.0	49.6	60.9	72.3	47.8	922
:10	65.4	76.8	52.1	68.2	79.0	49.8	67.0	78.1	51.2	68.1	82.2	52.9	64.9	77.2	51.0	984
:15	62.0	72.8	49.4	64.6	74.9	47.2	63.4	74.0	48.5	64.5	77.9	50.1	61.5	73.1	48.3	932
:20	59.5	69.9	47.4	62.0	71.9	45.3	60.9	71.0	46.5	62.0	74.8	48.1	59.1	70.2	46.4	895
:25	63.0	74.0	50.2	65.7	76.1	48.0	64.5	75.2	49.3	65.6	79.2	51.0	62.6	74.3	49.1	948
:30	66.0	77.5	52.6	68.8	79.8	50.3	67.6	78.8	51.6	68.8	83.0	53.4	65.5	77.9	51.4	993
:35	62.0	72.9	49.4	64.7	74.9	47.2	63.5	74.0	48.5	64.6	78.0	50.2	61.6	73.2	48.3	933
:40	62.3	73.2	49.6	64.9	75.3	47.4	63.8	74.4	48.7	64.9	78.3	50.4	61.8	73.5	48.5	937
:45	65.7	77.2	52.3	68.5	79.4	50.0	67.3	78.4	51.4	68.4	82.6	53.1	65.2	77.5	51.2	988
:50	66.7	78.3	53.1	69.5	80.6	50.8	68.3	79.6	52.2	69.4	83.8	53.9	66.2	78.6	52.0	1003
:55	60.8	71.4	48.4	63.3	73.4	46.3	62.2	72.5	47.5	63.3	76.4	49.1	60.3	71.7	47.3	914
1:00	60.3	70.8	48.0	62.8	72.9	45.9	61.7	72.0	47.2	62.8	75.8	48.8	59.9	71.1	47.0	907
TOTAL	1254	1473	999	1307	1515	955	1284	1497	981	1306	1576	1014	1245	1479	977	18862

Table A8 (cont.)
LANE DISTRIBUTION OF TRAFFIC AT SITE151
ACCIDENT 3 ON SEPTEMBER 30,1996

CHI SQUARE TABLE

	OCTOBER 7, 1996			OCTOBER 14, 1996			OCTOBER 21, 1996			OCTOBER 28, 1996			NOVEMBER 4, 1996			
AM/PM	LANE 1	LANE 2	LANE 3	LANE 1	LANE 2	LANE 3	LANE 1	LANE 2	LANE 3	LANE 1	LANE 2	LANE 3	LANE 1	LANE 2	LANE 3	TOTAL
11:25	0.5	1.9	1.1	0.0	0.23	0.1	1.7	0.0	0.0	0.6	0.1	0.3	0.0	0.0	1.5	8.2
:30	0.5	1.0	0.0	0.0	0.2	0.2	2.3	5.8	0.2	2.9	1.6	2.5	1.9	0.1	0.1	19.4
:35	0.2	0.0	0.9	0.1	5.7	0.1	5.1	0.9	0.0	0.2	0.0	0.1	0.2	1.3	0.0	14.9
:40	0.2	1.4	0.0	1.6	0.1	1.7	1.1	0.1	0.0	6.5	1.6	0.0	1.2	0.0	1.6	17.2
:45	1.8	0.0	0.4	0.7	0.0	0.9	1.5	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	6.2
:50	0.7	0.0	0.0	0.6	0.0	0.0	0.4	0.4	0.7	1.0	3.9	0.0	0.6	0.4	0.2	8.9
:55	0.1	4.6	0.9	0.0	1.5	0.6	0.0	1.3	0.3	2.2	0.0	0.5	1.8	0.1	0.1	14.1
12:00	0.5	0.0	1.6	0.0	0.0	0.1	1.3	0.2	0.1	0.6	1.4	0.5	0.3	1.3	0.0	7.7
:05	0.2	0.1	0.0	1.2	0.0	0.3	0.7	0.4	0.1	0.0	1.0	0.0	0.6	0.2	1.4	6.3
:10	0.2	0.0	0.2	3.8	0.6	0.3	2.2	0.0	0.9	0.0	0.9	0.2	0.6	0.2	0.2	10.3
:15	0.3	0.8	0.2	0.0	2.6	1.0	0.5	0.7	1.5	0.0	0.0	0.0	0.5	0.1	0.0	8.2
:20	0.3	0.0	0.0	0.3	0.2	0.3	2.3	0.7	0.1	0.8	0.4	0.3	2.5	0.7	1.0	9.9
:25	0.0	0.2	1.9	0.0	0.5	0.0	0.5	0.4	1.1	0.3	0.0	1.6	0.1	0.0	0.2	6.8
:30	0.5	0.0	0.2	0.7	0.1	0.1	0.9	1.5	0.9	10.8	2.4	0.1	3.2	0.1	0.6	22.0
:35	1.0	0.1	3.1	0.0	0.0	0.1	0.2	1.6	0.0	0.0	0.2	0.0	0.5	0.7	0.1	7.7
:40	0.4	0.1	0.9	0.1	0.0	0.0	0.1	0.3	1.6	3.4	0.3	0.0	1.7	1.0	0.0	9.9
:45	0.1	0.2	0.1	1.9	0.2	0.0	0.0	0.0	0.0	0.2	0.4	0.7	0.2	0.4	1.6	6.0
:50	0.4	0.5	1.5	0.1	0.4	0.8	0.0	0.1	2.7	0.0	1.1	2.6	0.3	2.4	0.3	13.2
:55	0.0	0.4	1.2	0.0	2.2	0.6	0.2	0.0	0.6	0.2	0.0	1.0	0.0	0.2	0.4	7.1
1:00	0.0	0.1	0.5	0.0	0.0	0.6	2.8	0.2	0.1	0.0	0.6	0.4	0.4	0.1	0.0	5.8
TOTAL	8.1	11.5	14.9	11.2	14.6	7.7	23.8	14.6	10.9	29.8	16.0	11.4	16.5	9.2	9.8	209.9
								PROB								0.999

CONCLUSION:

BASED UPON ROW AND COLUMN TOTALS THE TABLE OF TRAFFIC VOLUMES FOR NON-ACCIDENT DAYS DISPLAYS VALUES HOMOGENEITY.

TWENTY TWO CELLS IN A TOTAL OF 300, DISPLAYING NO CONSISTENT PATTERN, HAVE CHI SQUARE GREATER THAN 2.00.
LANE 1 ON 10/28/96, HOWEVER, HAD 5 OF THESE VALUES, THE LARGEST OF WHICH WAS 10.80.

Table A9

LANE DISTRIBUTION OF TRAFFIC AT SITE151

ACCIDENT 3 ON SEPTEMBER 30,1996

NULL HYPOTHESIS: ACCIDENT-DAY AND NON-ACCIDENT DAY DATA ARE HOMOGENEOUS

LANES ORDERED FROM INSIDE (1) TO OUTSIDE (3)

ACCIDENT DATE
SEPTEMBER 30, 1996

AM/PM	LANE 1	LANE 2	LANE 3	TOTAL	SUM#
11:25	58	67	57	182	987
:30	61	81	43	185	942
:35	72	87	43	202	959
:40	60	83	53	196	947
:45	65	74	40	179	958
:50	71	77	44	192	926
BEGIN MESSAGE DISPLAY					
:55	63	66	39	168	875
12:00	68	69	39	176	912
:05	51	52	29	132	922
:10	54	52	33	139	984
:15	49	58	34	141	932
:20	54	62	32	148	895
:25	53	65	20	138	948
:30	50	80	42	172	993
END MESSAGE DISPLAY					
:35	63	76	51	190	933
:40	58	78	53	189	937
:45	63	74	45	182	988
:50	60	79	50	189	1003
:55	59	82	42	183	914
1:00	55	55	46	156	907
TOTAL	1187	1417	835	3439	18862
SUM#	6396	7540	4926		18862

TOTALS FOR ALL NON-ACCIDENT DAYS

EXPECTED VALUES: NON-ACCIDENT DAYS
SEPTEMBER 30, 1996

AM/PM	LANE 1	LANE 2	LANE 3	TOTAL
11:25	61.7	72.8	47.5	182.0
:30	62.7	74.0	48.3	185.0
:35	68.5	80.7	52.8	202.0
:40	66.5	78.4	51.2	196.0
:45	60.7	71.6	46.7	179.0
:50	65.1	76.8	50.1	192.0
BEGIN MESSAGE DISPLAY				
:55	57.0	67.2	43.9	168.0
12:00	59.7	70.4	46.0	176.0
:05	44.8	52.8	34.5	132.0
:10	47.1	55.6	36.3	139.0
:15	47.8	56.4	36.8	141.0
:20	50.2	59.2	38.7	148.0
:25	46.8	55.2	36.0	138.0
:30	58.3	68.8	44.9	172.0
END MESSAGE DISPLAY				
:35	64.4	76.0	49.6	190.0
:40	64.1	75.6	49.4	189.0
:45	61.7	72.8	47.5	182.0
:50	64.1	75.6	49.4	189.0
:55	62.1	73.2	47.8	183.0
1:00	52.9	62.4	40.7	156.0
TOTAL	1166	1375	898	3439

CHI SQUARE TABLE
SEPTEMBER 30, 1996

AM/PM	LANE 1	LANE 2	LANE 3	TOTAL
11:25	0.2	0.5	1.9	2.6
:30	0.0	0.7	0.6	4.7
:35	0.2	0.5	1.8	2.5
:40	0.6	0.3	0.1	1.0
:45	0.3	0.1	1.0	1.4
:50	0.5	0.0	0.8	1.3
BEGIN MESSAGE DISPLAY				
:55	0.6	0.0	0.5	1.2
12:00	1.2	0.0	1.1	2.2
:05	0.9	0.0	0.9	1.7
:10	1.0	0.2	0.3	1.5
:15	0.0	0.0	0.2	0.3
:20	0.3	0.1	1.1	1.6
:25	0.8	1.8	7.1	9.7
:30	1.2	1.8	0.2	3.2
END MESSAGE DISPLAY				
:35	0.0	0.0	0.0	0.1
:40	0.6	0.1	0.3	0.9
:45	0.0	0.0	0.1	0.2
:50	0.3	0.2	0.0	0.4
:55	0.2	1.1	0.7	1.9
1:00	0.1	0.9	0.7	1.6
TOTAL	9.0	8.2	19.4	36.6
PROB				0.53

CONCLUSION:

THERE IS NO EVIDENCE OF ANY LANE DISPLACEMENT ON THE ACCIDENT DAY.

LANE 3 AT 12:25 HAS A CHI SQUARE VALUE OF 7.1, THE ONLY UNUSUAL ONE.

APPENDIX B

EMISSIONS ESTIMATE CALCULATION

WORKSHEETS

AND MOBILE 5a EMISSION FACTORS

Table B1
EMISSIONS ESTIMATE WORKSHEET FOR BEFORE PERIOD
AM PEAK HOUR

HC Emissions (typical summer day)

	Eastbound						Westbound						
	Link Data				Emission	Link	Link Data				Emission	Link	Site Total
Site	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Emissions (gr)
2	8527	0.67	5714	54	1.453	8,302	3688	0.65	2397	62	1.675	4,015	*12,317*
3	5309	0.53	2813	58	1.546	4,349	5977	0.49	2929	53	1.457	4,267	*8,616*
4	4590	0.27	1240	42	1.581	1,960	6049	0.19	1149	38	1.669	1,918	*3,878*
5	3334	0.34	1133	56	1.481	1,679	4123	0.70	2884	59	1.577	4,548	*6,226*
7	7473	0.55	4110	54	1.453	5,972	6344	0.55	3489	52	1.46	5,094	*11,066*
					Total HC Emissions:	*22,262*					*Total HC Emissions.*	*19,842*	*42,104*

NOx Emissions (typical summer day)

	Eastbound						Westbound						
	Link Data				Emission	Link	Link Data				Emission	Link	Site Total
Site	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Emissions (gr)
2	8527	0.67	5714	54	2.738	15,644	3688	0.65	2397	62	3.428	8,218	*23,862*
3	5309	0.53	2813	58	3.061	8,612	5977	0.49	2929	53	2.662	7,796	*16,407*
4	4590	0.27	1240	42	2.216	2,747	6049	0.19	1149	38	2.174	2,498	*5,245*
5	3334	0.34	1133	56	2.894	3,280	4123	0.70	2884	59	3.147	9,075	*12,355*
7	7473	0.55	4110	54	2.738	11,254	6344	0.55	3489	52	2.486	8,674	*19,928*
					Total NOx Emissions:	*41,537*					*Total NOx Emissions:*	*36,261*	*77,797*

CO Emissions (typical winter day)

	Eastbound						Westbound						
	Link Data				Emission	Link	Link Data				Emission	Link	Site Total
Site	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Emissions (gr)
2	5975	0.67	4004	57	12.06	48,285	4690	0.65	3049	60	15.77	48,075	*96,359*
3	6,197	0.53	3284	53	9.56	31,394	6352	0.49	3112	61	17.01	52,939	*84,334*
4	5277	0.27	1425	49	9.49	13,525	5941	0.19	1129	40	10.95	12,358	*25,883*
5	3731	0.34	1268	51	9.52	12,075	4643	0.70	3247	59	14.53	47,186	*59,261*
7	7693	0.55	4231	57	12.06	51,028	6965	0.55	3831	55	9.6	36,775	*87,803*
					Total CO Emissions:	*156,307*					*Total CO Emissions:*	*197,333*	*353,640*

Table B2
EMISSIONS ESTIMATE WORKSHEET FOR BEFORE PERIOD
PM PEAK HOUR

HC Emissions (typical summer day)

	Eastbound						Westbound						
	Link Data				Emission	Link	Link Data				Emission	Link	Site Total
Site	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Emissions (gr)
2	4864	0.67	3259	59	1.577	5,140	7249	0.65	4712	63	1.709	8,053	*13,192*
3	4914	0.53	2604	62	1.675	4,362	6085	0.49	2981	61	1.643	4,898	*9,260*
4	4590	0.27	1240	42	1.581	1,960	4861	0.19	923	49	1.473	1,360	*3,320*
5	4027	0.34	1369	58	1.546	2,117	3380	0.70	2364	61	1.643	3,884	*6,001*
7	5950	0.55	3273	52	1.46	4,778	7150	0.55	3933	55	1.45	5,702	*10,480*
					Total HC Emissions:	*18,356*					*Total HC Emissions:*	*23,898*	*42,253*

NOx Emissions (typical summer day)

	Eastbound						Westbound						
	Link Data				Emission	Link	Link Data				Emission	Link	Site Total
Site	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Emissions (gr)
2	4864	0.67	3259	59	3.147	10,257	7249	0.65	4712	63	3.53	16,633	*26,890*
3	4914	0.53	2604	62	3.428	8,927	6085	0.49	2981	61	3.332	9,934	*18,861*
4	4590	0.27	1240	42	2.216	2,747	4861	0.19	923	49	2.381	2,199	*4,946*
5	4027	0.34	1369	58	3.061	4,191	3380	0.70	2364	61	3.332	7,877	*12,068*
7	5950	0.55	3273	52	2.486	8,135	7150	0.55	3933	55	2.814	11,066	*19,201*
					Total NOx Emissions:	*34,257*					*Total NOx Emissions:*	*47,709*	*81,965*

CO Emissions (typical winter day)

	Eastbound						Westbound						
	Link Data				Emission	Link	Link Data				Emission	Link	Site Total
Site	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Emissions (gr)
2	5404	0.67	3621	65	22.05	79,845	8850	0.65	5753	63	19.52	112,289	*192,134*
3	5485	0.53	2907	58	13.29	38,629	6693	0.49	3279	48	9.48	31,088	*69,717*
4	5818	0.27	1571	54	9.58	15,053	5207	0.19	989	34	12.69	12,552	*27,605*
5	4498	0.34	1529	58	13.29	20,322	3601	0.70	2519	60	15.77	39,719	*60,042*
7	7017	0.55	3859	62	18.26	70,472	8090	0.55	4450	42	10.51	46,764	*117,236*
					Total CO Emissions:	*224,321*					*Total CO Emissions:*	*242,412*	*466,734*

Table B3

EMISSIONS ESTIMATE WORKSHEET FOR AFTER PERIOD

AM PEAK HOUR

HC Emissions (typical summer day)

	Eastbound						Westbound						
	Link Data				Emission	Link	Link Data				Emission	Link	Site Total
Site	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Emissions (gr)
2	5515	0.67	3695	33	1.814	6,704	3327	0.65	2163	65	1.776	3,841	*10,544*
3	6055	0.53	3209	56	1.481	4,752	5345	0.49	2619	57	1.514	3,965	*8.717*
4	4190	0.27	1132	51	1.464	1,657	3958	0.19	752	46	1.509	1,135	*2.791*
5	3513	0.34	1194	58	1.546	1,846	4493	0.70	3143	55	1.45	4,557	*6.403*
7	5208	0.55	2864	55	1.45	4,153	8365	0.55	4601	54	1.453	6.685	*10.838*
					Total HC Emissions:	*19,112*					*Total HC Emissions:*	*20,182*	*39.294*

NOx Emissions (typical summer day)

	Eastbound						Westbound						
	Link Data				Emission	Link	Link Data				Emission	Link	Site Total
Site	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Emissions (gr)
2	5515	0.67	3695	33	2.142	7,916	3327	0.65	2163	65	3.744	8,097	*16,012*
3	6055	0.53	3209	56	2.894	9,286	5345	0.49	2619	57	2.976	7,794	*17,080*
4	4190	0.27	1132	51	2.518	2,849	3958	0.19	752	46	2.276	1,711	*4,561*
5	3513	0.34	1194	58	3.061	3,656	4493	0.70	3143	55	2.814	8.843	*12.499*
7	5208	0.55	2864	55	2.814	8,060	8365	0.55	4601	54	2.738	12,597	*20.657*
					Total NOx Emissions:	*31,767*					*Total NOx Emissions:*	*39,042*	*70,809*

CO Emissions (typical winter day)

	Eastbound						Westbound						
	Link Data				Emission	Link	Link Data				Emission	Link	Site Total
Site	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Emissions (gr)
2	7285	0.67	4882	48	9.48	46,277	3696	0.65	2402	65	22.05	52,973	*99,250*
3	6015	0.53	3187	62	18.26	58,204	5941	0.49	2911	57	12.06	35,105	*93,309*
4	4314	0.27	1165	54	9.58	11,162	5896	0.19	1120	46	9.79	10,965	*22,127*
5	4025	0.34	1368	61	17.01	23,276	4805	0.70	3361	55	9.6	32,263	*55,539*
7	5609	0.55	3085	54	9.58	29,554	8113	0.55	4462	52	9.54	42,569	*72,123*
					Total CO Emissions:	*168,471*					*Total CO Emissions:*	*173,875*	*342,347*

Table B4
EMISSIONS ESTIMATE WORKSHEET FOR AFTER APERIOD
PM PEAK HOUR

HC Emissions (typical summer day)

	Eastbound						Westbound						
	Link Data				Emission	Link	Link Data				Emission	Link	Site Total
Site	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Emissions (gr)
2	3822	0.67	2561	47	1.493	3,824	6876	0.65	4469	25	2.156	9,636	*13,460*
3	5573	0.53	2953	58	1.546	4,566	5960	0.49	2920	52	1.46	4,263	*8,829*
4	5231	0.27	1413	57	1.514	2,139	3361	0.19	638	46	1.509	963	*3,102*
5	4531	0.34	1540	61	1.643	2,531	3852	0.70	2694	51	1.464	3,944	*6,475*
7	5942	0.55	3268	52	1.46	4,771	7108	0.55	3909	50	1.469	5,743	*10,514*
					Total HC Emissions:	*17,831*					*Total HC Emissions:*	*24,550*	*42,381*

NOx Emissions (typical summer day)

	Eastbound						Westbound						
	Link Data				Emission	Link	Link Data				Emission	Link	Site Total
Site	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Emissions (gr)
2	3822	0.67	2561	47	2.294	5,875	6876	0.65	4469	25	2.135	9,542	*15,417*
3	5573	0.53	2953	58	3.061	9,040	5960	0.49	2920	52	2.486	7,260	*16,300*
4	5231	0.27	1413	57	2.976	4,204	3361	0.19	638	46	2.276	1,453	*5,658*
5	4531	0.34	1540	61	3.332	5,133	3852	0.70	2694	51	2.518	6,784	*11,917*
7	5942	0.55	3268	52	2.486	8,124	7108	0.55	3909	50	2.448	9,570	*17,695*
					Total NOx Emissions:	*32,376*					*Total NOx Emissions:*	*34,609*	*66,985*

CO Emissions (typical winter day)

	Eastbound						Westbound						
	Link Data				Emission	Link	Link Data				Emission	Link	Site Total
Site	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Volume (veh)	Length (mi)	VMT (veh-mi)	Speed (mph)	Factor (gr/veh-mi)	Emissions (gr)	Emissions (gr)
2	5584	0.67	3742	62	18.26	68,323	7169	0.65	4660	59	14.53	67,708	*136,031*
3	5999	0.53	3179	66	23.32	74,135	6061	0.49	2970	53	9.56	28,390	*102,525*
4	5497	0.27	1485	49	9.49	14,089	5379	0.19	1022	49	9.49	9,697	*23,786*
5	5147	0.34	1750	58	13.29	23,255	3953	0.70	2765	63	19.52	53,970	*77,225*
7	6399	0.55	3519	54	9.58	33,716	7819	0.55	4300	55	9.6	41,284	*75,001*
					Total CO Emissions:	*213,518*					*Total CO Emissions:*	*201,049*	*414,567*

Table B5
EMISSION FACTORS BY TRAVEL SPEED FOR CO, HC AND NOx

Speed	CO		Weighted	Speed	HC (as TOG)		Weighted	Speed	NOx		Weighted
(mph)	With IM	W/out IM	Average	(mph)	With IM	W/out IM	Average	(mph)	With IM	W/out IM	Average
25	16.21	24.35	17.06	25	2.056	3.02	2.156	25	2.098	2.452	2.135
33	12.38	18.87	13.05	33	1.733	2.512	1.814	33	2.104	2.47	2.142
34	12.03	18.38	12.69	34	1.702	2.465	1.781	34	2.109	2.476	2.147
38	10.85	16.68	11.46	38	1.596	2.301	1.669	38	2.135	2.506	2.174
40	10.36	15.99	10.95	40	1.552	2.232	1.623	40	2.154	2.526	2.193
41	10.14	15.68	10.72	41	1.531	2.201	1.601	41	2.165	2.538	2.204
42	9.94	15.39	10.51	42	1.512	2.171	1.581	42	2.177	2.55	2.216
43	9.75	15.12	10.31	43	1.493	2.143	1.561	43	2.19	2.564	2.229
44	9.57	14.86	10.12	44	1.476	2.116	1.543	44	2.204	2.579	2.243
45	9.4	14.63	9.94	45	1.459	2.091	1.525	45	2.22	2.595	2.259
46	9.25	14.41	9.79	46	1.444	2.067	1.509	46	2.237	2.613	2.276
47	9.1	14.2	9.63	47	1.429	2.045	1.493	47	2.255	2.632	2.294
48	8.96	14	9.48	48	1.414	2.023	1.477	48	2.275	2.652	2.314
49	8.97	14.01	9.49	49	1.41	2.015	1.473	49	2.34	2.732	2.381
50	8.98	14.02	9.50	50	1.406	2.007	1.469	50	2.406	2.813	2.448
51	8.99	14.04	9.52	51	1.402	2	1.464	51	2.474	2.896	2.518
52	9.01	14.06	9.54	52	1.398	1.993	1.460	52	2.543	1.993	2.486
53	9.03	14.08	9.56	53	1.395	1.987	1.457	53	2.615	3.068	2.662
54	9.05	14.1	9.58	54	1.392	1.981	1.453	54	2.689	3.156	2.738
55	9.07	14.13	9.60	55	1.389	1.975	1.450	55	2.764	3.247	2.814
56	10.21	16.13	10.83	56	1.418	2.027	1.481	56	2.842	3.34	2.894
57	11.35	18.13	12.06	57	1.448	2.079	1.514	57	2.923	3.435	2.976
58	12.49	20.14	13.29	58	1.478	2.131	1.546	58	3.006	3.533	3.061
59	13.64	22.15	14.53	59	1.507	2.184	1.577	59	3.091	3.634	3.147
60	14.79	24.17	15.77	60	1.538	2.236	1.611	60	3.18	3.738	3.238
61	15.94	26.19	17.01	61	1.568	2.29	1.643	61	3.272	3.845	3.332
62	17.1	28.22	18.26	62	1.598	2.343	1.675	62	3.367	3.956	3.428
63	18.27	30.25	19.52	63	1.629	2.397	1.709	63	3.467	4.07	3.530
64	19.44	32.29	20.78	64	1.66	2.451	1.742	64	3.57	4.188	3.634
65	20.62	34.34	22.05	65	1.691	2.505	1.776	65	3.678	4.311	3.744