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Publication Date

2005-08-11

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Lianyu Chu, Hamed Benouar, Will Recker

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

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Report for RTA 65A0155

September 2005

ISSN 1557 2269

CALIFORNIA CENTER FOR INNOVATIVE TRANSPORTATION

Evaluation of Automated Workzone Information System (AWIS) – CHIPS (Computerized Highway Information Processing System)

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8/11/2005

A. Executive summary

Improved real-time automated motorist information around workzones can help relieve congestion and improve safety around those workzones. Several Automated Workzone Information Systems (AWIS) are being deployed around the nation. The California Department of Transportation (Caltrans) requested that The California Center for Innovative Transportation (CCIT) evaluate the Computerized Highway Information Processing System (CHIPS), which is an AWIS developed by ASTI Transportation Systems. The system is able to detect traffic congestion (using its traffic sensors) in the work zone area and then deliver appropriate messages to motorists (via its portable message signs) as they approach or pass through a work zone.

The CHIPS system was deployed in the work zone site located in the City of Santa Clarita, north of Los Angeles, on freeway I-5. It was evaluated from June 30th, 2003 to September 6th, 2004 with respect to four specified aspects, functionality, reliability, effectiveness, and cost. It was found that CHIPS provides most functions Caltrans wants. However, the system did not perform reliably during evaluation, especially at the beginning of its operation. CHIPS was found to have some technological problems, including inappropriate initial setting of the system, inaccurate setup and calibration of traffic sensors, communication failure, power and video system failure, sensor failure, and software error. After a period of fine-tuning, the system had only occasional hardware and software problems arising. The observation conducted on Sep. 6th, 2004 showed that the system has the capability to respond to traffic congestion automatically but still suffered from the problem of detecting traffic congestion accurately at one of its sensor location. The video subsystem of CHIPS is a separate part of the system, which is what Caltrans likes to have. However, it was turned out to be the very unreliable.

The effectiveness of the system was evaluated based on three criteria, safety, diversion, and responses from travelers. The results of these studies showed that (1) the driving environment after the use of CHIPS seemed safer; (2) obvious diversion were observed on two evaluation dates, July 6th, 2003 and September 1st, 2003; (3) positive responses about the system were obtained from driver surveys.

Based on the cost data from both Caltrans and the vendor, the total cost of the system was \$833,924 for the 26-month contract. We find this cost to be high considering its actual system performance and the expected performance. However, considering the benefits from the system, we feel this system shows promise because it automates work zone traveler information services and is a complete package that includes measurement, processing, and message delivery. When it works properly, this system is effective in diverting traffic and promoting smoother traffic flow during congested periods. As a result, a similar system with more robust performance and cheaper cost will be a viable technology.

Disclaimer

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Acknowledgements

The evaluation team would like to thank many people from Caltrans who provided us with various devices, data, reports and information. Denis Katayama of District 7 deserves particular mention for his helps throughout the entire evaluation phase.

We would like to thank all researchers that ever worked for this project, including Hee Kyung Kim, YounShik Chung, and Chris Breiland of UC Irvine, Robert Tam and Chao Chen of UC Berkeley, Professor Henry X. Liu of Utah State University.

We also would like to thank Professor Mike McNally of UC Irvine, who provided the EDCU equipment for the project to collect probe vehicle data.

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B. Description of the system to be evaluated

B.1 Introduction

Work zones are a source of congestion. Driver inattention and high speeds can also increase the potential for incidents around workzones. Automated real-time motorist information has the potential to reduce congestion and the likelihood of incidents around workzones. Such automated systems are made possible today by recent advancement in Intelligent Transportation Systems (ITS) technologies, especially in the areas of sensors, control and communication technology. New systems known as Automated Workzone Information Systems (AWIS) have been developed and deployed in the field. These systems are designed to deliver real-time information to the motorists as they approach or pass through a work zone and thus result in more alert drivers which in turn will reduce the occurrences of rear-end and other collisions in and near the work zone. A typical AWIS system usually integrates several traffic sensors and several Changeable Message Signs (CMSs) with a central controller that automatically determines appropriate messages to be shown on CMSs according to the detected traffic condition. The potential benefits of AWIS include increasing safety for both motorists and construction personnel and improving the efficiency of the traffic system.

Notable instances of AWIS systems include ADAPTIR (Automated Data Acquisition and Processing of Traffic Information in Real-time), CHIPS (Computerized Highway Information Processing System), Smart Zone, and TIPS (Traffic Information & Prediction System). Some ADAPTIR systems have been evaluated in Maryland, Iowa, Illinois, Kentucky, and Nebraska. The TIPS system has been evaluated in Ohio. It was found that most systems had various technological problems, such as initial setting of the system, communication and power failure, inability of the control algorithm to provide accurate traffic information¹.

The studies in Kentucky and Nebraska investigated if AWIS could cause diversion. 3% diversion was found in Nebraska but no diversion was found in Kentucky because of the system setting problem of AWIS. Although safety is a major expected benefit of AWIS, no study performed a collision data analysis in order to see if there was any safety benefit. The ADAPTIR system was checked for its effect on speed and lane distribution, which can be regarded as an alternative of safety measure. It was found that traffic flow had no significant difference under un-congested traffic condition. However, the study under congestion was not performed because there was no traffic congestion during both before and after studies.

According to the above-mentioned evaluation experiences, most studies paid attention to the evaluation of system functionality and reliability.

¹ Fontaine, M. D. (2003) Guidelines For The Application Of Portable Work Zone Intelligent Transportation Systems, In Transportation Research Record: Journal of the Transportation Research Board, No. 1824, TRB, National Research Council, Washington, D.C., pp. 15-22

In order to evaluate existing AWIS effectiveness including their cost, the California Department of Transportation (Caltrans) request that The California Center for Innovative Transportation (CCIT) perform AWIS evaluation on three workzone sites. Due to lack of funding within the construction projects, only one AWIS system was installed.

This report describes our comprehensive evaluation study on the one system that was deployed called Computerized Highways Information Processing System (CHIPS). The CHIPS system was deployed at a Caltrans work zone site near Los Angeles.

B.2 CHIPS system

CHIPS is developed by ASTI Transportation Systems². As shown in Figure 1, the CHIPS system is composed of facilities in the field and the command center.

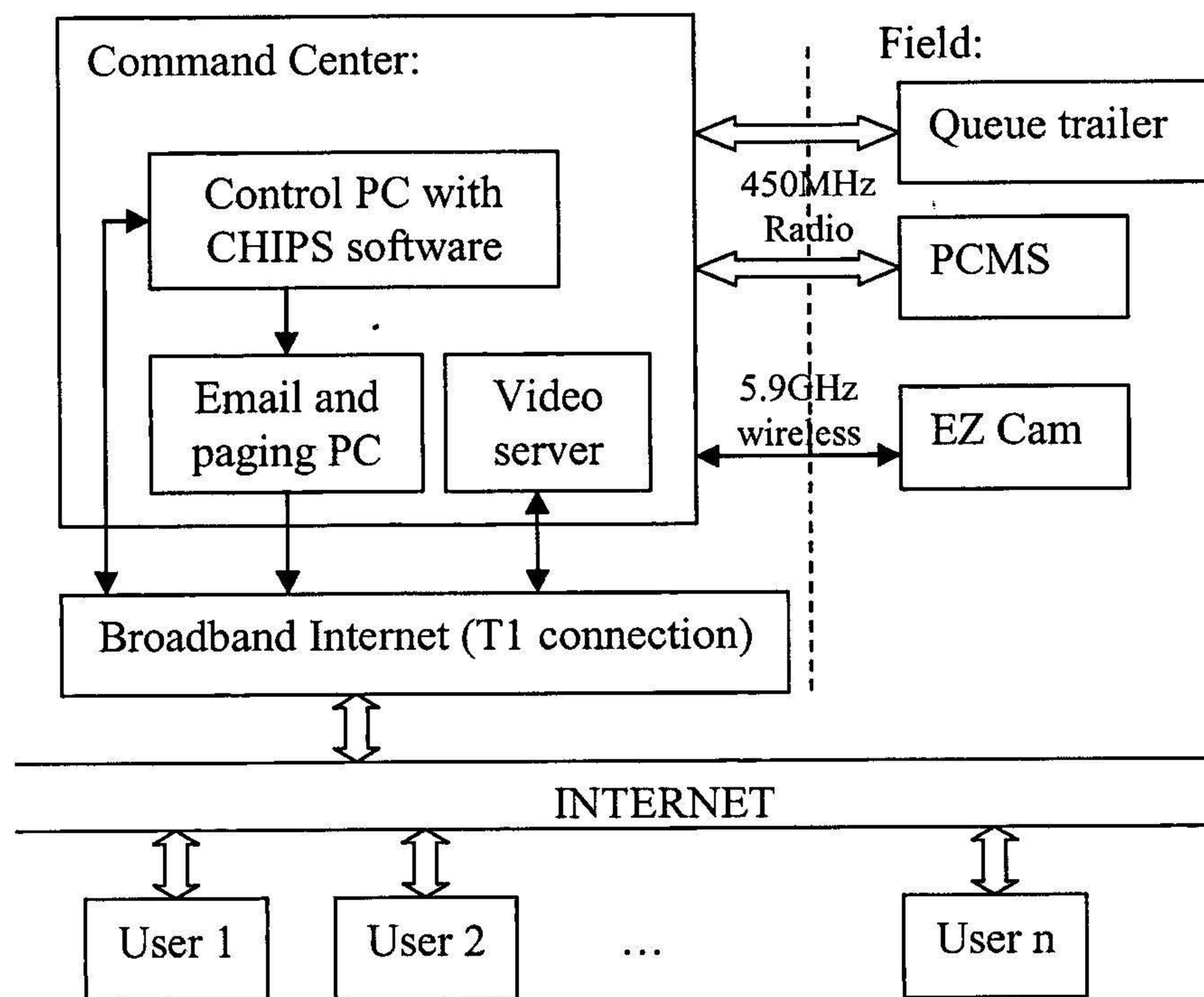


Figure B-1 Framework of CHIPS

The facilities in the field include

- (1) Quick queue trailers,
- (2) EZ cam Mobile video trailers, and
- (3) Portable Changeable Message Signs (PCMS).

The quick queue trailer is employed as the speed sensor to detect traffic changes in traffic flow and its main component is a Remote Traffic Microwave Sensor (RTMS), made by Electronic Integrated Systems (EIS) Inc. PCMS displays real-time traffic information to

² ASTI website: <http://www.asti-trans.com/>

travelers. The EZ cam is a trailer mounted Closed Circuit TV (CCTV) camera, used to monitor the traffic condition in the field.

The command center has the following hardware and software: communication systems (including a 450 MHz radio and 5.9 GHz wireless video antennas and receiver), AXIS 2400 video server³, Email and paging server, and the control computer running the core CHIPS software. The command center communicates with quick queue trailers and PCMSs through a 450 MHz radio network, and the EZ Cams through a 5.9 GHz wireless video transmission system. The AXIS 2400 video server publishes surveillance video data received from the EZ Cams to the Internet. Email and paging server is a computer used as a server to send instant messages to users if trouble conditions are observed. The control computer running the core CHIPS software controls the operation of the system, which can be remotely accessed using software called PCAnywhere.

This section will introduce major components of the system and explain how they work.

B.2.1 Quick queue trailer

The quick queue trailer is a trailer-mounted device that is capable of monitoring the roadway traffic flow and determining if “alarm” conditions have subsided or if they are ongoing. The quick queue trailer is composed of a trailer, a queue detector, some add-on timing devices, a solar power system, and a 450MHz radio all mounted on a trailer. A photo of the quick queue trailer is shown in Figure B-2.



Figure B-2 An outlook of the quick queue trailer

³ AXIS website <http://www.axis.com/>

The main component of the quick queue trailer is the Remote Traffic Microwave Sensor (RTMS), made by Electronic Integrated Systems (EIS) Inc⁴. RTMS is a low-cost general-purpose all-weather traffic sensor that detects presence and measures traffic parameters in multiple independent lanes. As shown in Figure B-3, RTMS measures the distance to objects in the path of its microwave beam⁵. The microwave beam of the quick queue trailer covers all lanes and looks at a twelve-foot slice of the highway, which is called the detection zone of an RTMS where the traffic is detected. The zones of an RTMS are defined through the RTMS software. The quick queue trailer can setup its RTMS to have either one zone or multiple zones. Each zone needs to work with an add-on timing device.

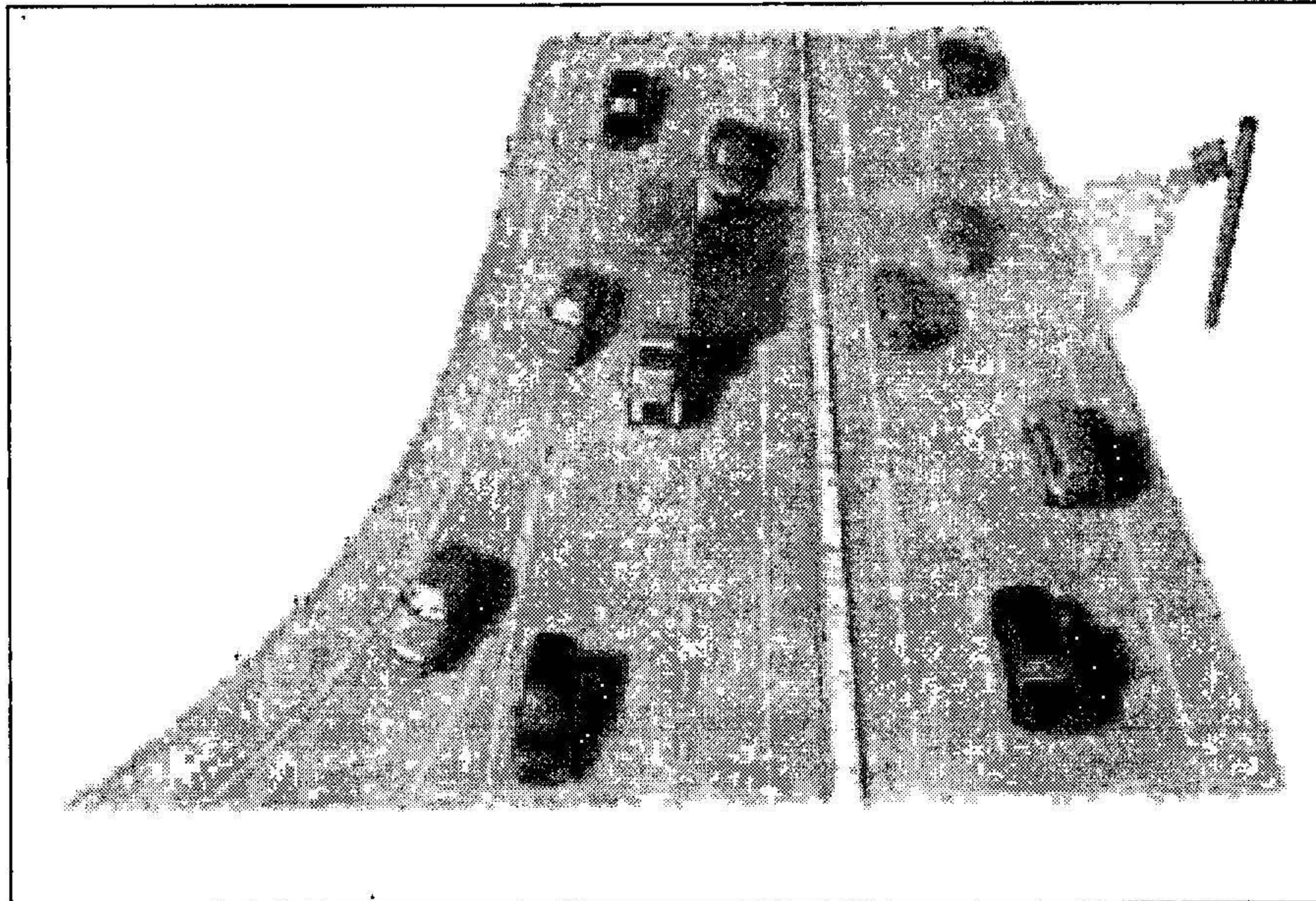


Figure B-3 RTMS microwave beam and its footprint (from <http://www.nortechdetection.com.au/>)

The quick queue trailer uses the presence function of RTMS, which reports a state of either “tripped” or “clear.” The “Tripped” signal represents either stopped or congested traffic condition in the corresponding zone area. The “clear” represents free flow traffic condition or the traffic condition that traffic congestion has subsided. When there is a vehicle present in a zone, the RTMS simply makes a contact closure. The contact closure initiates the “closure timer” of the corresponding add-on timing device. If the contact closure is longer than a pre-determined time, the queue detector is tripped. The predetermined time is called “on-delay”, which is a user-definable parameter, ranging from 2 to 20 seconds. Once traffic starts moving again, a re-set timer of the corresponding add-on timing device will start. If this timer is longer than another pre-determined time, called “off-delay”, ranging from 5 to 65 minutes, the state of RTMS will be set to “clear”. If traffic stops during this time period, the clearance timer starts again.

The quick queue trailer is battery powered with a solar recharging system. It relays the state of RTMS to other devices or the command center through a 450MHz radio network.

⁴ EIS website: <http://www.rtms-by-eis.com/>

⁵ EIS Electronic Integrated Systems Inc., RTMS User Manual, Issues 3

Also, it can be equipped with a data storage system, which logs the collected traffic data (such as volume, occupancy, speed, vehicle class, and long vehicle volume) by RTMS for up to 28 days when the time interval of data collection is 5 minutes. All above-mentioned devices are contained in a box on the quick queue trailer, as shown in Figure B-4.

Since the main component of the quick queue trailer is RTMS, we hereafter refer to the quick queue trailer as RTMS in this report.

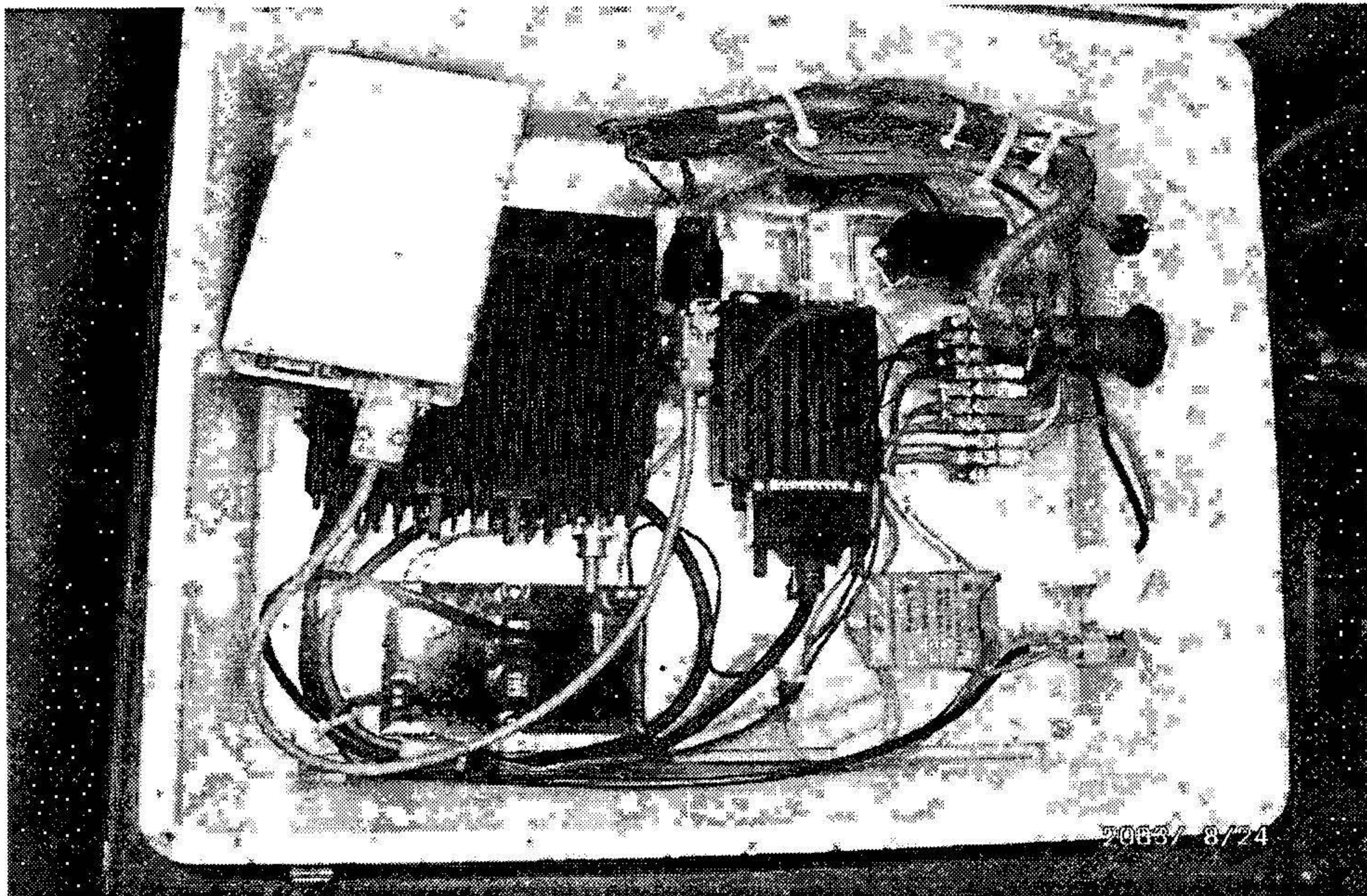


Figure B-4 The devices inside the box of a quick queue trailer

B.2.2 PCMS

As shown in Figure B-5, PCMS (Portable Changeable Message Sign) of CHIPS is a 24-character message board that is mounted on a trailer. It is used to show messages about the traffic conditions to drivers. It includes a 450 MHz radio device that is used for communicating with the command center of CHIPS. The command center of CHIPS can activate PCMS in seconds through the 450MHz radio communication.

B.2.3 EZ Cam Mobile Video Trailer

As shown in Figure B-6, the EZ Cam Mobile Video Trailer is a trailer-mounted camera system. It is capable of capturing real-time video images and relaying them to the command center through a point-to-point wireless 2.4 GHz video transmission system. The devices of an EZ Cam Mobile Video Trailer include a trailer, a video camera, a battery charging system, an on-board lifting mast system, video transmitter, and video transmission antenna.

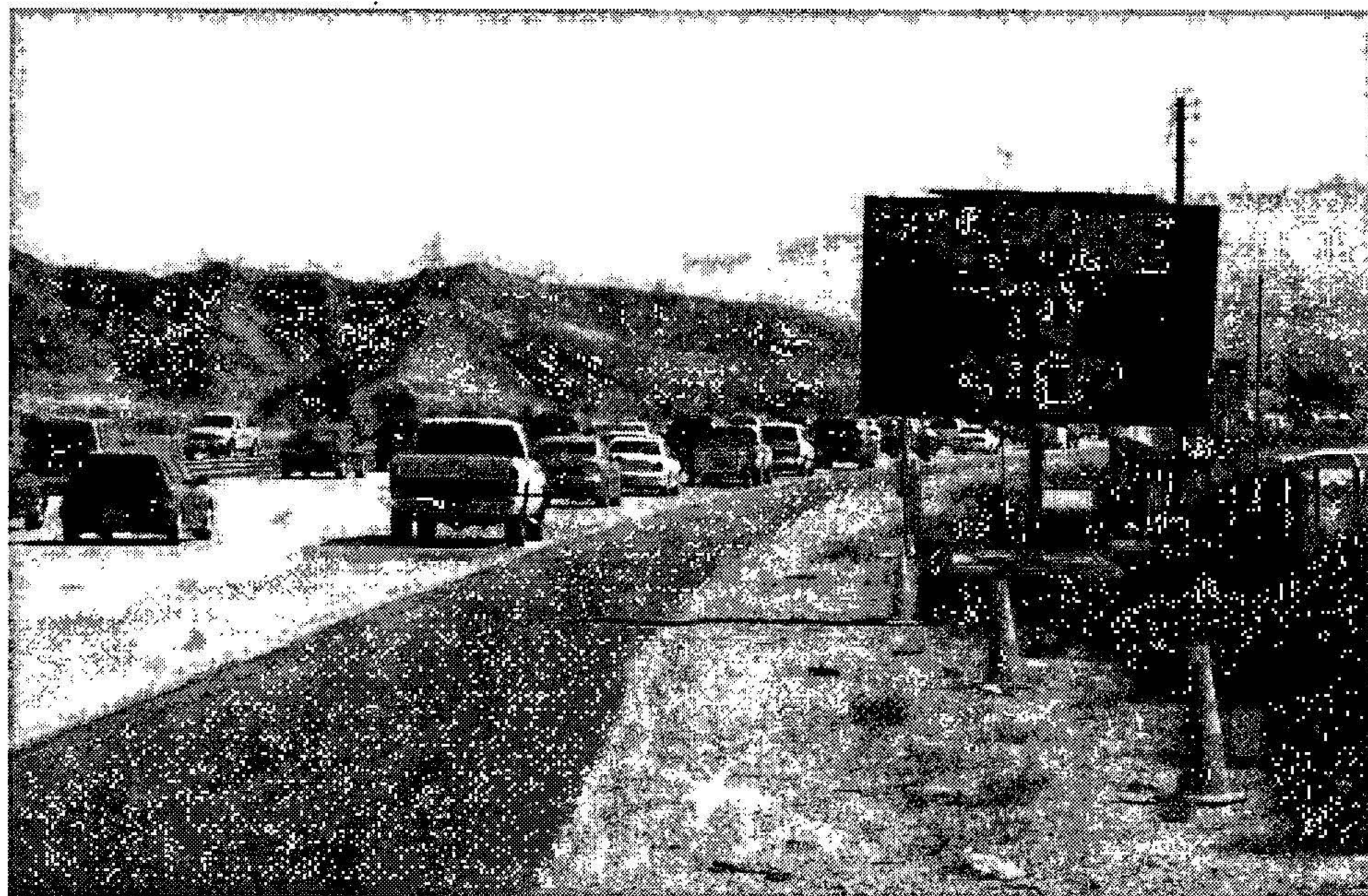


Figure B-5 Portable changeable message sign of CHIPS

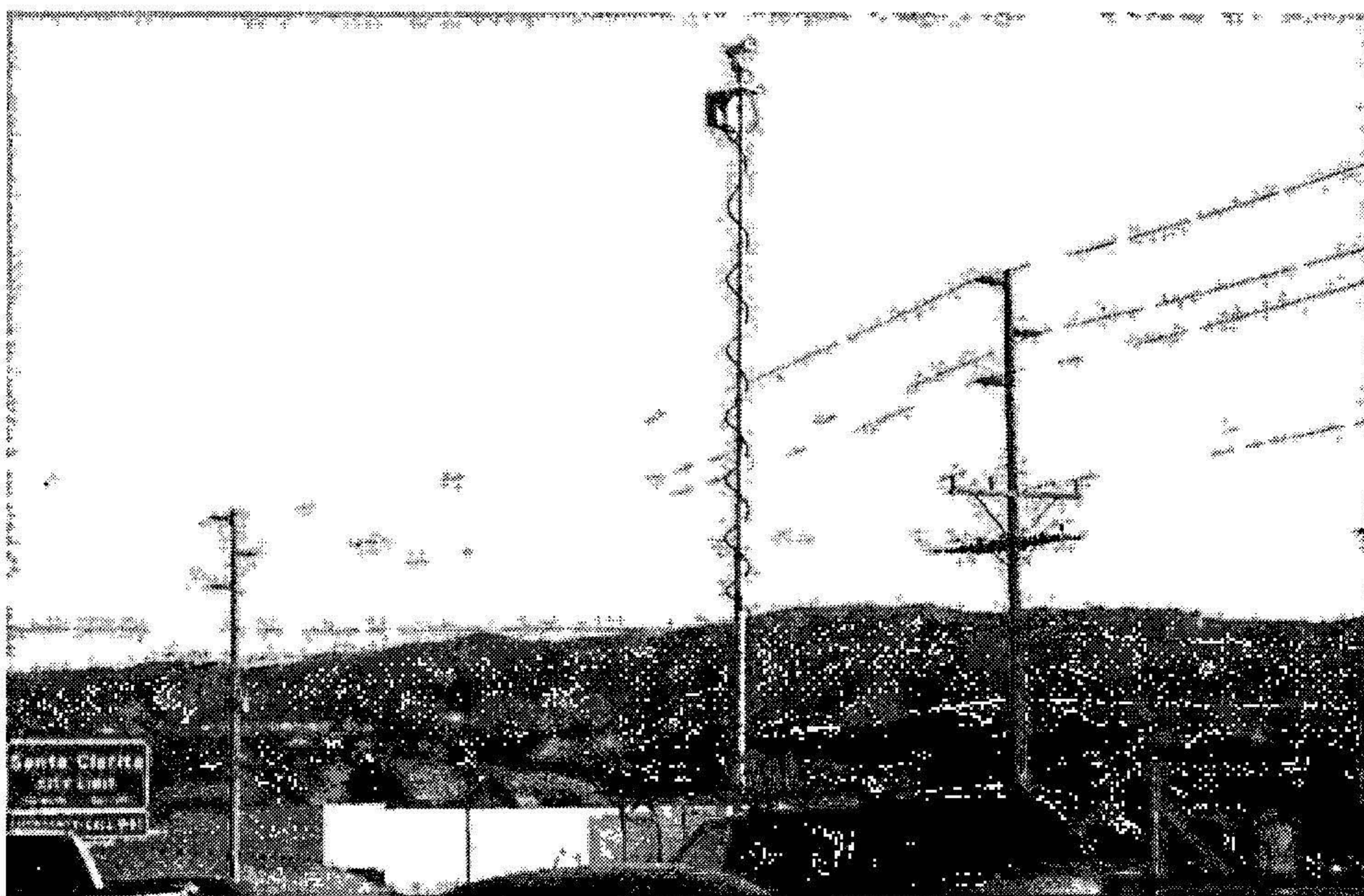


Figure B-6 The EZ Cam Mobile Video Trailer

The video camera is raised to appropriate viewing levels using the mast system. The Pan/Tilt & Zoom functions can be manually controlled at the trailer or at the command center using wireless communications. Since the AXIS video server at the command center publishes surveillance videos to the Internet, users can control cameras from their own computers.

For simplicity, this report refers to the EZ Cam Mobile Video Trailer as CCTV (Closed Circuit Television).

B.3 How CHIPS works

As illustrated in Figure B-7, the core CHIPS software installed in the control computer at the command center runs continuously in order to communicate with all devices in the field and control the operation of the system. The main window of the CHIPS software shows the graphical map of the work zone area, including locations and states of RTMSs and PCMSs.

CHIPS is an all-encompassing Traffic Management Package, which requires minimal programming to adjust to specific needs. Users need to self-define traffic management scenarios, which include traffic conditions and their corresponding traffic management schemes. In other words, users need to tell CHIPS what messages to be shown on PCMSs for each possible traffic condition. The Graphical User Interface (GUI) of the CHIPS software provides users a drop-down menu to input scenarios and configure CHIPS.

As mentioned above, communication between CHIPS and its devices in the field is through a 450MHz radio network. CHIPS polls a different device every 12 seconds to check its status. Thus, if there are 10 devices (e.g., five PCMSs and five queue trailers), it will take 120 seconds to poll all of the devices. When polled, the RTMS sends back its current state ("tripped" or "clear") and the PCMS sends back its current message to the command center. Any time an RTMS "trips", it sends out a sub-audible signal to other radios in the network, telling them to stop broadcasting. The "tripped" RTMS will then send a message to the CHIPS software as to what state it has changed to. When CHIPS detects a state change in the RTMS, it will search for the traffic management scenarios that have been entered into the system. If a matching scenario is found, its corresponding messages will be shown on the PCMSs. After CHIPS sends out these new messages to PCMSs, it goes back to the polling routine.

The states of RTMSs and PCMSs are shown in the graphical map of the CHIPS software, giving users the ability to see the condition of any RTMS at a glance. RTMS shows green color for the "clear" state and red color for the "tripped" state. Through clicking each PCMS on the map, users can check the current message being displayed on the PCMS. Details on how to use the core CHIPS software are explained in CHIPS user manual⁶.

CHIPS updates a record in the database indicating the last time a device has checked in and the check in time and date are shown on the Graphical User Interface (GUI) for users to check. If a device has not checked in for some time, this indicates that there may be a problem with the device's components or the communication system.

In addition to the database updates, CHIPS has a log system that records the state of each RTMS and the message of each PCMS every 5-6 minutes. The log provides historical records of the system operation and can help diagnose problems.

⁶ ASTI, CHIPS User manual, May 2003

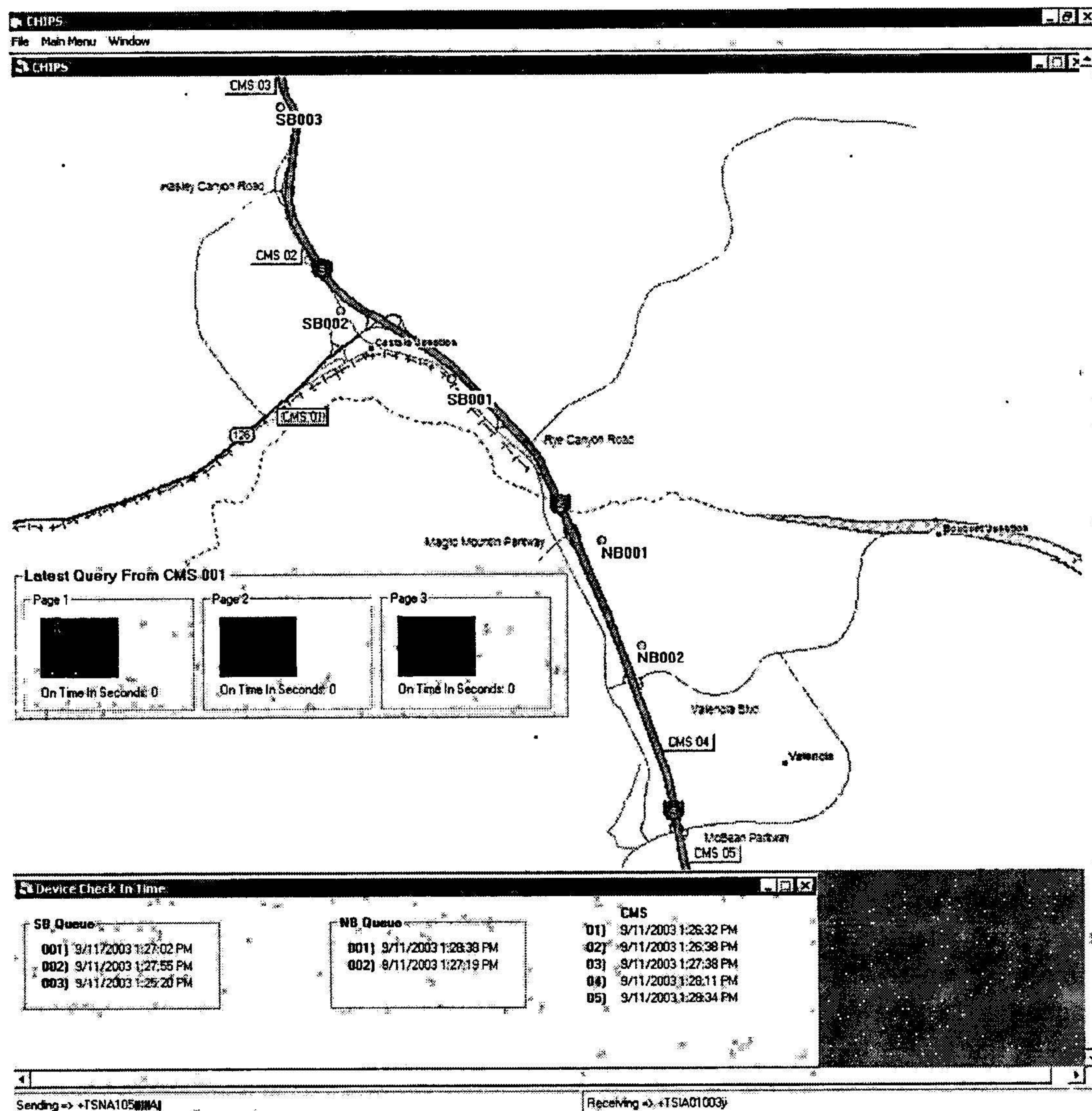


Figure B-7 The core software of CHIPS

C. Description of the site location

CHIPS was deployed at a work zone site on Interstate-5 between Magic Mountain Parkway and Rye Canyon Road in Santa Clarita, California. Interstate 5 is a major north-south route used for international, interstate, interregional and intra-regional travel and shipping. The study site is shown in Figure C-1.

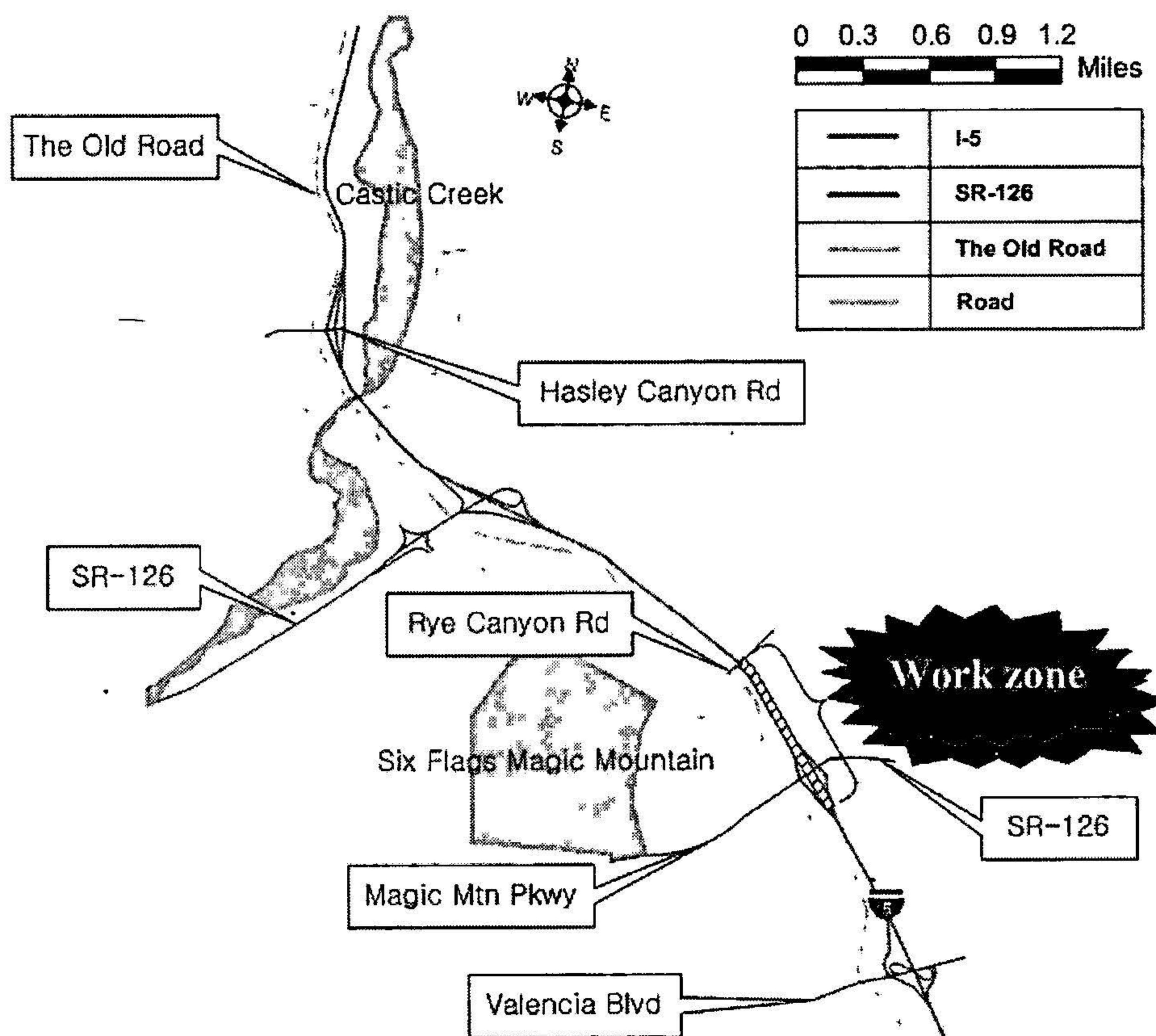


Figure C-1 work zone site location

The construction project is to replace the Santa Clara River Bridge on I-5 and the I-5/SR-126 Separation (Magic Mountain Parkway). The bridge work requires the total replacement of the existing separate NB and SB structures over the Santa Clara River with a single structure⁷. This construction project started January 22nd, 2002 and is scheduled to finish in the spring of 2006. Since July 30th, 2002, one southbound lane and one northbound lane have been closed from Magic Mountain Parkway to Rye Canyon Road, a length of 1.3 miles. The lane closures leave three lanes in each direction open to motorists. In case of traffic congestion, the Old Road is the suggested alternate route and has one lane in each direction in most places, with several signals and stop signs.

⁷ Caltrans website: http://www.dot.ca.gov/dist07/route5/corridor/fact_sheets/fs3.htm

Figure C-2 also shows locations of three traffic sensors of the CHIPS system (i.e. RTMS-1, RTMS-2, and RTMS-3). We will describe them later.

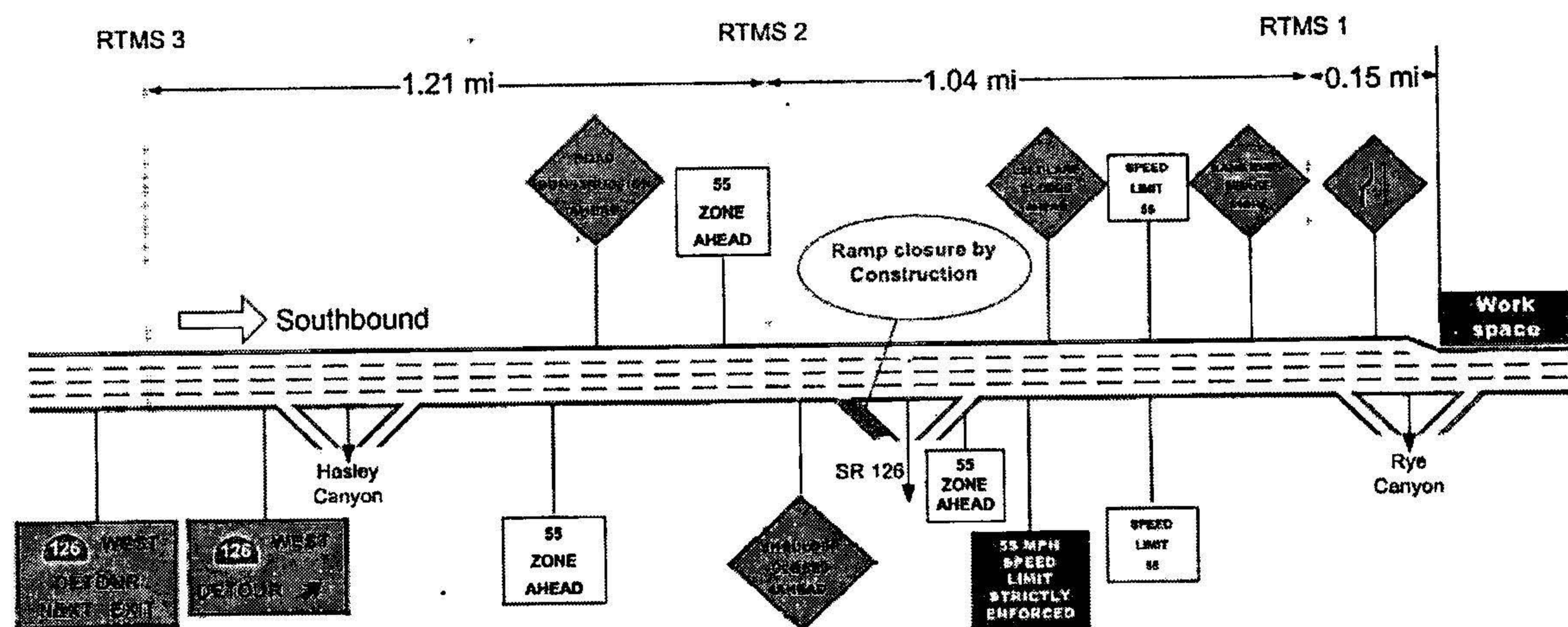


Figure C-2 Static signs in the work zone area

D. Description of the site traffic conditions

Based on the preliminary traffic data analysis from Caltrans, the traffic congestion on the southbound lanes is much more severe (especially during major holidays) than the congestion on the northbound lanes. Therefore, we focus our study on the southbound direction.

D.1 Holiday traffic condition based on observations

Since the start of the construction project, District 7's Traffic Management Team (TMT) has performed a set of on-site traffic condition observations on major holidays. Table D-1 is a summary of these observations, with the information of congestion time period, the maximum length of queue, and the estimated maximum delay for each observation day.

Table D-1 Summary of traffic condition observations conducted by District 7

Date	Congestion time period	Maximum Queue (miles)	Maximum Delay (minutes)	Notes
08/30/2002(Fr)	15:00-16:30	2	4	Labor Day
08/31/2002(Sa)	10:00-14:30	1	3	
9/2/2002 (Mo)*	N/A	N/A	N/A	
11/8/2002(Fr)	15:30-16:30	0.5	1	Veterans Day
11/10/2002(Su)	14:00-17:30	3	6	
11/27/2002(We)	10:30-20:30	5.5	24	Thanks-giving
11/28/2002(Th)	10:00-15:00	4	10.5	
11/29/2002(Fr)	14:15-18:00	2	4	
11/30/2002(Sa)	12:00-18:00	5	13	
12/1/2002(Su)	11:00-21:30	12	36	
12/24/2002(Tu)	13:45-17:15	1.5	3	Christmas
12/26/2002(Th)	11:45-19:30	4.5	16	
5/23/2003(Fr)	12:35-14:30	2	3	Memorial Day
5/26/2003(Mo)	11:00-22:30	13	41	
7/3/2003(Th)	15:15-17:15	2	3.5	Independence Day
7/4/2003(Fr)	10:00-17:00	2	4	
7/6/2003(Su)	10:30-21:15	14	47	
8/29/2003 (Fr)	14:00-18:00	1.5	3	Labor Day
8/30/2003 (Sa)	9:45-13:15	2.2	5.5	
9/1/2003 (Mo)	11:00-22:40	10	33	
11/26/2003 (We)	11:00 - 21:30	6.5	35	Thanks-giving
11/30/2003 (Su)	11:00 - 21:00	9.3	33	
12/24/2003 (We)	12:30 - 19:45	4.5	27	Christmas
12/28/2003 (Su)	12:45 - 17:30	4.8	15.5	

* According to Caltrans' data, a brush fire occurred between 9/1/2002 to 9/2/2002, which caused the change of traffic volume and pattern. The effect of the construction could not be determined due to this major incident.

From Table 1, it is found that traffic congestion always occurs at the first day and the last day of each holiday break due to high travel demands traveling to the Southern California area:

- (1) People from the north travel to the south at the first day of the holiday (the first day actually corresponds to the day just before the holiday);
- (2) People living in Southern California and visiting Northern California during the holiday usually travel back at the last day of the holiday break.

D.2 Traffic condition analysis using loop data

Based on the travel patterns identified above, traffic congestion may also occur on some Sundays with high traffic demands; this conjecture is supported by the analysis using loop detector data.

The freeway Performance Measurement System (PeMS), sponsored by the California Department of Transportation (Caltrans), collects historical and real-time traffic data from freeways in the State of California⁸. PeMS provides tools to compute performance measures, such as Vehicle Miles Traveled (VMT), Vehicle Hours Traveled (VHT), and travel time, for traffic planners, operators, and engineers for traffic analysis. Users can access the PeMS data through the Internet⁹.

Based on loop detector information from PeMS, there are five mainline loop detectors installed on the southbound approach to the work zone, as shown in Table D-2. Among these detectors, loop detector station 759927 has data with acceptable quality based on data from April 21st, 2003 to September 2nd, 2003.

Table D-2 Loop detectors along the southbound I-5 work zone area

Location: I-5S@	VDS ID	CA post-mile (absolute post-mile)	Loop data quality
Parker Road	759933	59.50 (266.38)	poor quality
Hasley Canyon	759927	56.76 (263.64)	Good quality
Rye Canyon	716017	54.20 (261.08)	Poor quality
Magic Mountain	759914	53.40 (260.28)	Bad loop
Valencia Blvd	759906	52.49 (259.37)	Bad loop

As well accepted by practitioners, 18% of percent occupancy generally corresponds to the occupancy at capacity. We assume that if the 5-minute aggregated occupancy (average of all lanes of a 5 minutes interval) is higher than 18% and the estimated speed by PeMS is lower than 50 mph, the traffic condition at the loop station is congested. Based on the above criteria, we queried data from the 5-min loop detector database, having the processed loop data including aggregated volume, occupancy and estimated

⁸ Chao Chen (2003), Freeway Performance Measurement System (PeMS), California PATH Research Report, UCB-ITS-PRR-2003-22

⁹ PeMS website: <http://pems.eecs.berkeley.edu/>

speed. During the time period from July 30th, 2002 to May 19th, 2003 (after the construction), we found congested periods occurred during several Sundays, as illustrated in Table D-3.

Table D-3 Traffic congestion after construction began and before deployment of CHIPS

Date	Congestion duration	Notes
8/11/2002	60 minutes	Sunday during summer
8/18/2002	165 minutes	Sunday during summer
3/30/2003	110 minutes	Sunday
5/4/2003	70 minutes	Sunday
5/11/2003	235 minutes	Sunday
5/18/2003	235 minutes	Sunday

E. Evaluation

E.1 Deployment of CHIPS

E.1.1 Configuration of CHIPS

CHIPS was deployed in the work zone site located in the City of Santa Clarita, north of Los Angeles, on freeway I-5, between Magic Mountain Parkway and Rye Canyon Road. Caltrans and the system vendor designed the configuration of the system based on characteristics of the target work zone area. The system has a total of five RTMSs, five PCMSs, and three CCTV cameras. The three CCTV cameras are used to monitor the traffic condition of both southbound and northbound directions.

Table E-1 Locations of RTMS and PCMS

Device Name	Device Location	Distance to the work zone	s-5 postmile
RTMS-1	SB 5 @Rye Canyon Rd. Off-Ramp	0.15	54.65
PCMS-1	EB 126 E/O Commerce Center Drive	N/A	N/A
RTMS-2	SB 5 @RTE 126 Off-Ramp	1.19	55.69
PCMS-2	SB 5 @Honor Ranch Road	1.25	55.75
RTMS-3	SB 5 @Hasley Canyon Rd. Off-Ramp	2.40	56.9
PCMS-3	SB 5 n/o Hasley Canyon Rd. Off-Ramp	2.45	56.95

Our evaluation study focused on the southbound approach to the work zone, which had three RTMSs and three PCMSs. Figure E-1 shows a GIS-based CHIPS system map for the southbound approach. According to Caltrans' postmile data, the construction zone starts at postmile 54.5 and ends at postmile 53.0. The distances from RTMS-1, RTMS-2 and RTMS-3 to the starting point of the construction are 0.15, 1.19 and 2.40 miles, as shown in Table E-1.

As a result, the maximum queue that the system could detect and manage is 2.4 miles. If traffic queues were longer than 2.4 miles (beyond the RTMS-3), Caltrans used its own CMSs, i.e. "Caltrans CMS" and "Caltrans PCMS", to provide information to travelers. "Caltrans CMS" is a fixed CMS facility located between Parker Rd and Hasley Canyon Rd. "Caltrans PCMS" was located upstream of Lake Hughes Rd. According to District 7, Caltrans did not invest additional money for adding more RTMSs and PCMSs to the system because serious traffic congestion does not occur frequently. "Caltrans PCMS" and "Caltrans CMS" could be used as parts of CHIPS when there was serious congestion in the field.

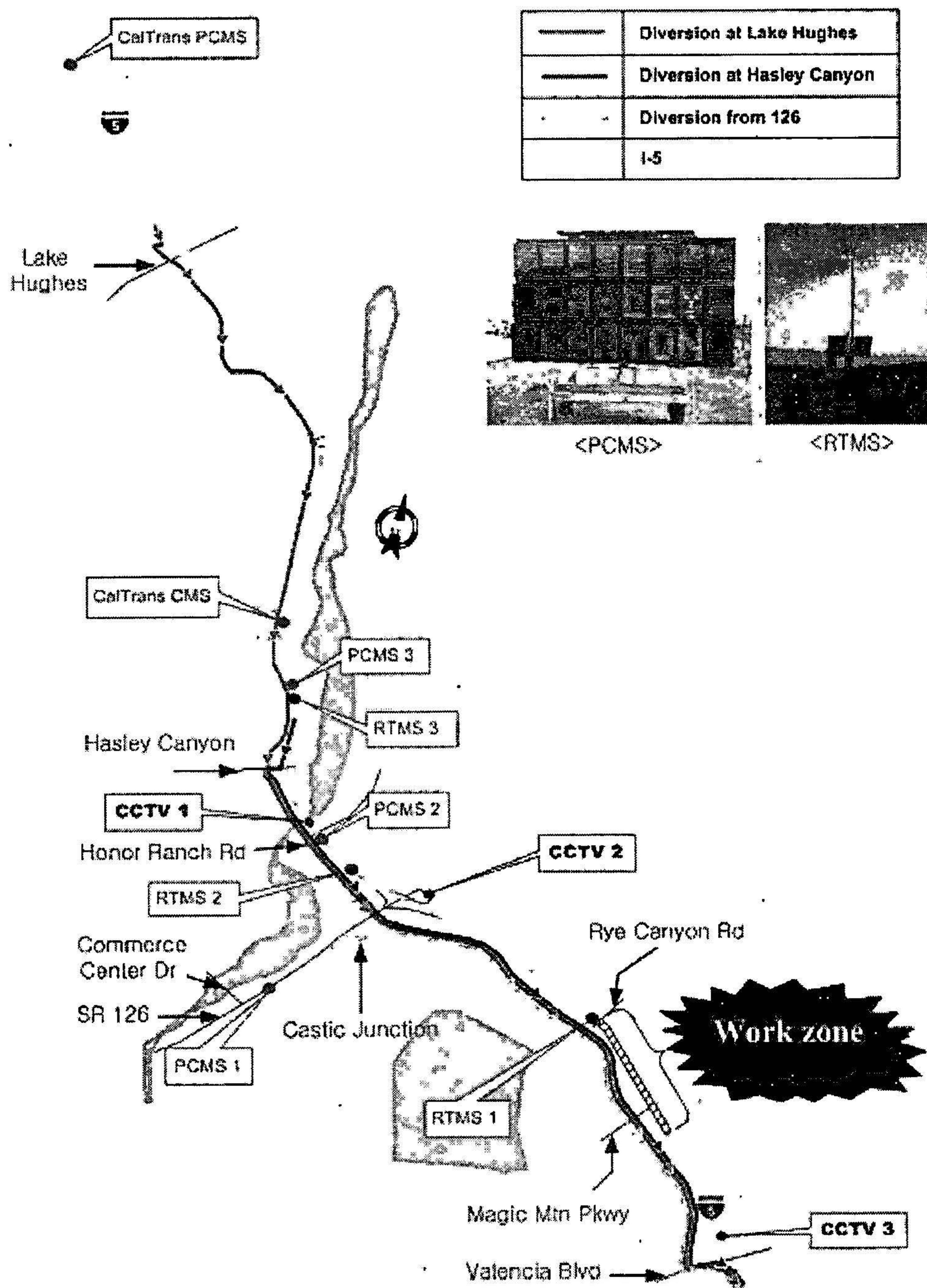


Figure E-1 Setup CHIPS in the work zone area

E.1.2 Setup traffic detection parameters

Traffic congestion detection is the most important part of the system. As explained in Section 1, CHIPS uses RTMSs (i.e. quick queue trailers) to detect traffic congestion based on a presence-based method. As shown in Figure E-2, each RTMS sets up three zones to cover four lanes (The system was designed to have three zones per RTMS).

When a vehicle is present in a zone, RTMS simply makes a contact closure, which initiates the closure timer of the add-on timing device. If the contact closure is longer than “on-delay”, defined as 4 seconds¹⁰, the RTMS is considered “tripped.” The “tripped” condition corresponds to congested or stopped traffic. Once traffic starts moving again, a re-set timer of the add-on timing device is initiated. If the re-set time is longer than off-delay, pre-determined as 5 minutes, the state of RTMS will be set to “clear”. If an RTMS is “tripped” again during this time period, the re-set timer starts again. The on-delay and off-delay settings for all RTMSs were initially set to 7 seconds and 5 minutes. Due to the poor detection performance, the two settings were fine-tuned and set to 4 seconds and 5 minutes after December 2003.

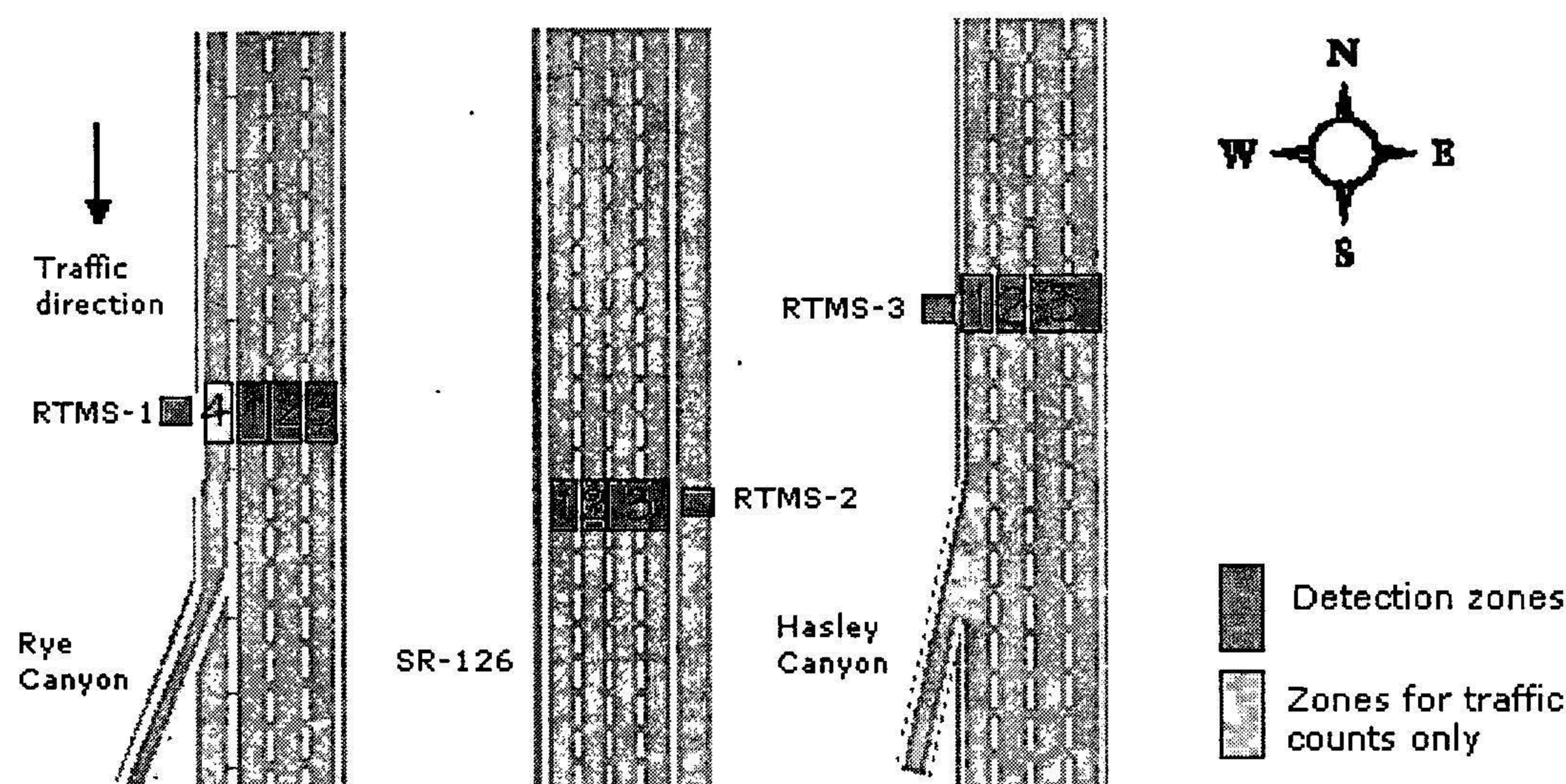


Figure E-2 Detection zones setup for three southbound RTMSs (Source:)

E.1.3 Setup traffic control scenarios

As described in Section B, CHIPS needs some basic programming from users, i.e. scenario setup. In other words, Caltrans users need to determine what messages should be shown on PCMSs for each traffic condition scenario.

As shown in Table E-2, four scenarios were setup. Scenario SBS01 corresponds to the situation that there is no traffic congestion and thus no message is shown on PCMSs. Scenario SBS02 corresponds to the scenario that only RTMS-1 has queued traffic and PCMS-1, PCMS-2, and PCMS-3 show messages CMB02, CMB03, and CMB05, respectively, as listed in Table E-3. Scenario SBS03 corresponds to the scenario that there is traffic congestion at RTMS-1 and RTMS-2 and thus the three PCMSs show messages CMB06, CMB07, and CMB03, respectively. Under this scenario, Caltrans CMS is also activated by Caltrans to show message CMB10.

¹⁰ The vendor claimed that the queue detector is activated by vehicles traveling at approximately 20 mph or less if the on-delay setting is 4 seconds.

If all three RTMS locations are detected to have queued traffic, the three PCMSs show messages CMB06, CMB07, and CMB08, respectively. PCMS-1 and "Caltrans CMS" provide diversion information in order to divert vehicles to the Old Road at the Castaic Junction off-ramp and Hasley Canyon Rd off-ramp, respectively. Also, "Caltrans PCMS" provides diversion information in order to divert vehicles to the Old Road at the Lake Hughes Rd off-ramp. The alternate route, i.e. the Old Rd generally has one lane in each direction and several signals and stop signs. In any event, vehicles could take the on-ramps at Magic Mountain Pkwy or Valencia Blvd to get back on the freeway.

Table E-2 Current Southbound I-5 Message Board Scenarios

Scenario	Queue Detector			CMS Combo Message				
	RTMS-1	RTMS-2	RTMS-3	PCMS-1	PCMS-2	PCMS-3	Caltrans CMS	Caltrans PCMS
SBS01	F	F	F	CMB01	CMB01	CMB01		
SBS02	T	F	F	CMB02	CMB03	CMB05		
SBS03	T	T	F	CMB06	CMB07	CMB03	CMB10	
SBS04	T	T	T	CMB06	CMB07	CMB08	CMB09	CMB11

Note : T = Queue being detected, F = No queue being detected

Table E-3 List of Messages

Message Number	Page 1(1st Flash)	Page 2(2nd Flash)
CMB01	BLANK	BLANK
CMB02	TRAFFIC/JAMMED	SOUTH 5/AT RYE/CANYON
CMB03	SLOW/TRAFFIC/AHEAD	PREPARE/TO/STOP
CMB04	TRAFFIC/JAMMED/NXT 2 MI	EXECT/5MIN/DELAY
CMB05	TRAFFIC/JAMMED/AHEAD	126 FWY/TO MAGIC/MOUNTAIN
CMB06	SOUTH 5/TRAFFIC/JAMMED	AUTOS/USE NEXT/EXIT
CMB07	JAMMED/TO MAGIC/MOUNTAIN	EXPECT/10 MIN/DELAY
CMB08	JAMMED/TO MAGIC/MOUNTAIN	EXPECT/15 MIN/DELAY
CMB09	TRAFFIC JAMMED TO MAGIC MTN	AVOID DELAY USE NEXT EXIT
CMB10	TRAFFIC JAMMED ROUTE 126 TO MAGIC MTN	
CMB11	SOUTH 5 ALTERNAT ROUTE	AUTOS USE NEXT 2 EXITS
CMB12	TRAFFIC JAMMED TO MAGIC MTN, 20 MIN/DELAY	
CMB13	SOUTH 5 ALTERNAT ROUTE	AUTOS USE NEXT EXIT

E.2 Evaluation of the system functionality

Functionality of CHIPS was evaluated with respect to general system functionality, traffic data acquisition, motorist information messages, and system communications. For each aspect, a list of function requirements has been specified by Caltrans. The method to evaluate CHIPS' functionality was to compare the capabilities of CHIPS reported by the vendor and the actual performance observed by the evaluation team between June 30th, 2003 and September 6th, 2004. Field observations were conducted on July 6th, August 17th, August 25th, and September 1st of 2003 and September 6th, 2004. Among these days, we made a thorough observation of how the system worked on September 1st, 2003 and September 6th, 2004.

In September 2003, we interviewed two members of the vendor's support staff to obtain information about the capabilities of CHIPS. Also, we performed a subjective evaluation of the CHIPS system based on phone and email interviews with five Caltrans employees who have the first-hand experience with the system.

E.2.1 General System Functionality

Table E-4 summarizes the evaluation results on the aspect of "general system functionality", which includes a series of functions, pre-specified by Caltrans.

Table E-4 Evaluation results of the general system functionality

Function requirement	System capability	Actual performance
1) Acquire traffic data and select motorist information messages automatically without operator intervention after system initialization	Yes	Yes.
2) Utilize full-size portable Changeable Message Sign (CMS) units to convey real-time traffic condition information to motorists	Yes	Yes
3) Operate continuously (24 hours, 7 days a week) for the duration of the construction project.	Yes	Yes.
4) Control locally (in the vicinity of the construction area) as well as remotely, by a separate computer, via a standard telephone connection	Yes	Yes. Broadband Internet connection is used.
5) Support special circumstances that allow authorized users to manually override motorist information	Yes	Yes

messages, both locally and remotely		
6) Have critical system operator control functions password protected.	Yes	Yes
7) Provide current operational status (i.e., current traffic data and messages, communications system, and battery status) locally (in the vicinity of the work zone) and remotely via a standard telephone connection	Yes	Yes (except the battery status)
8) Deliver voice messages via telephone to alert support staff to trouble conditions.	No	Instead of voice messages, the system sends page and email.
9) Generate trouble alerts for conditions such as: (1) low roadside equipment battery voltage; (2) system communications failure; (3) low speed traffic detected; and (4) excessive delay detected.	Yes/No (through page and email)	(1) No (2) The vendor claimed yes. (3) and (4) Yes, when slow traffic (instead of delay / speed) is detected.
10) Adjust the thresholds of reduced speed and congestion-induced delay at which the system initiates a telephone alert	Yes	Yes. CHIPS uses presence instead of speed / delay. There are two adjustable thresholds, on-delay and off-delay, placed in the queue trailer. CHIPS alerts users via page or email instead of telephone if any of two thresholds are reached.
11) Program the hours during which the trouble condition alerting sub-system initiates telephone calls to authorized users	No	No
12) Measure periodically and automatically the battery voltage of all equipment and alert support staff, locally and remotely via a telephone message, to low battery voltage conditions in time to provide supplemental charging before the system ceases to operate	No	The system uses solar system. The vendor provides a monthly maintenance that involves topping off battery fluids and cleaning solar arrays.
13) Have traffic sensors that require only setup or adjustment in their initial physical deployment	Yes	Yes

Additionally, we evaluate the following two functions provided by CHIPS, as shown in Table E-5.

Table E-5 Evaluation results of the two additional functions provided by CHIPS

Function requirement	System capability	Actual performance
1) Cameras can be used for surveillance of the traffic condition in the work zone.	Yes	But it is hard for users to remotely control the pan/tilt/zoom of cameras. The vendor believes the limited remote control is caused by foreign radio/micro waves in the area.
2) Deliver emails via internet to alert the appropriate personnel to trouble conditions and current operational status.	Yes	The email system experiences some delays in sending emails out. The delay may be derived from the SMTP server of ASTI.

E.2.2 Motorist Information Messages

CHIPS can only identify a traffic scenario using its RTMSs and then show messages (pre-specified by users) of a matched scenario on its PCMSs. CHIPS does not have capability to calculate speed or delay, nor generate messages to be shown. As a result, some of the listed functions by Caltrans are not appropriate for the evaluation of CHIPS. The evaluation results are shown in Table E-6.

Table E-6 Evaluation results of the motorist information message

Item	System capability	Actual performance
1) Provide speed, delay, and lane closure advisories to motorists	Yes	Yes. Although CHIPS is not able to calculate speed or delay, CHIPS can show any message (pre-specified by Caltrans users) on its message signs.
2) Include a time-stamp with the message to enhance message credibility	Yes	Yes. During the evaluation period, Caltrans did not include a time-stamp with messages.
3) Record motorist information messages in log files with time and date stamps	Yes	Yes
4) Display default messages when traffic conditions, system algorithms, and user parameters do not dictate that an advisory message should be displayed	Yes	Yes
5) Display separate, independent default messages on each CMS	Yes	Yes
6) Prompt motorists automatically to exit the mainline when delay through the work area exceeds an adjustable threshold	Yes	Yes. Based on the current scenario design, when RTMS-2 and RTMS-3 have congestion, diversion message will be shown.
7) Update its speed and delay	No	CHIPS does not have capability to

advisory CMS messages at least once per minute as traffic conditions change, consistent with the capabilities of the associated CMS equipment		calculate speed or delay and thus it is no need to update its speed and delay advisory at least once per minute.
8) Select messages for each CMS independently, based on the traffic conditions downstream of the CMS.	Yes	Yes
9) Notify motorists of downstream speeds to the nearest 5 mph	No	No
10) Field adjust the following parameters related to selection and presentation of motorist information messages: a. Message update frequency; b. Minimum delay necessary to trigger a delay advisory message; c. Persistence of delay before a delay message is displayed; d. Level of delay required to trigger a diversion message; e. Change in delay needed to cause a delay advisory message update; f. Change in downstream speed at which a speed advisory message update occurs	No	CHIPS works based on presence data measured by RTMSs.
11) Analyze traffic parameters in work zones in which there are multiple speed limits	No	No

E.2.3 System Communications

As shown in Table E-7, four aspects of system communication features in CHIPS are evaluated.

Table E-7 Evaluation results of the system communications

Function requirement	System capability	Actual performance
1) The wireless communications sub-system used to acquire traffic data and to specify motorist information messages shall be independent of the public cellular phone system to insure the reliability of communications	Yes	Vendor claimed that sometimes, the system encounters interference from other sources.
2) The communications sub-system shall incorporate an error detection/correction	Yes	Not sure. Sometimes, CHIPS software shows some truncated

mechanism to insure the integrity of all traffic conditions data and motorist information messages		messages such as "HEAD", "UNTAIN", or "AMMED", or some un-identified characters, such as "C+TSIA".
3) The communications sub-system shall be configured automatically during system initialization	Yes	Yes
4) It is possible to access and control the system remotely.	Yes	Yes

E.2.4 Summary

CHIPS uses several of the latest technologies, such as web-based video server, real-time email, and wireless communication. It provides most functions Caltrans wants except the delay estimation.

E.3 Evaluation of system reliability

We conducted the reliability study based on both objective evaluation and subjective evaluation. The reliability study includes the following aspects:

- (1) Reliability of system operation
- (2) Reliability in detecting traffic congestion and conveying accurate information
- (3) Reliability of system hardware and software

E.3.1 Reliability of system operation

The first objective is to evaluate whether the system can work automatically. According to the system design, the system should have capability to automatically detect traffic congestion scenario and display its corresponding messages on its portable message signs.

To check if the system can work automatically, the operation of CHIPS was observed since its deployment. The system was deployed and deemed ready by the vendor for operations right before the Memorial Day holiday of 2003. Based on field observations and operation logs, the system did not operate properly until December 2003. Table E-8 shows the system's operation observed in six holidays. It was found that the system could not implement the traffic management scheme independently, properly, and automatically at the beginning of its operation. The major problems include communication failure, traffic sensor failure, software errors, etc. The system finally could work automatically after early Dec of 2003.

Table E-8 System operation observed in six holidays

	Work automatically?	Major problems
July 6 th , 2003	No	(1) Communication failure with PCMS-3 (2) Traffic sensor (i.e. RTMS-2) failure
August 17 th , 2003	No	(1) System software error: system crash after detecting a new traffic condition scenario (2) Traffic sensor (i.e. RTMS-2) failure
September 1 st , 2003	No	(1) System software error: system crash after detecting a new traffic condition scenario (2) Traffic sensor (i.e. RTMS-2) failure
November 26 th , 2003	No	(1) RTMSs failed to detect queued traffic (2) Displaying incorrect scenario messages
December 24 th , 2003	Yes	
September 6 th , 2004	Yes	

E.3.2 Reliability in detecting traffic and conveying information

The next objective is to check if the system can work correctly. The first question is whether the traffic sensor, i.e. RTMS, can detect traffic condition accurately. The follow-up question is whether the system is capable of conveying accurate information (via message signs) to travelers and traffic management condition to operators (via remotely accessing the CHIPS software of the system). The operations of the CHIPS system were observed on July 6th, 2003, August 17th, 2003, September 1st, 2003, and September 6th, 2004. We will provide detailed evaluation results based on data collected on September 6th, 2004.

E.3.2.1 Data collection

As shown in Table E-9, a total of five survey personnel were involved in the data collection. Survey personnel #1, #3, and #4 observed and subjectively estimated the traffic conditions at locations RTMS-1, RTMS-2, and RTMS-3 throughout the evaluation period. The traffic condition could be stop-and-go, slow traffic (at a speed below 20 mph), or smooth and free flow. If a “stop and go” or “slow traffic” pattern was shown on any lane of an RTMS location, its traffic condition was regarded as “stop and go” or “slow traffic”. Survey personnel #2, #3, and #4 were asked to write down messages displayed on PCMS-1, PCMS-2, and PCMS-3. Survey personnel #5 was responsible for checking the status of all devices of CHIPS by remotely accessing the system from our lab. On September 6th, 2004, the system was operated from 11:20 to 22:12.

Table E-9 Data collection plan on September 6th, 2004

Survey Personnel	Location	Observation location	Tasks
1	RTMS-1	On the shoulder of the Old Road	1. Observe and write down the traffic condition at RTMS-1 with time stamp
2	PCMS-1 on SR126	On the shoulder side of EB 126	1. Write down messages shown on PCMS-1 with time stamp
3	PCMS-2 / RTMS-2	On the shoulder of the Old Road	1. Observe and and write down the traffic condition at RTMS-2 with time stamp 2. Write down messages shown on PCMS-2 with time stamp
4	PCMS-3 / RTMS-3	From a car parked on the shoulder of SB I-5.	1. Observe and and write down the traffic condition at RTMS-3 with time stamp 2. Write down messages shown on PCMS-3 with time stamp
5	UCI Lab	UCI Lab	Remotely access the system every 5 minutes: 1. Check status of sensors 2. Check messages showing on PCMSs

E.3.2.2 Reliability in detecting traffic congestion

The subjective estimation of traffic conditions at three RTMS locations are shown in Figure E-3. It was presumed that both “slow traffic” and “stop-and-go” were regarded as

the “tripped” state. As a result, the observed traffic condition scenarios are shown in Table E-10.

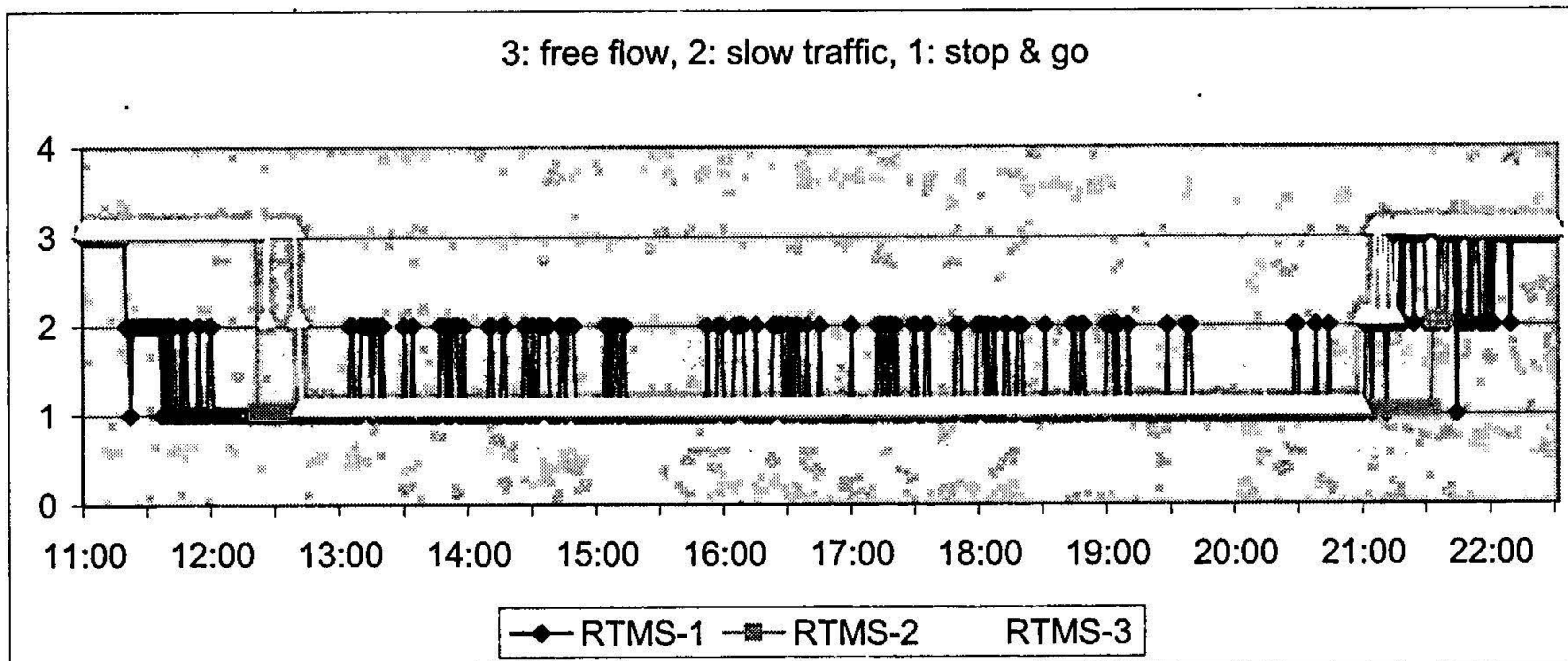


Figure E-3 Subjective estimate of traffic condition on Sep 6th, 2004

Table E-10 Observed traffic scenarios based on subjective estimate of traffic condition

	RTMS-1	RTMS-2	RTMS-3	Scenario
11:20 - 12:22	T	F	F	SBS02
12:22 - 12:40	T	T	F	SBS03
12:40 - 21:06	T	T	T	SBS04
21:06 - 21:39	T	T	F	SBS03
21:39 - 22:10	T	F	F	SBS02

According to the observed messages displayed on PCMSs and the pre-specified traffic scenarios shown in Table E-2, the detected traffic states at three RTMSs over the day were deduced, as shown in Figure E-4. Compared to the observed traffic states shown in Table E-10, it was found that the percentages of correct detection by RTMS-1, RTMS-2, and RTMS-3 are 99%, 95.6%, and 52.5%. RTMS-3 had problem to detect traffic congestion correctly. According to the field observation, the corresponding location of RTMS-3 started having congestion at 12:40. However, RTMS-3 did not detect it until 13:07. During the traffic congestion from 12:30 to 21:00, RTMS-3 frequently detected the “clear” state although the congestion was still on-going.

Accordingly, the traffic condition scenarios detected by CHIPS over the day were derived. Figure E-5 compares the detected traffic scenarios and the observed scenarios. It is found that CHIPS detected traffic condition scenarios accurately for 59% of the evaluation period.

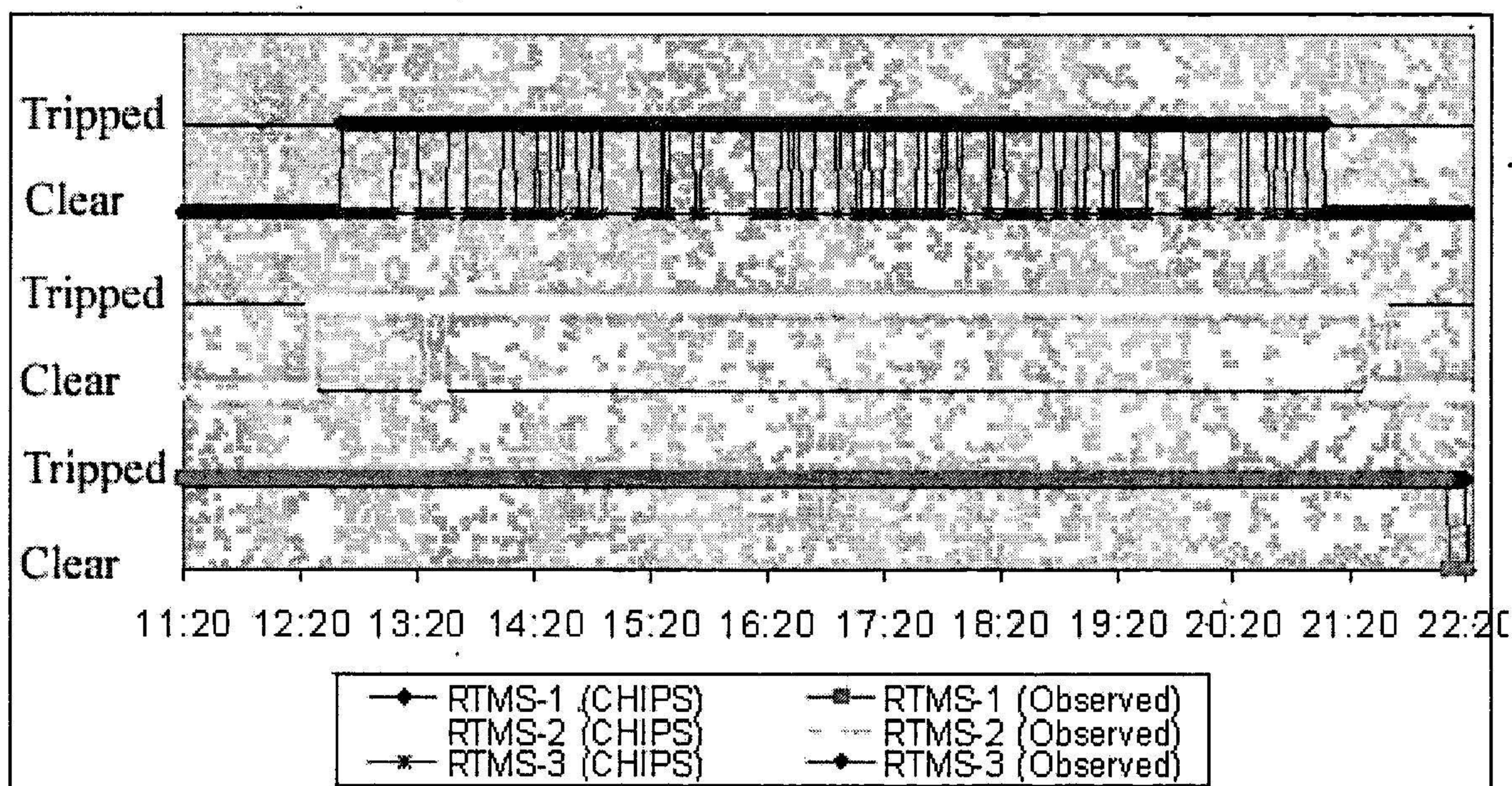


Figure E-4 Traffic condition detected by CHIPS and observed by surveyors

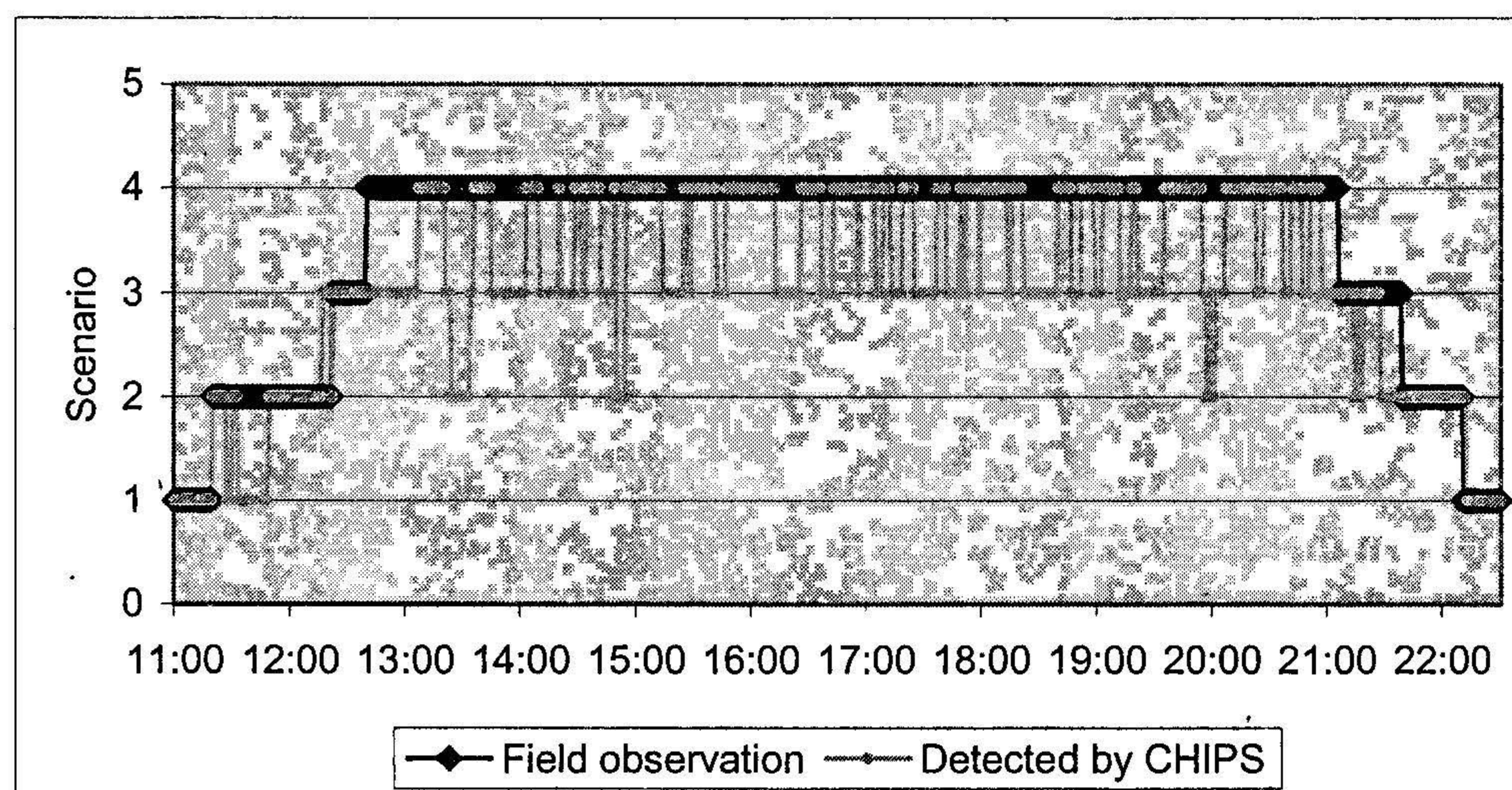


Figure E-5 Comparison of detected and observed traffic scenarios

E.3.2.3 Reliability in conveying accurate information

In this subsection, we will check (1) whether the system is capable of conveying expected information to travelers via message signs; (2) whether the system is capable of conveying accurate traffic management condition to operators by remotely accessing the CHIPS software.

As described earlier, the survey personnel #5 remotely accessed the system (i.e. the CHIPS software) every five minutes to check the status of all RTMSs and messages shown on PCMSs. The main window of the CHIPS software shows a geographical map of the work zone area, which dynamically displays the states of RTMSs and messages on

PCMSs. This is a significant feature, which makes it possible for traffic operators to monitor traffic conditions and traffic management in the work zone area.

Based on the states of all three RTMSs shown from the CHIPS software, messages of the corresponding traffic scenarios should be observed in the field. It was found that messages shown in the field exactly matched the messages that should be shown. It implied that the system has no communication failure between the control center and the PCMSs. The system showed correct messages to travelers on September 6th, 2004.

The graphical interface of the CHIPS software could not correctly show messages displayed on PCMSs in the field. Only truncated messages or unrecognized characters could be observed from the GUI of the CHIPS software. The truncated messages seemed to be part of the actual messages displayed in the field. The percentage of time for the system to show truncated messages and unrecognized messages were 23% and 77% respectively based on our observation. Possible reasons for the problem might be (1) communication failure; (2) software problem.

E.3.3 Reliability of system hardware and software

The system did not work automatically at the beginning of its operation (i.e. from May 2003 to October 2003). An important fine-tuning process was conducted from Oct. to early Dec. in 2003, involving the improvement of the zone setup and re-calibration of the queue detectors, the system could finally worked automatically, but the system still had occasional hardware problems arising.

Based on emails among the evaluation team, Caltrans, and the vendor from April 2003 to September 2004, Table E-11 illustrates problems the system experienced during the evaluation period. The table also provides the possible reasons of these problems, some of which are based on the explanation of the vendor and others are based on our engineering judgment.

E.3.3.1 Main part of CHIPS

The main part of CHIPS includes the traffic detection using RTMSs, traffic information display on PCMSs, and the CHIPS software. There are three aspects of problems:

(1) Inaccurate setup and calibration of RTMSs.

Accurate traffic congestion detection by RTMS is most important to the correct operation of CHIPS. The performance of RTMS depends on the zone setting and its calibration. How to setup the zones of an RTMS is an issue of the system. Before Oct 2003, each RTMS only had one detection zone, covering four lanes of mainline freeway. Because of system operation failure, the vendor setup three zones for each RTMS after November 2003.

It was found that the vendor did not spend time to calibrate RTMSs. Based on an RTMS manual from the manufacturer, EIS, volume calibration (or count verification) and speed calibration is required for correctly setting up an RTMS. For this system, presence data is used to detect whether the traffic is slow, thus, accurate presence measurements are required. The presence data actually corresponds to the time occupancy (or speed) data collected by RTMS. Consequently, if volume and speed are calibrated then RTMS can measure presence correctly. Although the method to calibrate the count and speed of an RTMS is provided in the RTMS manual from EIS, the vendor did not go through the process.

Based on CHIPS' method to detect traffic congestion, the local parameter, on-delay, of each queue trailer also needs to be well calibrated. The on-delay setting needs to be set to a value that represents a traffic congestion level expected to be detected for traffic management. On-delay was originally set to 7 seconds. Based on the study of the accuracy of traffic detection conducted on July 6th, 2003, RTMS-1 detected traffic congestion from 11:33 to 19:24 but the actual congestion period was from 10:30 to 21:13. It implies that the on-delay setting underestimates the traffic congestion. The incorrect on-delay setting continued to be effective until Dec 5th, 2003, when the vendor reset the parameter to 4 seconds. The 4-second setting was proved to work well for RTMS-1 and RTMS-2 based on data collected on Sep 6th, 2004. The vendor explained that the new setting (i.e. 4 seconds) could detect the slow traffic, approximately 20 MPH or less. The previous setting (i.e. 7 seconds) was set to read only stopped vehicles. The vendor did not explain whether a calibration method was used to establish the relationship between the on-delay setting and the traffic speed.

Based on the observation on September 6th, 2004, RTMS-3 still had some problems to detect traffic congestion. The evaluation team thinks a calibration process for RTMS-3 may help.

(2) Communication failure

PCMSs of CHIPS use a directional antenna to communicate with the command center through the 450MHz radio network. If the PCMS trailer is moved for whatever reason, the communication between the command center and the PCMS will be lost. The communication failure between PCMSs and the command center occurred for several times during evaluation.

(3) Software error

The system software was found to have bugs during its first 7-month of operation. It seems to work fine after Dec 2003.

E.3.3.2 Video system

The video sub-system suffered from many problems since it started operation. It turned out to be the most unreliable part of the CHIPS system. As shown in Table E-11, the major problems are:

(1) Controlling the video camera was difficult

The explanation from the vendor is that the video system was sensitive to other radio frequencies that would interfere with the video control.

(2) Solar power supply problem

During the period from November 2003 to May 2004, the three cameras did not work for most of time due to the solar power supply problem.

(3) AXIS video server

The real reason for the video system was not fully discovered since the evaluation team did not have the expertise. It seems that the AXIS video server might need to take some responsibilities for the poor performance. The vendor reported that a new AXIS video server was replaced with the old one.

Table E-11 Experienced problems of CHIPS during evaluation

	Date	Problem	Possible reasons
Main part of CHIPS	5/26/2003	PCMSs displayed incorrect messages	Inaccurate RTMS setup and calibration
	5/31/2003	A PCMS on NB 5 flashing a message intended for SB direction	Inappropriate initial scenario setup
	7/3/2003	A PCMS continued to display messages long after free flow conditions were observed	System software error or communication failure
	7/6/2004	(1) PCMS-3 showed no message during the system's operation. (2) RTMS-2 was not triggered.	(1) Communication failure; (2) RTMS hardware problem.
	8/17/2003	System crash when a new scenario that was not in Caltrans' list is detected.	Software error
	9/1/2003	(1) When Scenario SBS002 was observed, messages of SBS003 were displayed; (2) RTMS-2 was not triggered during traffic congestion; (3) System crashed when a new scenario is detected (same problem happened at Aug 17th, 2003).	(1) Software error (2) RTMS hardware problem; (3) Software error.

	10/10/2003	PCMSs were not checked in by the system.	Communication failure
	11/26/2003	PCMSs were either blank, turning on for short periods of time then turning off, or displaying incorrect scenario messages.	(1) Inaccurate RTMS setup and calibration; (2) Software error.
	6/30/2004	PCMS-2 did not work	Cable onnection problem
	9/6/2004	(1) RTMS-3 did not detect traffic congestion accurately; (2) Email notification of congestion does not work.	(1) Inaccurate RTMS setup and calibration (2) SMTP server problem
Video system	4/3/2003	Intermittent PTZ control problems with surveillance videos	Radio frequency interference
	5/12/2003	(1) Slow video (2) CCTV #3 did not operate properly	(1) Slow Internet connection (2) The wind moved the antenna
	6/24/2003	"VIDEO ALL" button doesn't work well	AXIS video server problem
	6/24/2003	PTZ control problem	Radio frequency interference
	8/18/2003	(1) Video preset did not work properly; (2) Video 3 was down.	AXIS video server problem
	10/24/2003	Camera's #2 and #3 did not work	Solar power supply problem
	10/31/2003	Camera #3 was out of focus and out of control.	Power supply on the repeater
	11/13/2003	Camera #1 and #3 were bad	Solar power supply for the cameras
	12/1/2003	All cameras were down	Solar power supply for the cameras
	3/11/2004	Camera 3, which suffered from poor picture quality recently, was down.	Strong wind moved antennas
	4/7/2004	Camera #1 had no PTZ capabilities. Camera #2 was bad.	(1) Radio frequency interference; (2) Solar power supply problem.
	4/26/2004	(1) PTZ control problem with all cameras; (2) Camera #3 is down.	Solar power supply problem

E.3.4 Summary

CHIPS was found to have some technological problems, including inappropriate initial setting of the system, inaccurate setup and calibration of traffic sensors, communication failure, power and video system failure, sensor failure, and software error. After a period

of fine-tuning, the system had only occasional hardware and software problems arising. The observation conducted on Sep. 6th, 2004 showed that the system has the capability to respond to traffic congestion automatically but still suffered from the problem of detecting traffic congestion accurately at one of its sensor location. The video subsystem of CHIPS is a separate part of the system, which is what Caltrans likes to have. However, it was turned out to be the very unreliable.

E.4 Evaluation of Effectiveness

Because AWIS provides useful traffic information to motorists as they approach or pass through a work zone, its direct benefits include adjusting drivers' speeds, reducing their anxiety and increasing safety for both motorists and construction personnel. A potential benefit of AWIS is that it can enhance the efficiency of the traffic system by diverting some motorists who want to avoid delay to an alternative route. As a result, three aspects of effectiveness studies were conducted, including: (1) safety effects; (2) traffic diversion effects; (3) drivers' acceptance to the system.

E.4.1 Introduction

As described in E.1, the system did not work properly on both July 6th, 2003 and September 1st, 2003. Caltrans' personnel had to manually implement the desired traffic management scheme using their backup portable changeable message signs. Under these conditions, we evaluated the effectiveness of the CHIPS system.

We collected traffic data under the following two scenarios for the effectiveness study:

- (1) Use non-electronic (static) lane closure sign display only. No message displayed by the CHIPS system sign.
- (2) Use non-electronic (static) lane closure sign display, the CHIPS system displays multiple sequential advisory (including traffic information, delay advisory, and diversion message).

The first scenario is the "before" scenario and the second one is the "after" scenario, implementing the current traffic management plan shown in Table E-3.

District 7 has determined what messages should be shown under certain traffic conditions. We could not test scenarios with only delay advisory messages, speed advisory messages, and lane change advisory messages.

E.4.2 Safety

E.4.2.1 Collision analysis

To evaluate the safety effect of the CHIPS system, the direct MOE is the number of collisions. The comparison of the collision data before and after the use of the system can be used to discover its contribution to the safety. In order to obtain a statistical comparison, the traffic flows of both "before" and "after" scenarios should be comparable, and both scenarios should cover a certain length of time period.

1. Collision data from the TASAS database

We obtained traffic collision data from the Traffic Collision Surveillance and Analysis System (TASAS) database maintained by Caltrans. The database covers police-reported

crashes that occur on the California State Highway system and contains detailed information of each collision. The collision data analysis only used important information about each collision, including occurrence date and time, postmile location, type of collision, causes of collision, and number of parties (usually vehicles) involved. Table E-12 shows some sample collision data.

Table E-12 Sample collision data from TASAS database

PM	Location	DAY	Time	Factor	Type	# of vehicles
53.65	ml	1	8/5/2001 16:35	5	C	2
53.48	ml	6	8/17/2001 15:40	5	C	3
53.406	ramp	3	8/21/2001 6:35	6	B	2
53.653	ramp	5	8/23/2001 17:10	3	D	2
54.25	ml	6	8/24/2001 22:30	2	C	2

The time period of our collision dataset is from Aug 1st, 2001 to Dec 31, 2003. Due to the data processing delay for the TASAS database, we could not access newer data for the study. Since the work zone construction started on July 30th, 2002, the collision dataset can be thus divided into two basic categories: before construction and after construction. The "after construction" category can be further divided into two portions: "before the deployment of CHIPS" and "after the deployment of CHIPS".

Table E-13 Category of collision dataset

Category		Time period
Before construction		8/1/2001 – 7/30/2002 (12 months)
After construction	Before deployment of CHIPS	7/31/2002 – 6/29/2003 (11 months)
	After deployment of CHIPS	6/30/2003 – 12/31/2003 (6 months)

2. Methodology

The purpose of the collision data analysis is to investigate if the use of CHIPS can decrease collisions. As explained in Section D, traffic congestion in the work zone site occurs principally on holidays and some Sundays with high travel demands.

Correspondingly, the monthly collision rate varies with respect to the time of the year, as shown in Figure E-6, which is drawn based on all collision data. Before construction, the monthly collision rate was very low throughout the year and peaks in December and those months in summer. After construction, the collision rate increases and peaks in December and from April to August. Due to this seasonal factor, it is better to compare the collision data of the same month of different years instead of different months of the same year.

As shown in Figure E-1, the CHIPS system introduces some dynamic signs, PCMS-1, PCMS-2 and PCMS-3, to the traffic system. They are located on SR-126, north of junction SR-126 on I-5, and north of junction Hasley Canyon Rd on I-5, respectively. CHIPS generally have two working modes:

- (1) If traffic congestions are detected, CHIPS shows dynamic messages on its PCMSs;
- (2) If there is no traffic congestion, CHIPS shows no message on its PCMSs.

The following two analyses will be conducted:

- (1) The overall safety effect based on all collision data over the whole time period.
- (2) The safety effect during traffic congestion based on collision data occurred during traffic congestion.

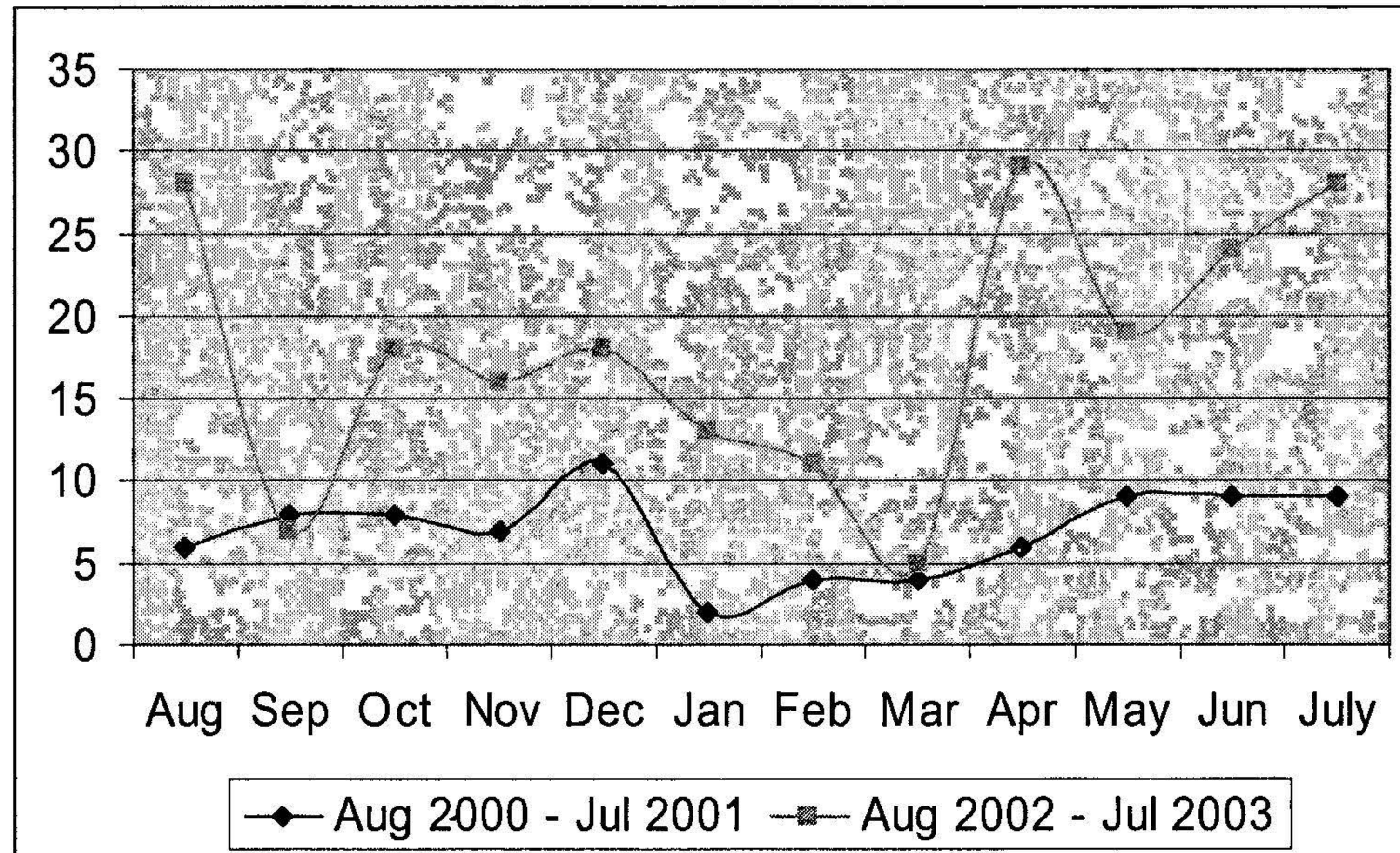


Figure E-6 Comparison of monthly collision rate before and after construction

A statistical analysis method is used to determine if the difference between before and after scenarios is statistically significant. We used the z statistic, computed as

$$z_1 = \frac{f_A - f_B}{\sqrt{f_A + f_B}}$$

z_1 is a test statistic representing the increase or decrease in collisions on the standard normal distribution, f_A is the number of collisions in the after scenario and f_B is number of collisions in the before scenario. If $P\{\text{abs}(z) < z_1\} \geq 0.95$, the difference between before and after scenarios is statistically significant at the 95% confidence level.

Based on the Standard Normal Distribution table, 95% of probability corresponds to a z_1 value of 1.645. Consequently, if z_1 is greater than 1.645, the increase of collisions is statistically significant at the 95% confidence level; if z_1 is lower than -1.645, the decrease of collisions is statistically significant with the 95% confidence level.

3. Determining the study area for collision data analysis

We first investigated which part of the target work zone site suffered from an unusually high collision rate due to the construction activity. As described earlier, the construction zone is located from postmile 54.5 to 53.0. The two PCMSs of CHIPS on I-5 south are located at postmile 55.75 and 56.95.

Based on collision data covering the postmile range from 52 to 58, Figure E-7 graphically compares the annual collision rate along the southbound I-5 construction zone before and after the construction activity. Table E-14 summarizes the results of the statistical analysis. It is shown that more collisions occurred between 55.4 and postmiles 53.8, corresponding to the section from the upstream of SR-126 interchange to the downstream of the Rye Canyon interchange, and between 56.2 and 56, corresponding to the downstream of Hasley Canyon Rd interchange. As a result, the collision data between postmile 56.2 and 53.8 were chosen for further analysis, as illustrated in Figure E-8.

Table E-14 Comparison of annual collision rate on each sub-section

Postmile range	Before construction	After construction	Statistic z
52-52.2	0	1	1.19
52.2-52.4	5	1	-1.42
52.4-52.6	6	8	0.48
52.6-52.8	2	4	0.65
52.8-53	0	1	0.84
53-53.2	1	2	0.63
53.2-53.4	2	1	-0.32
53.4-53.6	10	13	0.57
53.6-53.8	14	24	1.62
53.8-54	4	11	1.72
54-54.2	5	23	3.44
54.2-54.4	12	53	5.08
54.4-54.6	5	18	2.66
54.6-54.8	0	6	2.52
54.8-55	0	4	2.06
55-55.2	0	5	2.22
55.2-55.4	0	5	2.22
55.4-55.6	1	4	1.19
55.6-55.8	2	1	-0.32
55.8-56	2	0	-1.41
56-56.2	0	4	2.06
56.2-56.4	1	1	-0.23
56.4-56.6	1	1	0.27
56.6-56.8	4	4	0.08
56.8-57	2	1	-0.32
57-57.2	2	2	0.06
57.2-57.4	0	0	n/a
57.4-57.6	1	1	0.27
57.6-57.8	1	1	-0.23
57.8-58	0	0	n/a

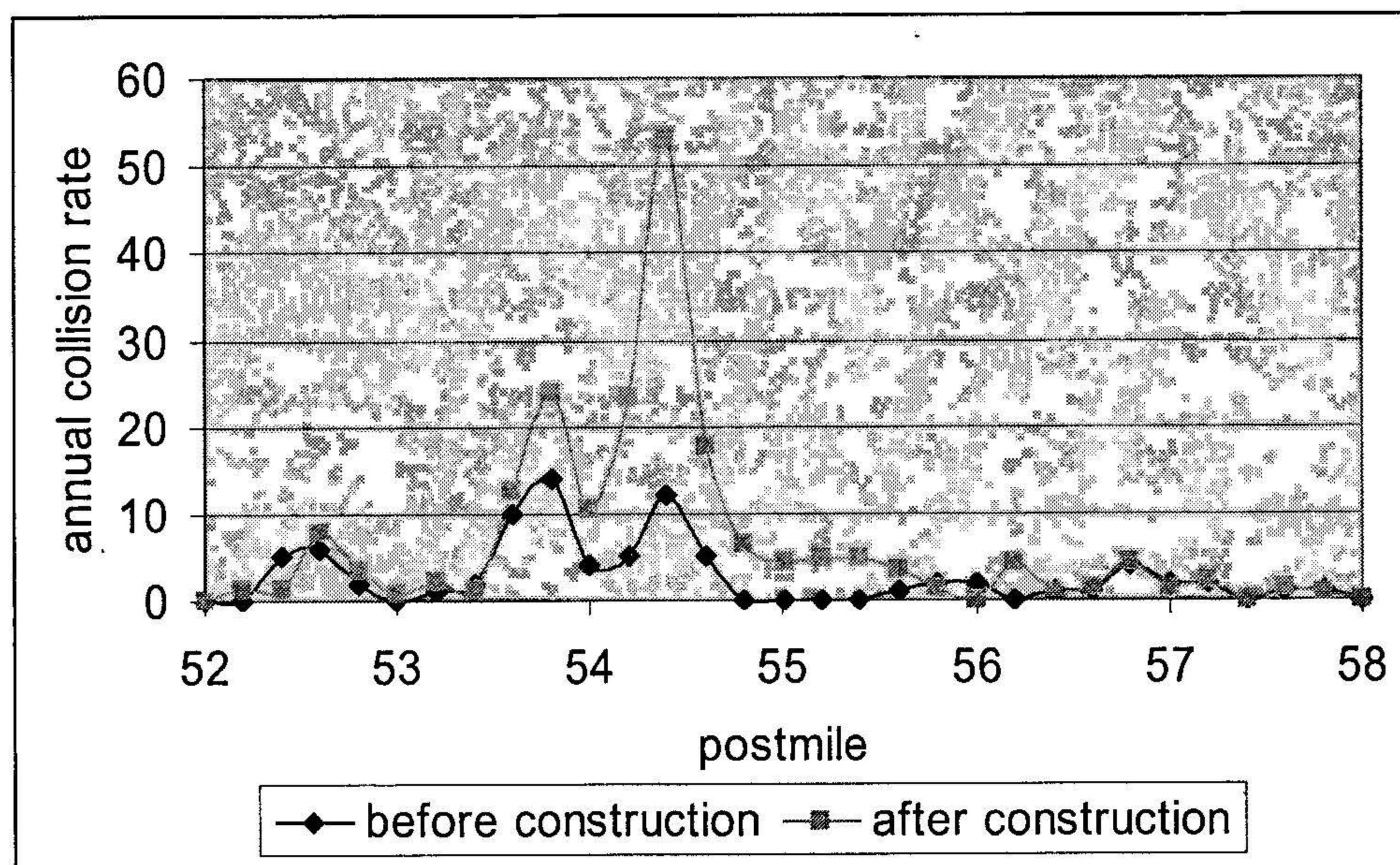


Figure E-7 Comparison of annual collision rate along the southbound I-5 construction zone before and after the construction activity

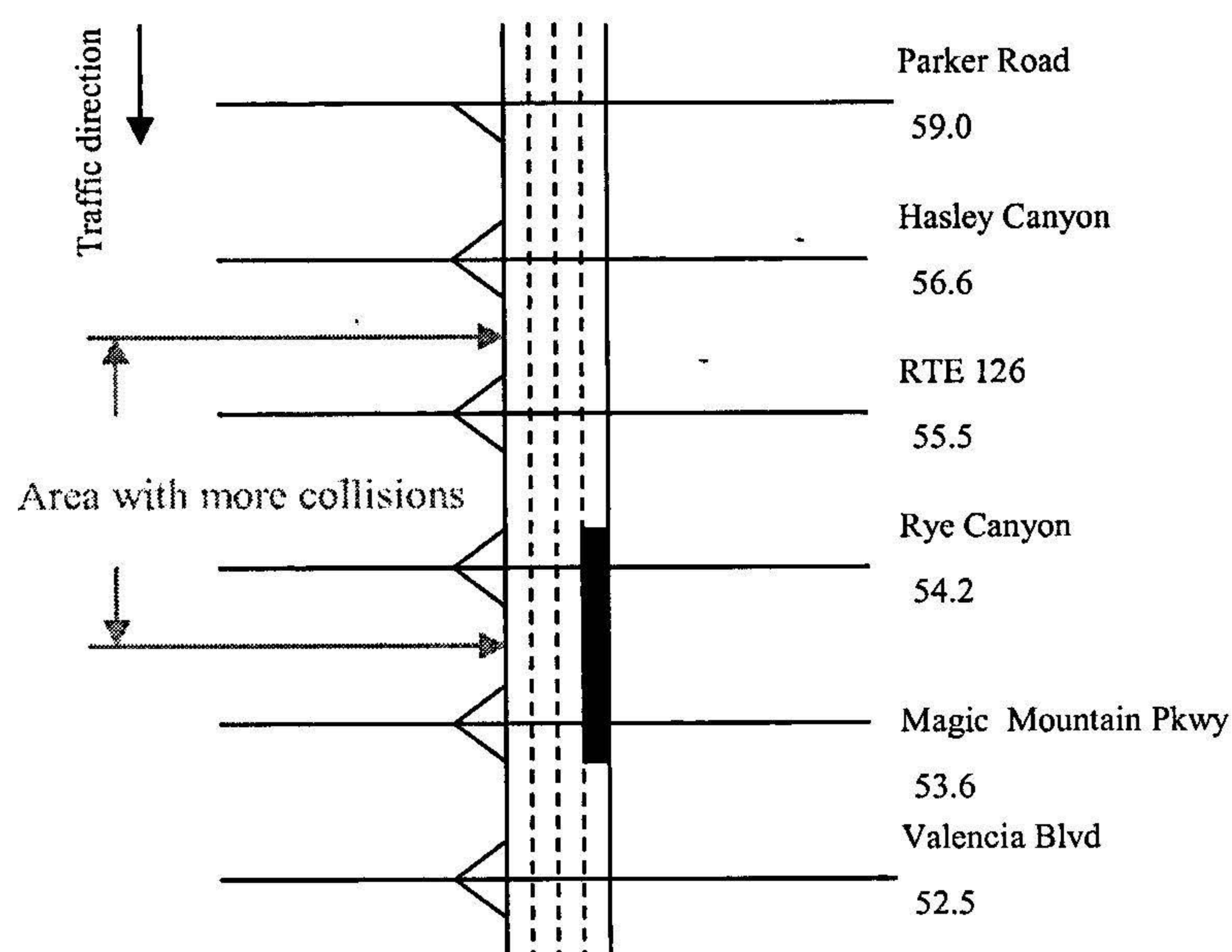


Figure E-8 The target work zone site

The value of the z statistic represents the correlation between the number of collisions on the subsection and the work zone construction. The larger the z statistic is and the greater the correlation is. Consequently, Table E-14 implies that the vicinity of the starting point of the construction (i.e. postmile 54.5), especially downstream of the starting point (i.e. from postmile 54.2 to 54.4), experienced the most significant increase of traffic collisions.

4. Overall safety effect

Due to the construction schedule, the lane drop configuration at the starting point of the work zone experienced a change on Sep 22nd, 2003. As shown in Figure E-9, there was a lane drop on the left side of the driving direction from July 31st, 2002 to Sep 22nd, 2003. Traffic on two leftmost lanes needed to merge together. Starting from Sep 22nd, 2003, southbound I-5 was re-stripped to three through lanes and one exit only lane to Rye Canyon Rd.

Because of the re-striping, the collision data for the "After deployment of CHIPS" scenario is divided into two portions:

- (1) "after 1" scenario: from June 30th, 2003 to September 22nd, 2003 (after use of CHIPS but without re-striping)
- (2) "after 2" scenario: from September 23rd, 2003 to December 31st, 2003 (after use of CHIPS and re-striping)

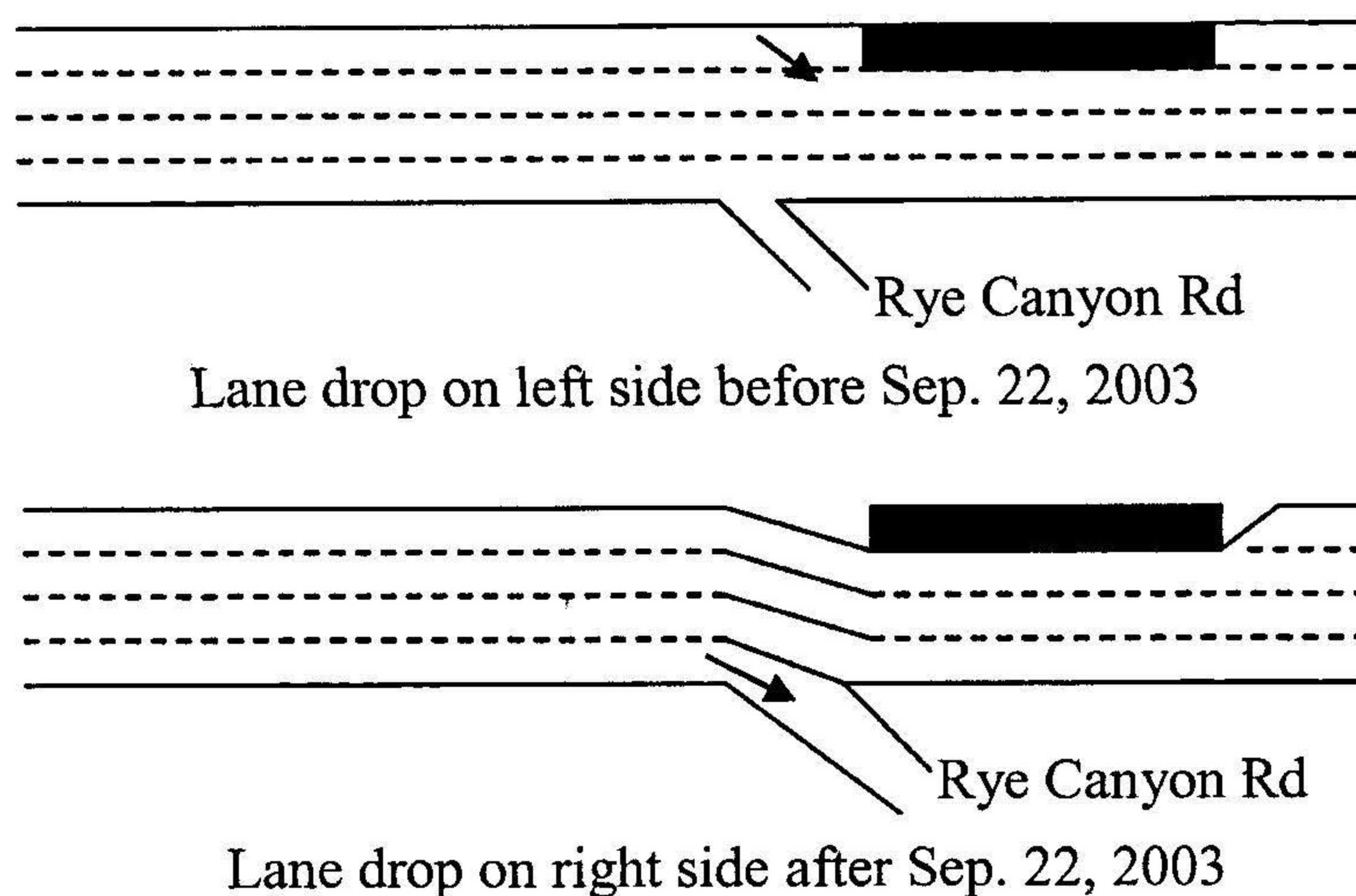


Figure E-9 Lane closure layout at the starting point of the work zone

Table E-15 shows the number of collisions between August and December in 2002 and 2003. Data for 2002 correspond to the scenario, "Before deployment of CHIPS." Data for 2003 correspond to the scenario, "After deployment of CHIPS." With respect to the 95% confidence interval, the total collision number is reduced significantly in 2003. The monthly collision rate is only reduced significantly in October and December.

Table E-15 Collision data occurred on the study area of collision analysis

	Year 2002 (before)	Year 2003 (after)	(After-before) / before * 100	Statistics z
Aug	23	22	-4.3%	0.15
Sep ¹	4	5	25.0%	-0.33
Oct ²	9	2	-77.8%	2.11
Nov	9	7	-22.2%	0.50
Dec	12	4	-66.7%	2.00
TOTAL	57	40	-29.8%	1.73

1. Time period is from Sep 1st to Sep 22nd.
2. Time period is from Sep 23rd to Oct 31st.

Table E-16 further explains that the “before” and “after 1” scenarios have the same level of collision rate and collisions are effectively reduced after the use of CHIPS and lane re-striping.

Table E-16 Analysis of collision data occurred in the work zone site

Study	Time periods for “before” and “after” scenarios	Number of collisions	(After-before) / before * 100	Significant?
1	Aug and Sep of 2002 (before)	27	0%	No
	Aug and Sep of 2003 (after 1)	27		
2	Oct, Nov, and Dec of 2002 (before)	30	-56.7%	Yes
	Oct, Nov, and Dec of 2003 (after 2)	13		

Although the total collision number in 2003 is decreased significantly, we could not draw the conclusion that the use of CHIPS could decrease collisions in the work zone site because statistically significant decrease in collision rates occurred only after the lane drop re-striping.

5. Collision rate during traffic congestion

The next study will attempt to see if CHIPS can reduce collision rates during congested periods. As found earlier, the work zone site only has traffic congestion on holidays and some Sundays. In the event of traffic congestion, CHIPS is designed to show messages on its PCMSs. These messages may improve the safety conditions in the congested areas resulting from the work zone.

Traffic Management Team (TMT) of District 7 conducted on-site traffic condition observations for every holiday after construction began. During our study period, i.e. from August to December, there are three major holidays, Labor Day, Thanksgiving, and Christmas. The traffic condition reports for these three holidays in 2002 and 2003 are shown in Table E-17, which provides time periods of traffic congestion. It is noted that the Labor Day (Sep 2nd, 2002) in 2002 had a bush fire occurred in the study area and thus TMT did not provide a report for the day with serious congestion.

Table E-17 Summary of traffic condition observations conducted by District 7

		Date	Congestion period (hr)	Maximum queue (mile)	Maximum delay (min)
Labor day	2002 (before)	08/30/2002	15:00 - 16:30	2	4
		08/31/2002	10:00 - 14:30	1	3
	2003 (after)	8/29/2003	14:00 - 18:00	1.5	3
		8/30/2003	9:45 - 13:15	2.2	5.5
		9/1/2003	11:00-22:40	10	33

Thanksgiving	2002 (before)	11/27/2002	10:30 - 20:30	5.5	24
		11/28/2002	10:00-15:00	4	10.5
		11/29/2002	14:15-18:00	2	4
		11/30/2002	12:00-18:00	5	13
		12/1/2002	11:00 - 21:30	12	36
Christmas	2003 (after)	11/26/2003	11:00 - 21:30	6.5	35
		11/30/2003	11:00 - 21:00	7	23
	2002 (before)	12/24/2002	13:45 - 17:15	1.5	3
		12/26/2002	11:45 - 19:30	4.5	16
		12/28/2002	12:30 - 19:45	4.5	27
	2003 (after)	12/28/2003	12:45 - 17:30	4.8	15.5

If the start time of a collision is within the congestion period listed in Table E-17, it is regarded as a collision that occurred during traffic congestion. As illustrated in Table E-18, a total of 14 collisions were found during traffic congestion and the type of all collisions is type C, corresponding to rear-end collision. The major factor of these collisions is either 5 (corresponding to "speeding") or 2 (corresponding to "following too close").

Table E-18 Collision happened during traffic congestion

PM	RAMP	DAY	TIME	FACTOR	TYPE	# OF VEH
54.59	ml	7	8/31/2002 10:18	5	C	3
54.29	ml	7	8/31/2002 11:45	5	C	3
54.95	ml	7	8/31/2002 13:45	5	C	4
54.15	ml	4	11/27/2002 14:40	5	C	3
54.29	ml	4	11/27/2002 20:10	5	C	3
55.44	ml	5	11/28/2002 12:44	5	C	2
54.39	ml	3	12/24/2002 15:43	2	C	2
54.2	ml	5	12/26/2002 12:20	5	C	2
53.84	ml	6	8/29/2003 15:25	5	C	3
54.21	ml	6	8/29/2003 17:00	5	C	2
54.99	ml	2	9/1/2003 17:10	5	C	2
54.2	ml	4	11/26/2003 13:10	5	C	2
54.21	ml	7	11/29/2003 13:44	5	C	3
54.39	ml	1	11/30/2003 14:40	2	C	4

Data shown in Table E-17 and E-18 were processed to form Table E-19. In these three holidays, the congested hours before and after the use of CHIPS were different. As a result, the collision rate, i.e. collision per hour, was used to compare the collision rate before and after the use of CHIPS. The statistic z was calculated based on the number of collisions after the use of CHIPS and the standardized number of collisions before the use of CHIPS with respect to congested hours after the use of CHIPS. It is found that the use of CHIPS results in lower collision rates occurred in Labor Day and Christmas holidays. But, the reduction of collision rate is significant for the Labor Day holiday. For the

Thanksgiving holiday, there is a higher collision rate in 2003, but the increase of the collision rate is not significant.

Obviously, the above collision analysis suffers from problems of short time periods and few collision data points. The statistical decision concluded based on the insufficient collision data is not persuadable. In next subsection, we will investigate CHIPS' effects on traffic flow, as "indirect" alternatives in the analysis of freeway traffic collision propensities.

Table E-19 Comparison of collisions occurred during traffic congestion in holidays

	before CHIPS			after CHIPS			(After-before) * 100 / before	Statistic z
	Cong. hours	# of collision	collision / hour	Cong. hours	# of collision	collision / hour		
Labor	6	3	0.50	19.17	3	0.16	-68.7	-1.86
Thanksg.	35.25	3	0.09	20.5	3	0.15	72.0	0.58
Christmas	11.25	2	0.18	12	0	0.00	-100.0	-1.46
total	52.5	8	0.15	51.67	6	0.12	-23.8	-0.50

6. Summary

Based on the above collision analysis, we conclude that the current deployment of CHIPS did not improve driver safety in the work zone site. Our conclusion is based on the comparison of 5-month collision data before and after CHIPS deployment. During the ten-month span of collision data, only 14 collisions were verified to have occurred during congested periods. Because there were relatively few data points to analyze, the safety effects of CHIPS during traffic congestion might have not been fully discovered.

E.4.2.2 Effects on traffic flow

During our evaluation period, the CHIPS system only worked for very limited percentage of time and as a result, we plan to use other MOEs that can be used as "indirect" alternatives in the analysis of freeway traffic incident propensities. A study showed that fatal incidents increase with higher speed limits¹¹. Based on our previous research, a major factor leading to collision is the variation of speed. It was found that reducing the speed variation increases safety and reduces the likelihood of a collision¹². Thus, vehicle speed and the variance in speed between vehicles may also be good MOEs for the safety study. Other research on traffic flow characteristics at freeway work zones found that the presence of a police patrol car on the shoulder of a busy freeway can stabilize the

¹¹ Raju, S., R. Souleyrette, and T.H. Maze. Impact of 65-mph speed limit on Iowa's rural interstate highways. In *Transportation Research Record 1640*, TRB, National Research Council, Washington, D.C., 1992, pp. 47-56

¹² Oh, C., Oh, S., Ritchie, S. and Chang, M. (2001) Real-time Estimation of Freeway Accident Likelihood, presented at TRB 2001

fluctuation of traffic flow by reducing both headway and the variability of headways¹³. As a result, headway and its variance may also be effective MOEs in the study of safety.

Unfortunately, the collection of speed and headway data of all vehicles in the field is impossible for this evaluation study. Instead, we will investigate the effects of the CHIPS system on the following traffic flow parameters:

- (1) Traffic volume
- (2) Traffic volume variance
- (3) Sample speed mean
- (4) Variance of speed samples

The parameters above can be used to represent headway, variability of headways, speed and speed variance, respectively.

1. Data collection

Traffic count and speed data were collected using Jamar DB-100 counters and Bushnell Speed Guns at two measurement locations where RTMS-1 and RTMS-2 are located, as shown in Figure E-10. The traffic count and speed data were collected at the same time, for a length of 30 minutes for both before and after scenarios. When we collected data at these two locations, the freeway traffic had been queued back to the far upstream of RTMS-2 location. As a result, we collected traffic data under queued traffic condition.

The traffic count and speed data for the after scenario were collected between 16:53 and 19:31 on September 1st, 2003, during the Labor Day holiday. The traffic data of the before scenario were collected between 17:30 and 20:40 on August 17th, 2003, which was a Sunday during the summer. The CHIPS system stopped working at 15:53 because of a software conflict problem and all PCMSs were blank afterwards. This was the condition without CHIPS, which is regarded as the before scenario.

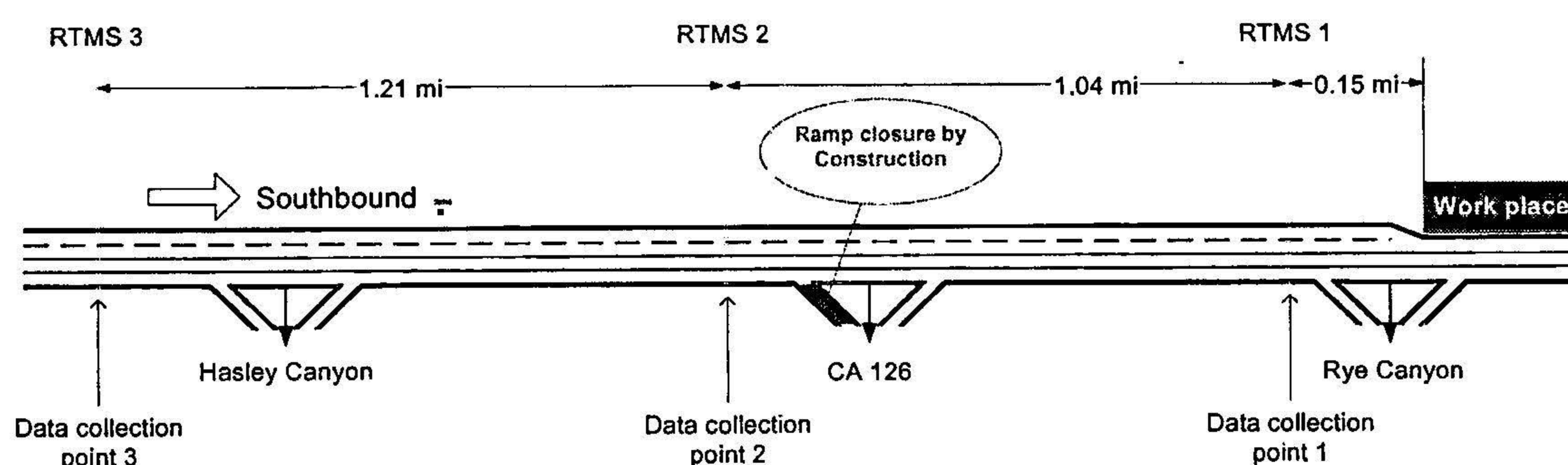


Figure E-10 Data collection points

¹³ Polus, A. and Schwartzman, Y. (1999) Flow characteristics at freeway work zone and increased deterrent zones. Transportation Research Record 1657, pp. 18-23

The collected traffic count data were used for the analysis of traffic volume and traffic volume variance. The collected speed samples were used for speed mean and speed variance analysis.

2. Traffic volume

Table E-20 shows the lane-based traffic volumes at two measurement locations. Lane 1 represents the innermost lane. Based on t-tests, significant differences (with 95% confidence interval) between before and after volumes were observed at lane 1 of RTMS-1. Based on lane-based volume data, the before-after lane distributions at two locations were obtained, as shown in Figure E-11.

Table E-20 Traffic count data collected at three locations

Lane	Location 1		Location 2	
	Before	After	Before	After
1	386	466	517	479
2	487	482	509	478
3	682	680	520	487
4	612	656	522	488
Total	2167	2284	2068	1932

■ : Difference between before and after values is significant (95% confidence interval)

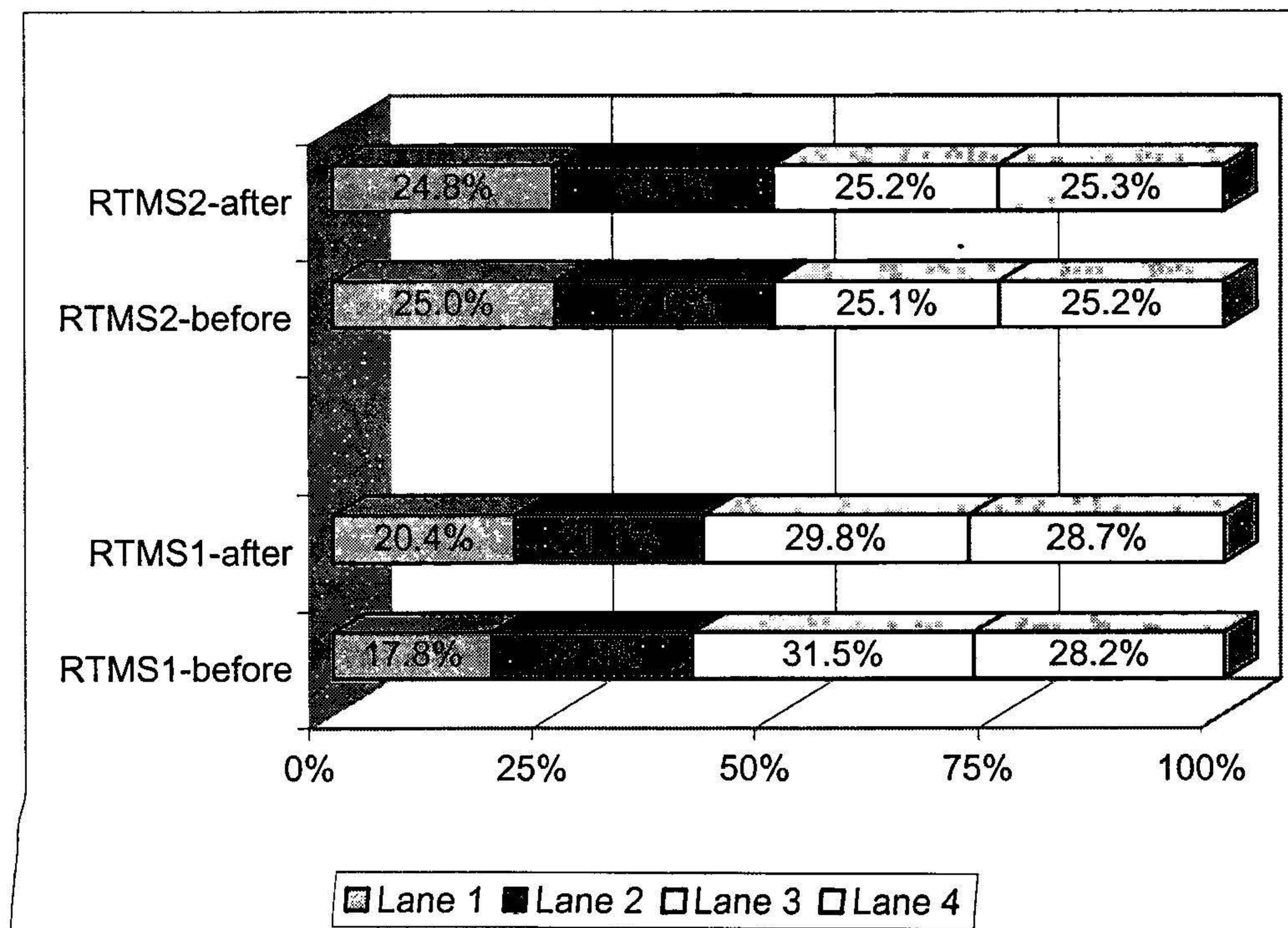


Figure E-11 Comparison of lane distributions at three measurement locations

The location 1 (RTMS 1) is related to an off-ramp and thus its traffic volume is greatly affected by the off-ramp traffic. RTMS-1 is only 0.15 miles upstream of the work zone.

Vehicles in lane 1 were required to merge to lane 2 because of the lane drop. CHIPS did not provide any lane closure information via PCMSs. Under both before and after scenarios, motorists obtained lane drop information from static signs, located prior to the RTMS-1 location. Compared to the before scenario (386 vehicles, corresponding to 17.8%), higher traffic volume was found on lane 1 under the after scenario (466 vehicles, corresponding to 20.4%). Almost the same number of vehicles took lane two for both before and after scenarios. This indicates that higher traffic volume was obtained on the mainline at RTMS-1 under the after scenario. The reason might be that a more stable traffic flow resulted because of CHIPS.

As shown in Figure E-11 and Table E-20, the traffic flow volume evenly distributed on each lane for both before and after scenarios at RTMS-2. This is because RTMS-2 is located at a place with less traffic weaving.

3. Traffic volume variance

Since both before and after scenarios were under congested traffic conditions, the variance of traffic volume can thus be used as a measure of the stability of queued traffic volume. Table E-21 shows the variances of lane-based traffic volumes and grouped traffic volumes based on 1-minute traffic volume data.

An F-test was conducted to see if the differences between variances of the before and after scenarios were significant (with 90% confidence interval). For the grouped traffic volume data, the difference of variance was significant at RTMS-1, which means that the variance of the after scenario was statistically smaller than that of the before scenario. For lane-based variance traffic volume data, the significant differences of variances were found for lane 1 and lane 2 at RTMS-1. These volume variance results suggest that traffic volume at RTMS-1 under the after scenario was more stable. The possible reason may have been that the messages on the portable signs made motorists drive more carefully and made them more aware of the static signs showing the lane drop information.

Table E-21 Volume variance study results

		Lane 1	Lane 2	Lane 3	Lane 4	Total
RTMS-1	Before	11.6	15.7	3.4	7.8	44.9
	After	6.5	6.3	4.5	7.6	25.4
RTMS-2	Before	4.4	2.8	3.9	1.8	37.4
	After	4.2	4.6	4.3	2.4	31.2

■ : Difference between before and after values is significant (90% confidence interval)

4. Speed mean and variance

Literature reviews show that the mean driving speed is an appropriate measure of safety. The variance of speed is also an appropriate measure of the stability of traffic flow. A lower value of speed variance represents a more stable traffic condition.

Table E-22 summarizes the statistics of the speed sample data collected during the same time periods as those of traffic volume data, and Figure E-12 shows the distribution of speed data at the two measurement locations graphically.

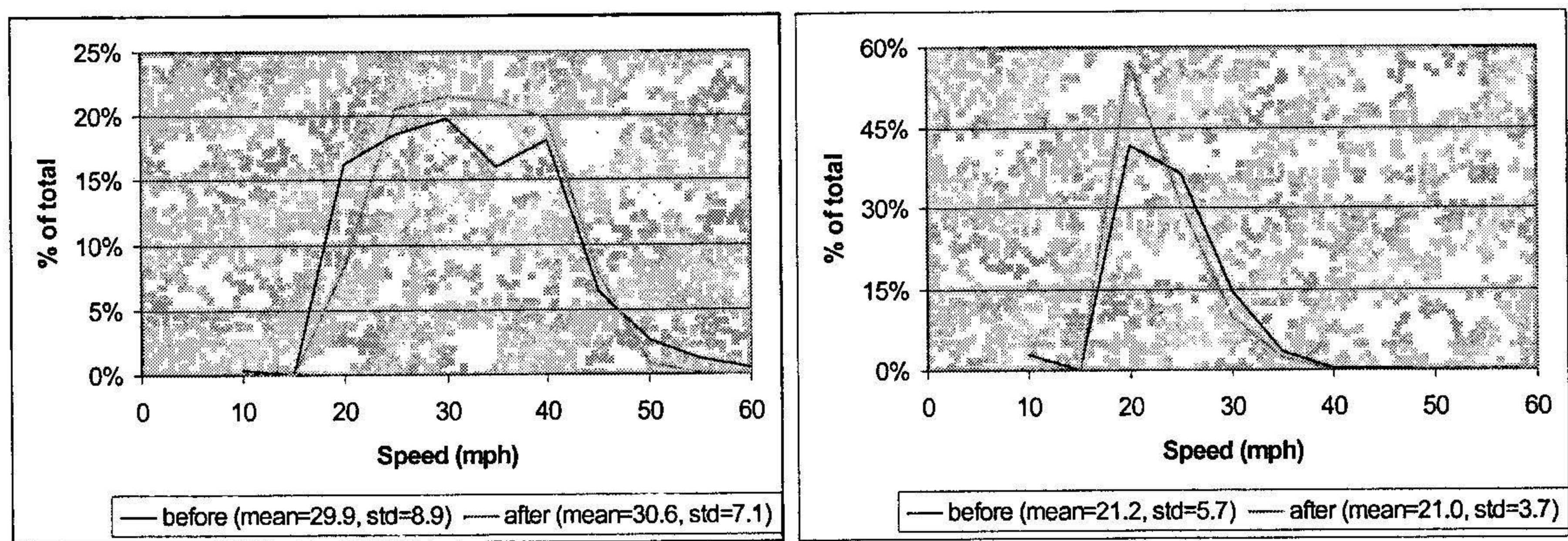
Table E-22 Speed mean and variance

		# of samples	Sample Mean	Standard deviation	Sample variance
RTMS 1	Before	979	29.9	8.9	80.0
	After	970	30.6	7.1	50.2
RTMS 2	Before	1186	21.2	5.7	32.4
	After	993	21.0	3.7	13.5

■ : Difference between before and after values is significant (95% confidence interval)

To statistically compare speed variances of two populations for the before case and after case, an F test was conducted. F test results showed that the speed variances of the after scenario were significantly smaller than those of the before scenario at two measurement locations. This result implies that the traffic condition under the after scenario was more stable than the before scenario.

Based on Z-test results, the average speeds at RTMS-1 and RTMS-2 were statistically the same for both before and after scenarios. This indicated that there were no driving speed difference between the before and after scenarios at RTMS-1 and RTMS-2, although a smoother traffic condition was obtained at these two locations based on the analysis on the speed variance data.



(a) RTMS-1

(b) RTMS-2

Figure E-12 Speed distribution at three measurement locations

5. Summary

The impact of the CHIPS system on traffic flow was investigated under before and after scenarios using measures of traffic volume, variance of traffic volume, sample speed mean, and variance of speed samples. The study on traffic throughput showed that a higher throughput was achieved on the freeway mainline under the after scenario. The reason for the higher throughput was that a more stable traffic condition was obtained.

Two measures, variance of speed and variance of traffic volume, were used for the study on the stability of the traffic flow. The variance of speed might also be an appropriate measure of traffic flow stability. However, we only collected speed samples of vehicles on the two rightmost lanes yet, we calculated the variance of traffic volume, which covers all lanes of freeway. Eventually, both of the two studies showed the same result: the traffic flow under the after scenario was more stable than the before scenario.

E.4.2.3 Summary

Although the use of CHIPS did not decrease number of collisions based on limited collision data, the driving environment after the use of CHIPS seemed safer according to the studies on a set of safety-related traffic flow parameters.

E.4.3 Diversion

As shown in Figure E-1, I-5 has one alternative route, the Old Road, in the work zone area. If there is congestion on the southbound approach to the work zone, the use of CHIPS may have diversion effects. Vehicles on the southbound I-5 may take the Old Road via the Hasley Canyon Rd off-ramp or Lake Hughes Rd off-ramp. Vehicles on the eastbound SR-126 may take the Old Road via the Castaic Junction/Henry Mayo off-ramp. These diverted vehicles heading for I-5 southbound may take two on-ramps at Magic Mountain Blvd and Valencia Blvd to travel back to the I-5 southbound.

The traffic pattern on the southbound I-5 is different for "weekdays" and "weekend & holidays." Consequently, the diversion study includes (1) weekday analysis and (2) weekend & holiday analysis. For each analysis, the diversion rates and volumes at the Lake Hughes Rd off-ramp, Hasley Canyon Rd off-ramp, and Castaic Junction/Henry Mayo off-ramp are estimated.

E.4.3.1 Data collection

In order to support the diversion study, we collected on-ramp and off-ramp traffic volume data for the before scenario and after scenario, as illustrated in Table E-23. The before data were collected from May 13th to May 18th. The after data were collected during two time periods, Independence Day Holiday weekend and (from June 30th to July 7th, 2003) and Labor Day Holiday weekend (from August 30th to September 2nd, 2003).

Because the traffic pattern on those days immediately before and after the holiday and weekends might be affected by holidays and weekend travel, we did not include data collected on May 16th, July 3rd, July 7th and September 2nd in the diversion study. As shown in Table E-24, for the weekday analysis, the before scenario includes three days, May 13th to May 15th, and the after scenario includes two days, July 1st and July 2nd. For the weekend study, the before scenario included only one day, May 18th and there are two after scenarios, Independence Day and Labor Day, which show different traffic patterns.

Table E-23 Data collection for the diversion study

Data	Data collection method	Data collection location
On-ramp and off-ramp traffic volume	Tube counters (District 7 was responsible for placing them in the field)	Six specified on-ramps and off-ramps: (1) Lake Huges Rd off ramp (2) Hasley Canyon Rd off ramp (3) SR-126 on ramp (4) Magic Mountain Pkwy on ramp (5) Valencia Blvd on ramp (6) EB SR-126 to the Castaic Junction / Henry Mayor off-ramp
Probe vehicle data (travel time data)	Two probe vehicles equipped with GPS device, called EDCU	GPS-equipped vehicles continuously traveled back and forth in the work zone area for collecting travel time and delay data on the mainline freeway and the alternative route.
Mainline loop detector data	Caltrans loop detector (obtained from PeMS)	Mainline loop detector station at Hasley Canyon Rd (VDS: 759927)

Table E-24 Data collection time of the weekday and weekend cases

		Dates	Tube counter data*	Probe vehicle data	Mainline loop detector data
Weekday	Before	5/13(Tue)-5/15(Thu)	Yes	No	Yes
	After	7/1(Tue)-7/2(Wed)	Yes	No	Yes
Weekend & Holiday	Before	5/18(Sun)	Yes	No	Yes
	After weekend 1	7/6(Independence Day weekend)	Yes	Yes	Yes
	After weekend 2	9/1(Labor Day weekend)	Yes	No	Yes

Notes: * Most tube counter data were collected with 15-minute time interval. During the Labor Day weekend, 1-hour time interval was used.

E.4.3.2 Mainline traffic volume

In order to calculate the diversion rate, the mainline traffic volumes at each diversion point were required. According to PeMS, we can use the loop detector at Hasley Canyon Rd (VDS: 759927) to provide freeway mainline data. To use the data for diversion study, we need to verify the accuracy of the data.

We collected a total of 30 minute traffic volume data at the location of RTMS-3 on August 17th, 2003 and Sep 1st, 2003. VDS 759927 is located on the freeway mainline between the on-ramp and off-ramp at the Hasley Canyon Rd. RTMS-3 is located upstream of the off-ramp at Hasley Canyon Rd. The distance between them is about 0.3

mile. Since there was a tube counter measuring the off-ramp traffic count, the traffic count at VDS 759927 could be estimated as:

$$V_l = V_{rms} - V_{off} \quad (E-1)$$

V_{rms} is the traffic count measured at RTMS-3 and V_{off} is the traffic count measured at Hasley Canyon Rd off-ramp. In order to calculate lane-based accuracy, we assumed that all vehicles exiting at Hasley Canyon Rd off-ramp are from the rightmost lane. Then, the estimated traffic volume was regarded as the ground truth data. The loop data from PeMS were evaluated with 5-minute interval. The evaluation results are shown in Table E-25 and E-26.

Regarding the lane-based data, PeMS data show negative percentage errors across all lanes in September 1st and on two rightmost lanes in August 17th. Regarding the grouped data, the percentage errors are 1.7% for August 17th and -7.3% for September 1st. The accuracy of loop detector data at VDS 759927 is thus acceptable for our diversion study.

Table E-25 Accuracy of loop detector data on August 17th, 2003

	Lane 1		Lane 2		Lane 3		Lane 4		Total	
Time	Manual Count	Loop Data	Manual Count	Loop Data	Manual Count	Loop Data	Manual Count	Loop Data	Manual Count	Loop Data
17:30	96	89	87	86	93	92	72	72	348	339
17:35	78	94	86	91	101	100	70	82	335	367
17:40	86	84	77	82	94	84	80	64	337	314
17:45	72	93	72	90	85	97	71	79	300	359
17:50	80	81	81	79	100	83	71	62	332	305
17:55	78	85	77	83	93	87	72	67	320	322
Total	490	526	480	511	566	543	436	426	1972	2006
Percent error	7.3%		6.5%		-4.1%		-2.3%		1.7%	

Table E-26 Accuracy of loop detector data on September 1st, 2003

	Lane 1		Lane 2		Lane 3		Lane 4		Total	
Time	Manual Count	Loop Data	Manual Count	Loop Data	Manual Count	Loop Data	Manual Count	Loop Data	Manual Count	Loop Data
18:20	82	89	90	87	97	92	62	72	331	340
18:25	91	77	86	74	100	77	62	55	339	283
18:30	93	83	102	81	104	83	59	62	358	309
18:35	81	82	91	79	100	82	59	61	331	304
18:40	75	75	83	72	88	74	64	52	310	273
18:45	86	91	89	88	96	92	59	72	330	343
Total	508	497	541	481	585	500	364	374	1999	1852
Percent error	-2.2%		-11.1%		-14.5%		-2.7%		-7.3%	

E.4.3.3 Methodology

1. Calculation of mainline traffic volume

Figure E-13 shows the upstream part of the traffic diversion map for the southbound approach to the work zone. The mainline traffic volume at the upstream side of the Hasley Canyon Rd off-ramp can be estimated based on the following equation:

$$V_H = V_0 + V_{off-H} \quad (E-2)$$

The mainline traffic volume at the upstream side of the Lake Hughes Rd off-ramp can be estimated based on the following equation:

$$V_L = V_0 + V_{off-H} - V_{on-L} - V_{on-P} + V_{off-L} \quad (E-3)$$

where V_0 is the mainline freeway volume at VDS 759927, whose data can be obtained from PeMS. V_{off-H} is the off-ramp traffic volume at Hasley Canyon Rd. V_{off-L} is the off-ramp traffic volume at Lake Hughes Rd, and V_{on-L} and V_{on-P} are the traffic volumes from the on-ramps at the Lake Hughes Rd and Parker Rd, respectively.

Because we did not collect traffic count data at the Lake Hughes Rd and Parker Rd on-ramps, we had to ignore them. The effect of ignoring the ramps was that the estimated traffic volume V_L was higher than the actual volume. This overestimated traffic volume can be rewritten as:

$$V_L = V_0 + V_{off-H} + V_{off-L} \quad (E-4)$$

Figure E-14 shows the downstream part of the traffic diversion map for the southbound approach to the work zone. The whole section of freeway mainline has four lanes and the work zone causes one lane to drop.

The mainline traffic volume upstream of the Henry Mayo off-ramp can be estimated by:

$$V_{HM} = V_{off-HM} + V_{on-126} \quad (E-5)$$

V_{off-HM} and V_{on-126} are traffic volumes collected by the tube counters at the SR-126 on-ramp to southbound I-5 and the Castaic Junction/Henry Mayo off-ramp on the eastbound SR-126, respectively. V_{HM} is actually the volume heading for the arterial and southbound I-5. The real V_{HM} needs to include the traffic volume heading for northbound I-5, which was ignored here because we did not have the data.

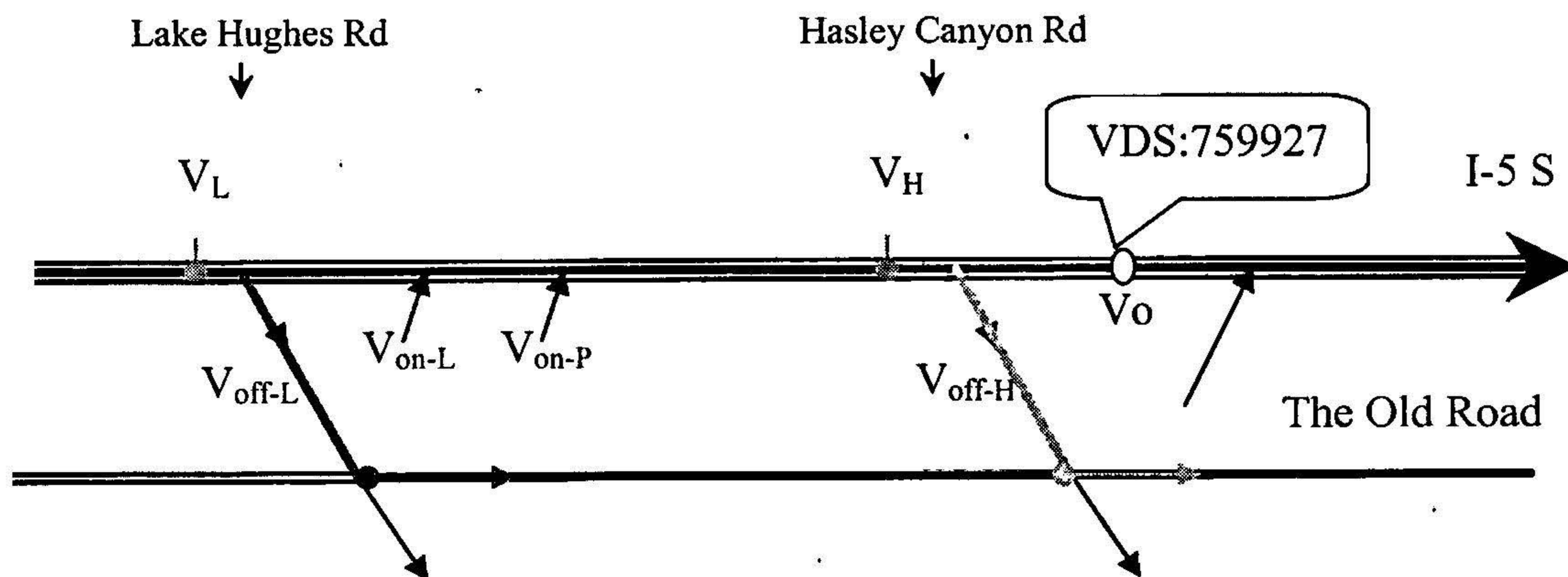


Figure E-13 The upstream part of the traffic diversion map

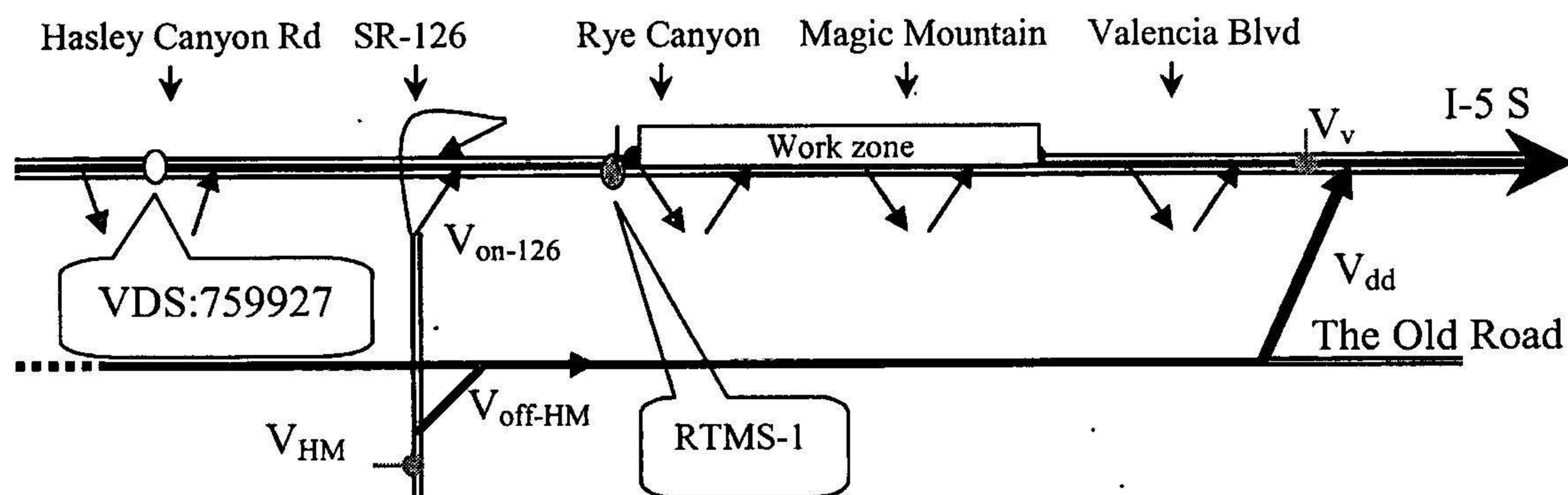


Figure E-14 The downstream part of the traffic diversion map

2. Calculation of diversion

Because the traffic demand and other traffic condition for the before and after scenarios are not the same in the real-world evaluation, a proportion-based method to estimate the diversion rate and diverted traffic volume caused by the system is proposed.

The proportion of the off-ramp traffic volume V_{off} with respect to the mainline traffic volume V can be calculated as follows:

$$p = \frac{V_{off}}{V} \quad (E-6)$$

It is presumed that the same proportion under both before and after scenarios is maintained at a certain off-ramp if there is no diversion caused by the system. If the proportion of the after scenario is higher than that of the before scenario, the diversion rate caused by the system is as follows:

$$\alpha = p_a - p_b = \frac{V_{off}^a}{V^a} - \frac{V_{off}^b}{V^b} \quad (E-7)$$

where P_a and P_b are the proportions of the after and before scenarios. V^a and V^b are the mainline traffic volume of the after and before scenarios which are calculated based on PeMS database available for each scenarios. The corresponding diversion traffic volume V_d can now be calculated:

$$V_d = \alpha \cdot V^a \quad (E-8)$$

If the proportion of the after scenario is lower than that of the before scenario, it is presumed that there is no diversion caused by the system.

E.4.3.4 Diversion estimation and analysis

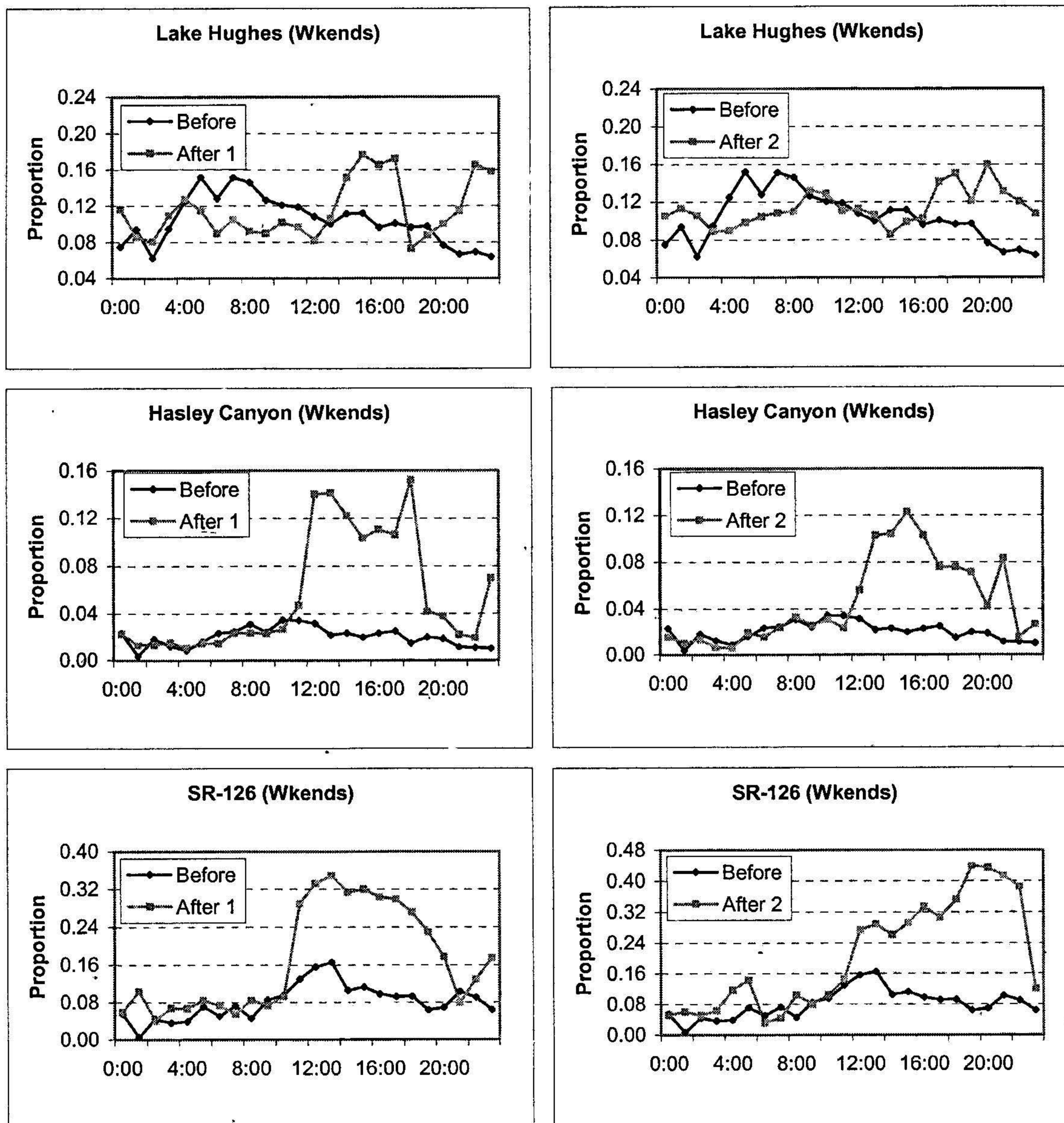
Using the methods described above, we estimated the diversion rates and diversion volumes at three off-ramp locations: Lake Hughes Rd off-ramp, Hasley Canyon Rd off-ramp, and SR-126 off-ramp to Castaic Junction / Henry Mayo, and the diversion volume at Valencia Blvd on-ramp.

1. Weekend & Holiday analysis

The data for the before scenario were collected on May 18th. There are two after scenarios, i.e. weekend 1 (collected on Jul 6th) and weekend 2 (collected on Sep 1st).

We calculated the proportions of the off-ramp traffic volumes with respect to the corresponding mainline traffic volumes at the three off-ramp locations under both the before scenario and two after scenarios. As illustrated in Figure E-15, these proportions are calculated once per hour. If the value of the proportion for the after scenario (the purple line) is higher than the corresponding proportion of the before scenario (the blue line), the difference between the two proportions is the diversion rate at the off-ramp.

The observed congestion periods were used as time windows to calculate the diversion rates and volumes. For the off-ramps at Hasley Canyon Rd and Castaic Junction / Henry Mayo, diversion might occur when the PCMSs of CHIPS showed appropriate messages. Based on the observations from the field, the mainline traffic was congested from 10:30 to 20:50 on July 6th and from 11:00 to 22:40 on September 1st. Due to system problems, CHIPS showed messages on its PCMSs from 11:33 to 19:24 on July 6th and from 11:40 to midnight on September 1st, the diversion time period at these two off-ramps might be from 11:33 to 19:24 on July 6th and from 11:40 to midnight on September 1st. For the Lake Hughes Rd off-ramp, diversion might occur when the "Caltrans PCMS" showed traffic information. The diversion time period at Lake Hughes Rd might be from 14:00 to 18:00 on July 6th and from 16:50 to 22:00 on September 1st.



(a) Weekend 1 (July 6th)

(b) Weekend 2 (Sep 1st)

Figure E-15 Off-ramp traffic proportions under the before and after scenarios

(1) Diversion rate and diversion volume

Using Equations E-5 and E-6, the time-dependent diversion rates and traffic volumes were estimated, as shown in Table E-27 and E-28. Figure E-16 shows the diversion volumes at three off-ramps and the sum of diversion volumes with respect to the time of day. Figure E-16 (a) and (b) show different diversion patterns at the Halsey Canyon Rd and Lake Hughes Rd off-ramps. Compared to the Lake Hughes Rd off-ramp, the Hasley Canyon Rd off-ramp is closer to the work zone and thus has a longer period of traffic congestion.

Table E-27 Estimated diversion rates and diversion volumes on Jul 6th, 2003

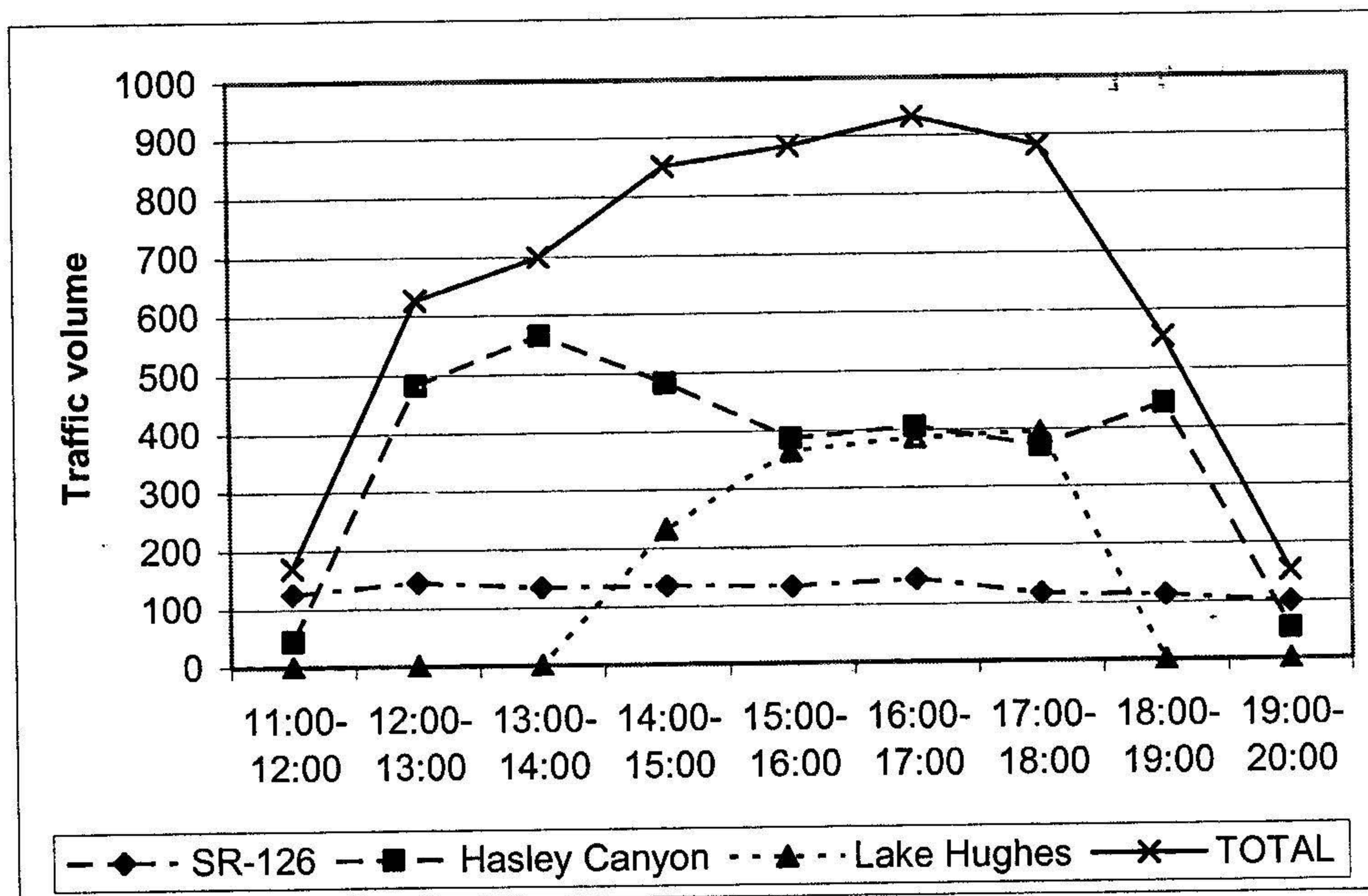
Time period	SR-126		Hasley Canyon Rd		Lake Hughes Rd		TOTAL
	Rate	Volume	Rate	Volume	Rate	Volume	
11:00-12:00	15.9%	126	1.3%	44	0%	0	170
12:00-13:00	17.6%	144	10.9%	482	0%	0	627
13:00-14:00	18.4%	134	12.0%	565	0%	0	699
14:00-15:00	20.9%	136	9.9%	483	4.0%	232	851
15:00-16:00	20.7%	133	8.4%	386	6.5%	364	883
16:00-17:00	20.5%	143	8.7%	405	6.9%	386	933
17:00-18:00	20.6%	117	8.1%	370	7.2%	395	881
18:00-19:00	17.8%	112	13.8%	442	0%	0	555
19:00-20:00	16.6%	99	2.2%	53	0%	0	152
TOTAL	18.7%	1144	8.7%	3231	6.1%	1377	5751

Table E-28 Estimated diversion rates and diversion volumes on Sep 1st, 2003

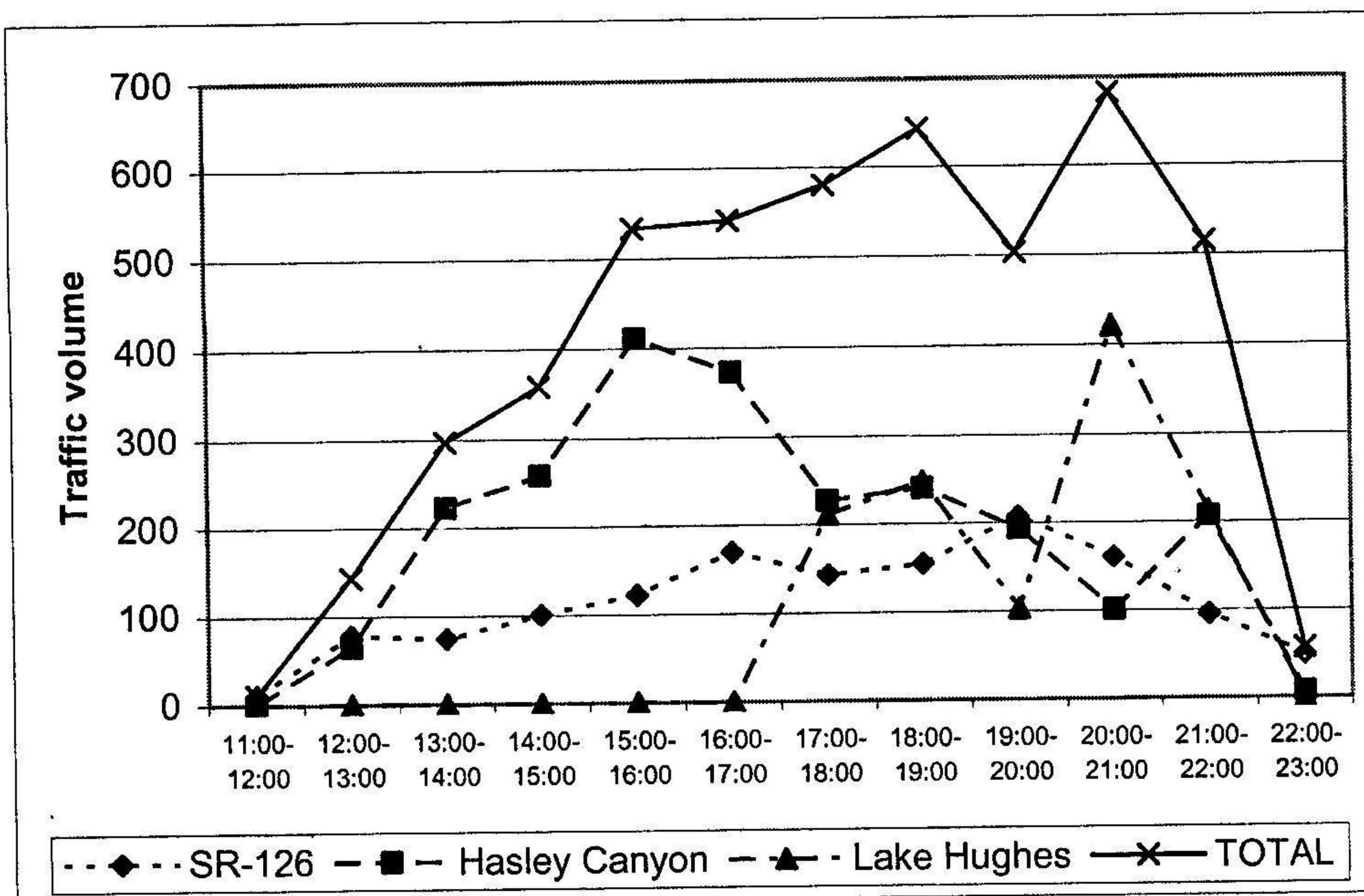
Time	SR-126		Hasley Canyon Rd		Lake Hughes Rd		TOTAL
	Rate	Volume	Rate	Volume	Rate	Volume	
11:00-12:00	1.6%	11	0%	0	0%	0	11
12:00-13:00	11.7%	78	2.5%	65	0%	0	143
13:00-14:00	12.3%	74	8.1%	222	0%	0	297
14:00-15:00	15.6%	100	8.1%	258	0%	0	359
15:00-16:00	17.9%	122	10.3%	412	0%	0	534
16:00-17:00	23.5%	169	8.0%	373	0%	0	542
17:00-18:00	21.4%	142	5.1%	227	4.1%	211	581
18:00-19:00	25.9%	155	6.1%	240	5.4%	248	643
19:00-20:00	37.5%	207	5.2%	193	2.4%	103	503
20:00-21:00	36.5%	161	2.4%	101	8.3%	421	683
21:00-22:00	31.0%	95	7.2%	206	6.4%	213	514
22:00-23:00	29.5%	49	0.5%	7	0%	0	56
TOTAL	20.2%	1364	5.7%	2305	5.3%	1196	4865

The method employed assumes that the proportion of the off-ramp traffic volume with respect to the corresponding mainline traffic volume is the same under no-diversion traffic condition. As shown in Figure E-15, for the off-ramps at Hasley Canyon Rd and Castaic Junction / Henry Mayo, the before and after scenarios show the same proportion during the un-congested time period but different proportions during the congestion time period. These results validate the assumption of our proportion-based method at these two off-ramps. For the Lake Hughes Rd off-ramp, our assumption is not supported. However, it is clear that the proportion of the after scenario is larger than that of the before scenario during the congestion time period.

Based on Caltrans' traffic report on July 6th, the maximum delay during the period of congestion was 47 minutes and occurred between 15:30 to 17:30. Figure E-16(a) shows that the most serious diversions happened exactly during this time period.



(a) Weekend 1: July 6th, 2003 (congestion period: 11:00 – 20:00)



(b) Weekend 2: Sep 1st, 2003 (congestion period: 11:00 – 23:00)

Figure E-16 The estimate of the diversion traffic volumes

Based on Caltrans' traffic report on September 1st, the maximum delay during the period of congestion was 33 minutes occurring between 17:30 and 20:00. Figure E-16(b) shows that the greatest proportion of diversions happened at the hours of 17:00, 18:00, and 20:00. The traffic congestion of September 1st was not as severe as that of July 6th but the duration of congestion is longer. The total diversion volume of September 1st was lower than that of July 6th.

(2) Travel time on mainline and alternative route

The travel time data from Lake Hughes Rd to Valencia Blvd (collected by GPS-based probe vehicles) are shown in Figure E-17, in which the blue line and the purple line represent the travel time using the mainline freeway and the alternative route, respectively. The chart shows that when congestion occurred on the mainline, the travel time along the alternative route was always less than that of the mainline. Most of the time, the alternative route would save about 3-4 minutes (from Lake Hughes Rd to Valencia Blvd) and 2-3 minutes (from and from Lake Hughes Rd to Valencia Blvd), respectively. The maximum time saving was about ten minutes, and occurred between the times of 14:15 and 15:04. The field observations showed that the queue on the freeway was between Hasley Canyon Rd and Lake Hughes Rd during this time period.

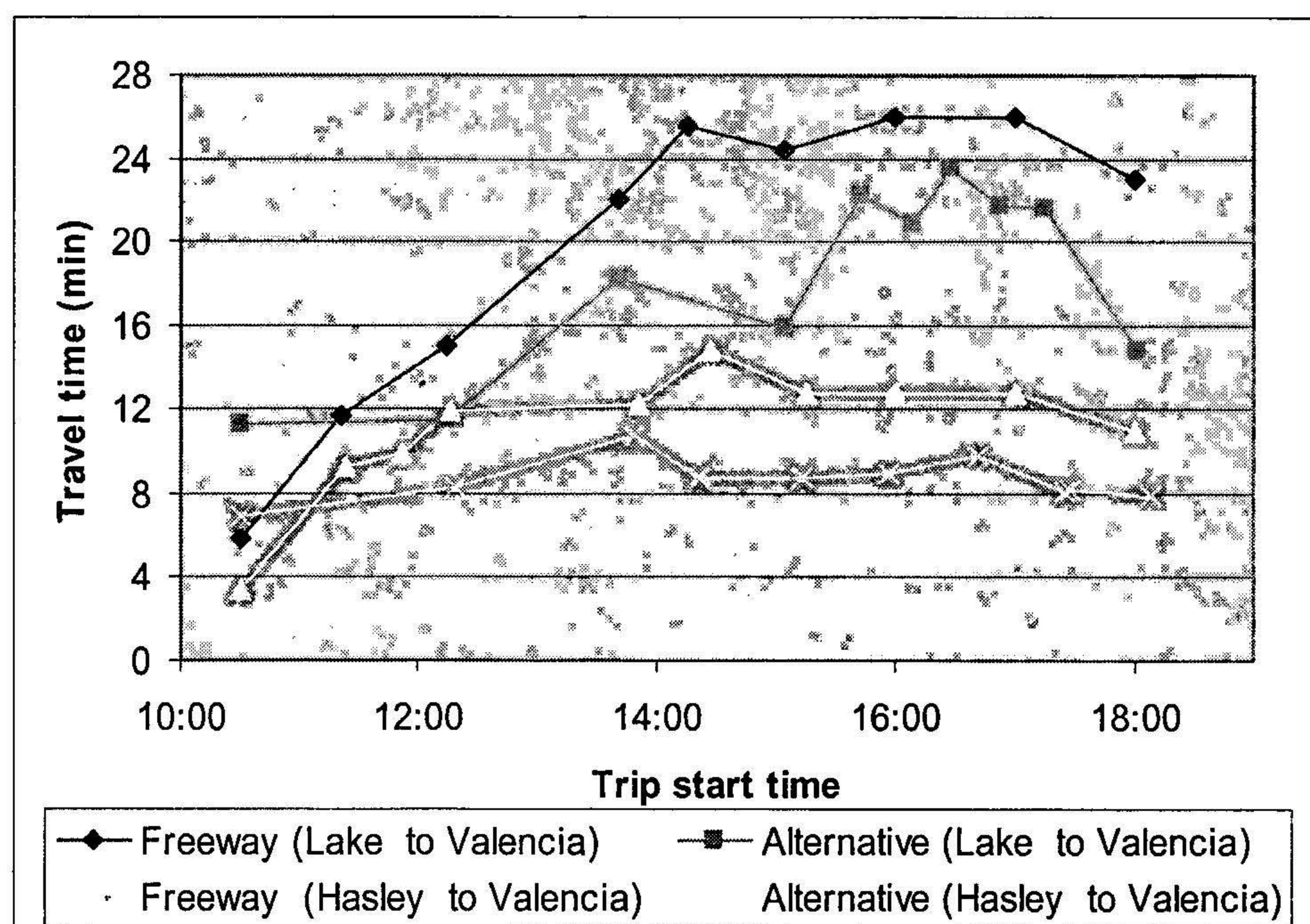


Figure E-17 Comparison of travel times along the mainline freeway and the Old Road

(3) Discussion

As shown in Figure E-15, the assumption mentioned above did not hold at the Lake Hughes Rd off-ramp. There are two possible reasons: (1) only some of the vehicles exiting at the Lake Hughes Rd off-ramp head for the residential areas. Quite a few exiting vehicles are heading for the rest area for food, gas, or a break because the previous rest area is more than 30 miles away. These vehicles usually go back to the freeway after their activities at the rest area via the on-ramp at Lake Hughes Rd. (2) The estimation of mainline traffic volume at Lake Hughes Rd using Equation E-4 is not accurate.

2. Weekday analysis

The before data were collected from May 13th to May 15th. The after data were collected from July 1st to July 2nd. Based on the system logs and emails sent by CHIPS, the system was not activated during the two days of the after scenario. So, the CHIPS system did not detect any traffic congestion on the mainline and showed no message on its PCMSs. Based on loop data from PeMS, we obtained the same no-congestion conclusion.

Because of the problems discussed above, we only consider the Hasley Canyon Rd off-ramp in this analysis. Based on the previously described method, we calculated the proportions of the off-ramp traffic volumes with respect to the corresponding mainline traffic volumes under both the before and after scenarios. The results are shown in Figure E-18. Note that the diversion proportion profiles of the before and after scenarios are very similar during the daytime. Based on a t-test with a 95% confidence interval, there is no statistical difference between the proportions of the before and after scenarios during the time period from 11:00 to 22:00, the time period when diversion most possibly occurred. This indicates that if there is no congestion on the mainline, the blank PCMSs of CHIPS have no effect on the drivers' behaviors on taking the alternative route.

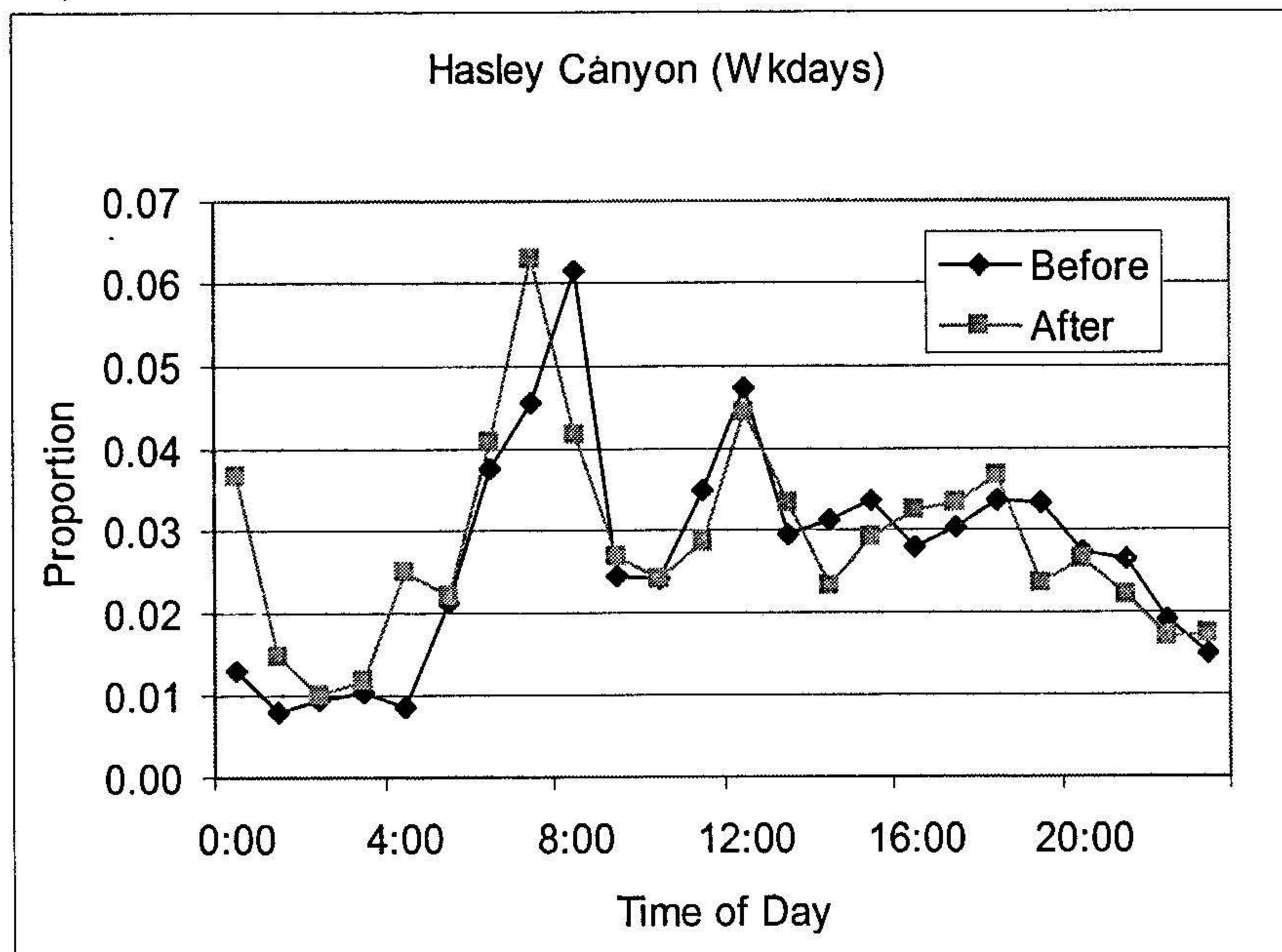


Figure E-18 Off-ramp proportion at Hasley Canyon Rd off-ramp under the weekday case

E.4.3.5 Summary

The weekday analysis showed that CHIPS had no impact on traffic diversion because the system was not activated. The weekend analysis showed obvious diversion occurred at three off-ramps of the work zone site during traffic congestion. The probe vehicle study showed that the motorists taking the alternative route could save time during traffic congestion on the mainline.

E.4.4 Driver survey

A postcard-based survey was designed to obtain travelers' comments on the work zone information system. The off-ramps at Lake Hughes Rd and Hasley Canyon Rd were selected as the driver survey locations. The travelers were asked to fill out the questions on the postcard and mail it back. Though this survey method only samples those travelers exiting the freeway via the two off-ramps, they are appropriate to be selected for commenting the system because the alternative route they are traveling on is very close to the freeway mainline. Travelers on the alternative route can see the mainline traffic condition and thus evaluate if they benefit from the diversion.

E.4.4.1 Driver survey design

We bought stamped 3.5 by 5.5 inch postcards from the post office. Due to the small size of the postcard, the questions and layout of the postcard had to be carefully designed, as shown in Figures E-19 and E-20.

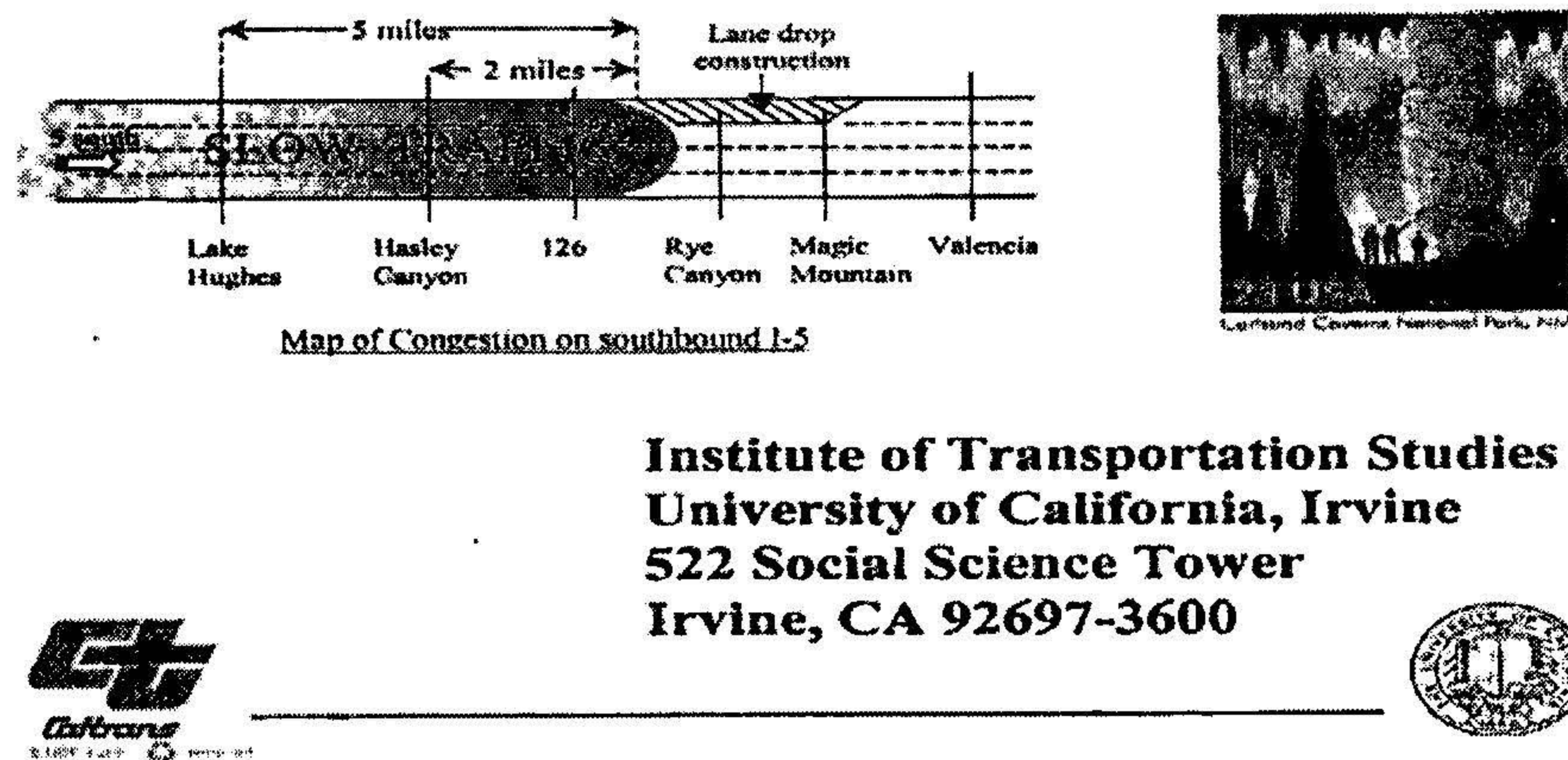


Figure E-19 Front side of postcard

U.C. Irvine is conducting this survey for Caltrans to improve work zone traffic management. Your participation is voluntary and there is no risk to you. When answering these questions, please only tell us about the trip you are now making. When you are done, please send it back to us. Thank you.

1. Why did you get off the I-5 south? (Check all that apply): ☐- Avoid traffic ☐- Arrived at destination ☐- Buy gas, foods, or others 2. Did you see any electronic traffic signs regarding construction and/or traffic delays? ☐- Yes ☐- No If "Yes", continue with the next question. If "No", you finished the survey.	3. Did the traffic signs influence your choice of route? ☐- Yes ☐- No 4. Did you find these signs useful? (Check all that apply) ☐- useful for driving safety ☐- useful for avoiding delay ☐- useful for reducing anxiety ☐- useful for providing information ☐- useful for taking alternative route ☐- NOT useful ☐- Other (Specify: _____)
--	--

Thank you! Please drop it in your mailbox. No postage is needed.

Figure E-20 Survey questions on the postcard

The front side of the postcard includes a return address and a map explaining the construction zone and its current traffic conditions. The purposes of the map are:

- (1) The postcards were distributed at Lake Hughes Rd and Hasley Canyon Rd off-ramps. The distances from the two off-ramps to the construction zone are provided as information. The Old Road, which is the alternative route, is not drawn in the map so that drivers' routing behavior is not affected.
- (2) If travelers answered questions after their trip, this map could remind them where they received the postcard.

The question side of postcard is shown in Figure E-20. The questions include:

- (1) Why did you get off the I-5 south?
- (2) Did you see any electronic traffic signs regarding construction and/or traffic delays?
- (3) Did the traffic signs influence your choice of route?
- (4) Did you find these signs useful?

Among them, questions 2 and 3 are "yes or no" choices and questions 1 and 4 are multiple of multiple choices.

E.4.4.2 Driver survey data collection

The driver surveys were conducted from 1:40 to 4:30 PM on Sunday, July 6, 2003 with helps from Caltrans and CHP officers. From 1:40 to 3:00 PM, about 100 postcards were distributed to travelers at Hasley Canyon Rd off-ramp. After 3:00 PM, there was less diversion of traffic at Hasley Canyon Rd off-ramp because the mainline queue had backed up to Lake Hughes Rd. Then we moved to the Lake Hughes Rd off-ramp and distributed about 300 postcards there.

Since this survey was based on postcards, it took one month to receive a total of 100 postcards back. The response rate was 25%.

E.4.4.3 Analysis of driver survey

As mentioned above, exactly 100 postcards were sent back, Figure E-21 shows the distribution of the returned postcards by region. The cancellation postmark was used to determine where the return postcards were mailed from. Based on the postmark data, 62 postcards were from Los Angeles County. Among them, 23 postcards were returned from the city of Santa Clarita, where the construction zone is located. A total of 9 postcards were regarded as "others" because we could not identify where they were sent from.

In response to the first question, 78 respondents selected "avoid traffic", 24 respondents selected "buy gas and foods" and 5 respondents picked "arrived at destination". Based on the second question, 99% of respondents saw messages on the PCMSs. The reason for the high percentage of PCMS observances may be that at the time when the survey was conducted, the queue on the mainline freeway was beyond the off-ramp location where the survey postcards were distributed. This implies that motorists become more aware of the driving environment when they are facing traffic congestion. The answers to the third question show that 78% of those respondents (corresponding to 77 respondents) who saw

the PCMS message changed their route based on the information on PCMSs. This implies that PCMS messages did affect the routing behaviors of many motorists.

The last question of the survey asks how useful the PCMS messages are. As illustrated in Figure E-22, 70% thought they were useful for providing information; 63% thought they were useful for taking alternative routes; 53% thought they were useful for avoiding delay; 48% thought they were useful for reducing anxiety; 36% thought they were useful for driving safety. There were 9% who thought they were NOT useful. The responses to this question suggest that information on message boards is important to drivers when congestion occurs and that the information needs to be accurate. One possible reason for the existence of those 9% of respondents who did not find the signs useful was that they thought they did not save time or save enough time on the alternative route.

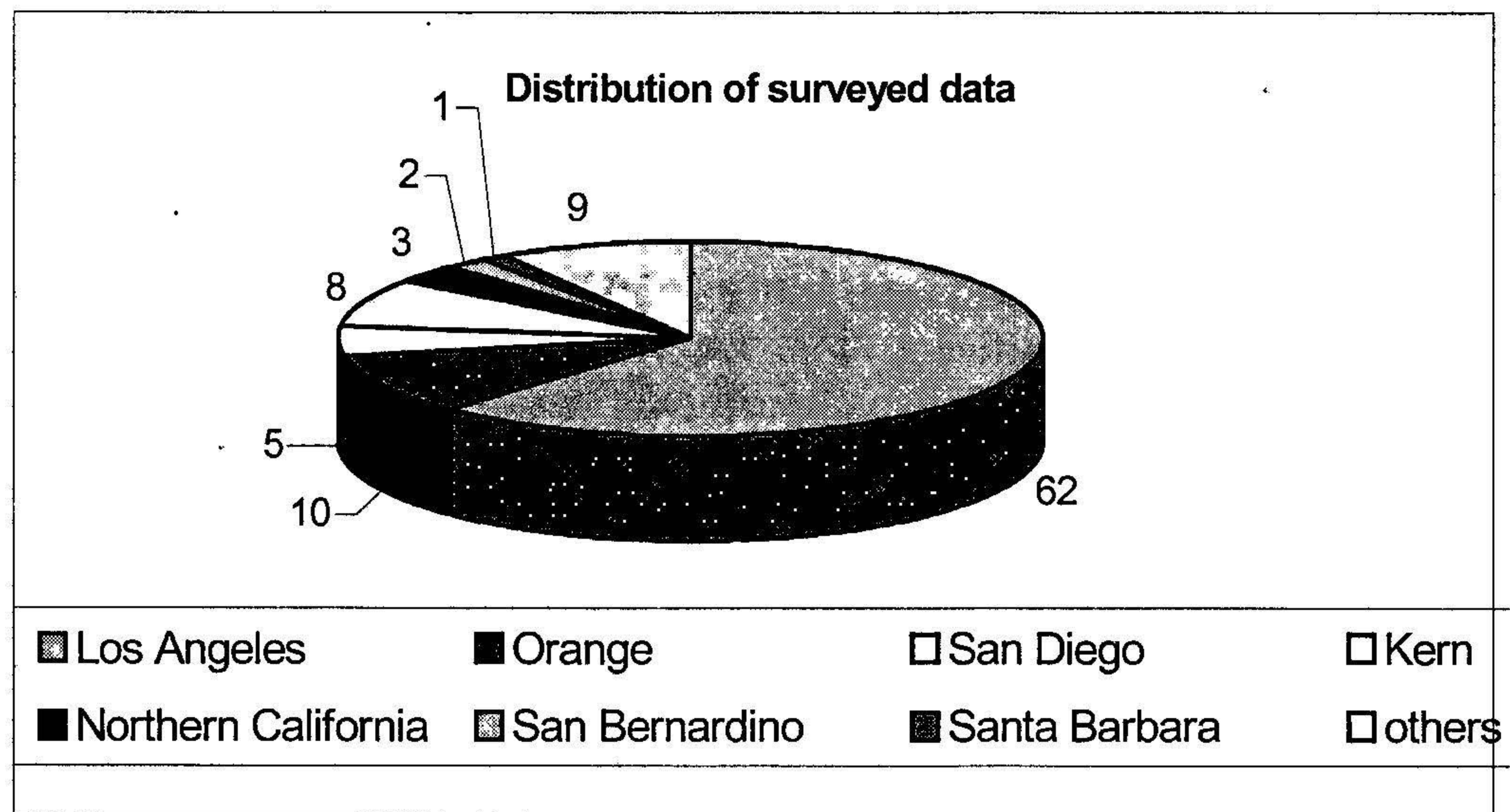


Figure E-21 Distribution of the region of returned postcards

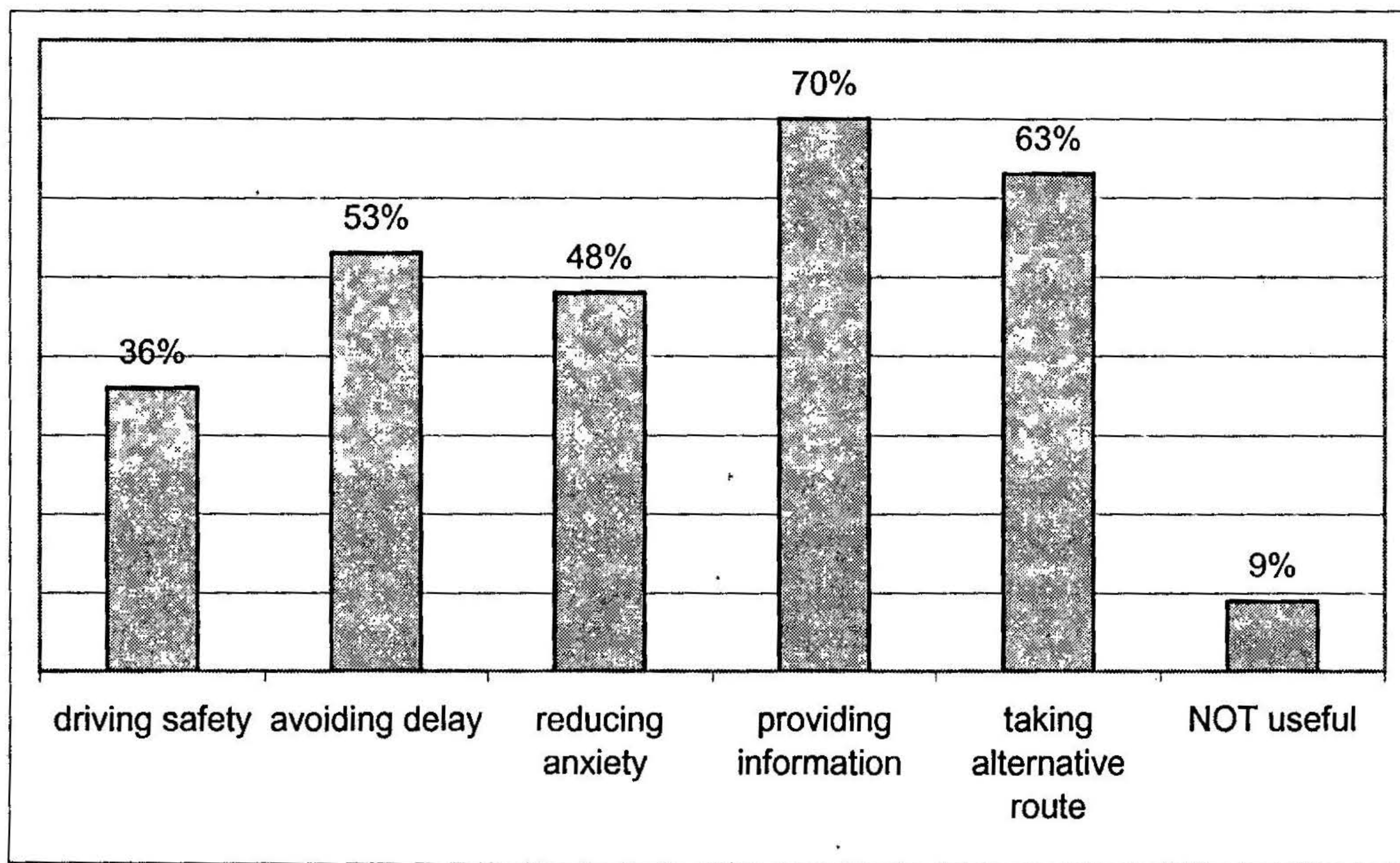


Figure E-22 How useful are PCMS messages?

E.5 Evaluation of the system cost

When the decision was made that the construction zone would benefit from an automated information system to warn motorists of congestion ahead, two vendors were invited to Caltrans District 7 to present their system for this application. From the different presentations, the team of Road-Tech Safety Services Inc. and ASTI Transportation Systems Inc. were chosen and the CHIPS system.

The contract called for 5 detector trailers and changeable message signs with radios, 3 CCTV trailers, computers, software, maintenance, and testing of the equipment. The itemized cost of each component of the system is shown in Table E-29. All the costs are on a monthly lease basis. The contract was for 26 months at a price of \$32,074 per month. The total cost of the system for the 26-month contract (starting from May 2003) is about $\$32,074 \times 26 = \$833,924$. In addition, the vendor also provides Caltrans with an option of purchasing the system from the vendor at a price of \$60,588 at the end of the contract.

Table E-29 Itemized monthly cost of CHIPS

Item	Quantity	Cost	Subtotal/month
Quick Queue Trailer	5	\$850.00	\$4,250.00
Changeable Message Sign with radio	5	\$995.00	\$4,975.00
CCTV Trailer	3	\$3,000.00	\$9,000.00
CHIPS software			\$3,800.00
Three Computers with installation, training, software, and maintenance			\$1,266.45
T1 line and DSL			\$3,000.00
Maintenance (cleaning the solar arrays and topping off the battery fluids)			\$900.00
Insurance			\$500.00
TOTAL			\$27,691.45
8.25% Sales Tax			\$2,284.54
Grand TOTAL			\$29,975.99
Prime Contractor's Markup			\$2,098.01
Caltrans' cost / month			\$32,074.00

Based on the cost data from both Caltrans and the vendor, the time and money all parties used to make the system work, and the actual system performance, we find this cost to be high. However, considering the benefits from the system, we feel this system shows promise because it automates work zone traveler information services and is a complete package that includes measurement, processing, and message delivery. When it works properly, this system is effective in diverting traffic and promoting smoother traffic flow during congested periods. As a result, a similar system with more robust performance and cheaper cost will be a viable technology.

F. Limitations of the system

1. Documentation and training

The CHIPS system has poor documentation and a lackluster manual. The training class from the vendor was just an introduction to the functions of the system, and did not provide Caltrans users chances to practice.

The correct operation of the system requires some computer knowledge. The system needs users to access the control computer through PcAnywhere. If the connection is successful, users will see the desktop of the control computer, which runs the CHIPS software, in a window. Every time users stop connection with the control computer, they need to make sure that they do not close the CHIPS software. If user clicks on the 'X' in the upper right hand corner of the screen, it stops the CHIPS core software and the system will not work. Caltrans users made this mistake several times at the beginning of the system's operation. Caltrans users also had some other difficulties in using this system, but these difficulties were eventually solved through communication with the vendor.

Caltrans thinks "all of this confusion could have been avoided with a better written manual showing exact steps (written & visual screen plots) on how to log in, log out, etc".

2. One user at a time

The CHIPS system is installed in the command center, located in a remote location close to all devices in the field. If a user wishes to check the system, he or she must access the system remotely through PcAnywhere. Three users, Sylmar Construction Field Office of Caltrans, Traffic Operations of District 7 and UCI evaluation team, and two vendors, ASTI and Road Tech can access the system.

CHIPS is designed to allow only one user to access the system at a time. If a user stays in the system, any other users cannot gain access. Consequently, the system's availability becomes a problem during the peak hours when all users want to check the system.

Of the three users mentioned above, Sylmar Construction Office can access and stay in the system as long as they want. Users of Traffic Operations of District 7 and the evaluation team can access and remain online for a maximum of 3 hours (1 hour at beginning) and 5 minutes, respectively. On several occasions, no user could access the system because the unrestricted user, Sylmar Construction Field Office, stayed connected and forgot to log out.

3. Security

Users in Traffic Operations of District 7 have the privilege to setup scenarios for the system. In order to setup scenarios, they need to access the system first and then log in as

the power user. But, CHIPS only allows the user in District 7 to remain online for three hours.

If the Traffic Operations user does not log off and stop the connection, the system will automatically kick him out. If this condition occurs, the next user logging in the system will still have the privilege to setup scenarios; this situation is not secure.

4. Video system

The video system uses AXIS 2400 video server to publish the surveillance videos to the web, which can be accessed by users. The video system is regarded as one of the advantages of the system. It allows users to monitor traffic operations on a daily basis from a remote location. It saves a lot of time for traffic operation engineers because the one-way trip between the office and the job site takes up to 45 minutes. However, the video system was not reliable based on its operation history.

Initially the CCTV system performed very well. Then the cameras were found to be unreliable. It was difficult to move cameras, zoom in or zoom out. On some occasions, the camera did not respond to user's input. On other occasions, especially when remotely panning the camera, the camera would continue rotating until it came to rest in a "tilt limit" position. This rest position often caused the camera to point to the upper horizon or the ground beneath the camera. When Caltrans inquired about this malfunction, the vendor indicated that this was due to "outside" interference (due to bridge and construction work with pile drivers working directly in-line with line-of-sight). On November 13th, 2003, two of three cameras stopped working. The vendor argued that the solar array is too small to provide enough power. They plan to replace all three cameras with 24 volt units in March 2004.

5. Wireless communication

Wireless communications is the weak link in all portable ITS systems, including CHIPS. CHIPS uses two wireless communication links, 450MHz for the communication between the command center and the field devices and 5.9 GHz for video transmission. The wireless communication devices placed in the field are subject to vandalism, which has been a problem since its operation.

The video transmission system needs any one camera in the EZ Cam Mobile Video Trailer to have a dish antenna pointing to another dish antenna in the command center. The direction of two dishes should be in a line-of-sight. It was found for several times that there was no picture or the picture quality was bad from a camera because the EZ Cam Mobile Video Trailer was moved.

A number of PCMSs of CHIPS use a directional antenna to communicate with the command center through the 450MHz radio network. Caltrans may need to turn one of these PCMSs away from the traffic if wrong messages are displayed on it (this situation

occurred once). Then the PCMS trailer may be moved and thus the communication between the command center and the PCMS is lost.

6. Detection zones setup for RTMS

The original design of the system only had one detection zone to cover all four lanes for each RTMS. Because of poor performance, the vendor setup three zones to cover four lanes, which means that one zone needs to cover two lanes. This system design may cause inaccurate traffic detection.

7. Delay calculation

Caltrans wants the CHIPS system to have the ability to calculate delay. However, the system is designed to use presence as the measurement of traffic condition. Although RTMS can measure speed, volume and occupancy based on its zone setting, these data are not used, saved or transmitted to the command center. Consequently, the system is not capable of estimating delay.

8. Vandalism

Vandalism is a serious threat to the normal operation of the system. There have been four episodes of vandalism so far. The first two involved the theft of solar panels and one of the sensors from the system. It happened just after midnight on a Sunday and it was fixed by Wednesday of that week. Later problems have been only with camera 3, the southernmost camera. Vandals have pulled on the wiring harness and pulled some of the wires out of the camera and/or the antenna. That has only caused problems with the pan/tilt/zoom controls and the vendor repaired it each time within 48 hours. One thing that is clear is that the closer the equipment is to the active work zone, the less likely it is to be vandalized. All of the problems have been at the far north or far south end of the work area. The California Highway Patrol is now aware of the vandalism and is keeping a closer watch for vandals.

G. Conclusions

A complete ITS work zone information system, CHIPS, was evaluated in the work zone site located in the City of Santa Clarita, north of Los Angeles, on freeway I-5, between Magic Mountain Parkway and Rye Canyon Road. There were four evaluation aspects, system functionality, reliability, effectiveness and cost.

From the perspective of system functionality, the system provides almost all the features Caltrans wants except the delay estimation. However, CHIPS was found to have some technological problems, especially at the beginning of its operation. The system was not able to work until six months after its operation. Although the system shows the capability to automatically respond to traffic congestion and execute pre-specified traffic management plans, it suffers from the problem to detect traffic condition accurately.

The effectiveness of the system was evaluated based on three criteria, safety, diversion, and responses from travelers. The results of these studies showed that (1) the driving environment after the use of CHIPS seemed safer; (2) obvious diversion were observed on two evaluation dates, July 6th and September 1st; (3) positive responses about the system were obtained from driver surveys.

Based on the cost data from both Caltrans and the vendor, the total cost of the system was \$833,924 for the 26-month contract. We find this cost to be high considering the actual system performance.

In summary, CHIPS has showed its capability to respond to traffic congestion automatically. However, we found the system to be unreliable and costly. Despite its flaws, we feel this system shows promise because it automates work zone traveler information services and is a complete package that includes measurement, processing, and message delivery. When it works properly, this system is effective in diverting traffic and promoting smoother traffic flow during congested periods. As a result, a similar system with more robust performance and cheaper cost will be a viable technology.

H. Recommendations for system improvements and operational improvements

CHIPS is a complete ITS work zone information system, which is composed of several components. The evaluated system has experienced some operational problems since it was deemed to be ready in May, 2003. Our recommendations for system and operational improvements are listed below. However, due to its high cost, Caltrans is unable to deploy many of these systems in its workzones. CCIT will investigate the possibility of lower cost, more effective and less complex systems that can meet the needs of Caltrans in terms of improved safety and better managing congestion around workzones.

Recommendations for improvements:

1. Traffic congestion detection using RTMS

Traffic congestion detection using RTMS is the most important part of CHIPS. Because RTMSs are placed on trailers that may be moved due to many reasons, the vendor may need to regularly check the performance and calibration of RTMSs in order to keep the system work properly. The reason for addressing this issue is that Caltrans did find a long queue (at Hasley Canyon Rd) prior to the work zone over the President's Day weekend (Feb 16th, 2004). However, the system did not respond to this congestion well.

2. Problem-solution process

The specific traffic patterns at the work zone show that traffic congestion only happens on holidays and some Sundays. Because the vendor does not work during holidays or weekends when the system was activated, they could not identify and solve problems in a timely manner.

The problem-solution process is time-consuming. Caltrans finds a problem and then reports it to the vendor. Though the vendor always responds quickly, Caltrans has to wait until the next holiday weekend to verify if the problem has been solved. After one problem is verified to be solved, another one shows up and it again takes time to be solved and verified. If the problem is verified to be unsolved, another problem-solution cycle is required. The following facts show how the limitation of the system affected the operation of the system.

- PCMS-2 did not show messages on May 26th, 2003. The same problem happened on July 6th, 2003.
- On August 17th, 2003, the system stopped working at 15:53 with the following error: "Run-time error 3021: Either BOF or EOF is true, or the current record has been deleted. Requested operation requires a current record." The same problem happened at 15:43 of September 1st, 2003.
- During the time period from May 20th, 2003 to September 2nd, 2003, RTMS-2 was never triggered and the error has yet to be identified.

The following improvements may be required:

(1) System testing method

Before the system is delivered to Caltrans, the system needs to be ready for normal operation. A more effective system testing method needs to be developed in order to shorten the problem-solution process. In other words, it would be better if there was some way to inject a defined traffic condition from the quick queue sensor to the CHIPS software to test the scenarios.

(2) Working over holidays and weekend

For the current system, at the current site, the vendor may need to work when traffic congestion is expected. By working holidays and weekends, the vendor can fine-tune the system and respond to and solve new problems in a timelier manner. Under typical weekday conditions, it will be very hard for the vendor to find solutions to a problem based on observations from Caltrans.

(3) The vendor may need to spend more time monitoring and fine-tuning the system.

The CHIPS system is developed by ASTI and ASTI provides most of the technical services. If Caltrans wants some system logs, only ASTI can retrieve those data. If the system experiences a problem, such as losing communication with a device, the system will e-mail / page ASTI only. Then, ASTI will notify Road Tech about the problem (mostly maintenance or hardware checks). Road Tech owns the system and provides the maintenance for Caltrans.

A support staff from ASTI claimed that "I access the system every day to see if everything looks good. If I see discrepancies are found, I go through the logs to get a better idea of what may be the issue. I then communicate these issues to Road-Tech" However, we did feel that the vendor depends too much on Caltrans to tell them of any system malfunction. If Road Tech and ASTI can spend more time on this system, it will serve both Caltrans and the public in a better way.

3. Device check-in

The system checks the communication and the status of one of its devices (including RTMSs and PCMSs) every 12 seconds. This is the major task for the system on a general day. The vendor states that if a device has not checked in for some time, there may be a problem with the device or the communication system. The check-in procedure allows the vendor to be aware of any problems with any device in the system.

The vendor claimed that if the communication with a device is lost for a specific, user definable period of time, the system will send out an e-mail or page to the appropriate personnel. Currently, the system only notifies ASTI if any device has a communication

problem. Because Caltrans cares more about the operation and performance of the system, Caltrans users are on the list of appropriate personnel that are contacted. Consequently, Caltrans personnel will be able to know the status of the system without referring to the system logs.