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

Final Report: Mobile Surveillance and Wireless Communication Systems Field Operational Test; Volume 1: Executive Summary

Lawrence A. Klein

California PATH Research Report
UCB-ITS-PRR-99-6

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

Report for RTA 65W404

March 1999

ISSN 1055-1425

CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

Final Report: Mobile Surveillance and Wireless Communication Systems Field Operational Test

Volume 1: Executive Summary

Prepared by:
Lawrence A. Klein, Ph.D.

Prepared for:
University of California at Irvine

January 1999

Preface

The Mobile Surveillance and Wireless Communication Systems Field Operational Test (FOT) contained two evaluation tests, the Anaheim Special Event Test and the Interstate-5 (I-5) Test. The Anaheim Special Event Test assessed the ability of the surveillance trailers to transmit video imagery to a traffic management center in support of arterial traffic signal control. This test occurred during the Spring of 1997 in conjunction with heavy traffic experienced during hockey playoff games at the Arrowhead Pond in Anaheim, CA. The I-5 Test evaluated the ability of the mobile surveillance and ramp meter trailers to transmit video imagery and data in support of freeway ramp metering. It occurred a year later in Spring 1998 along I-5 in Orange County, CA. The results of these tests and other conclusions from the FOT are presented in three volumes. The first volume serves as the Executive Summary of the FOT. It describes the project objectives, results, conclusions, and recommendations in condensed fashion. The second volume discusses the overall goals and objectives of the FOT and the design of the mobile surveillance and wireless communication system in more detail. Technical and institutional issues that surfaced before either of the two FOT tests was conducted are described. The specific objectives of the Anaheim Special Event and the I-5 Tests, lessons learned, test results, and recommendations are expanded upon in this volume. Photographs and drawings are used liberally to illustrate the types of equipment and test configurations that were tested. Volume 2 also incorporates revisions to the evaluation plans that were originally prepared by Pacific Polytechnic Institute (PPI). The evaluation plans and preliminary results from the planning and design phases of the FOT and the Anaheim Special Event Test were originally published by California Partners for Advanced Transit and Highways (PATH) under Report 97-C34. The third volume consists of ten appendices that contain data and other information gathered during the tests.

The test planning and execution were a cooperative effort among the partner agencies and companies. These were the Federal Highway Administration, California Department of Transportation divisions in Sacramento and Orange County, California Partners for Advanced Transit and Highways, University of California at Irvine Institute of Transportation Studies, California Highway Patrol, City of Anaheim Department of Public Works, Hughes Aircraft Company (now Raytheon Systems Company), Pacific Polytechnic Institute, and Lawrence A. Klein, Consultant.

This report was prepared in cooperation with the State of California, Business Transportation and Housing Agency, Department of Transportation. The material is based on work supported by the Federal Highway Administration, the State of California, Department of Transportation under prime contract number RTA-65A0012, and the Regents of the University of California.

Synopsis of Project

The Mobile Surveillance and Wireless Communication Systems Field Operational Test (FOT) evaluated the performance of wireless traffic detection and communications systems in areas where permanent detectors, electrical power, and landline communications were not available. The FOT partners designed and built six surveillance and three ramp meter trailers, a video and data retransmission or relay site, and video and data reception facilities at the Caltrans District 12 and Anaheim Traffic Management Center (TMCs) and the University of California at Irvine Institute of Transportation Studies (UCI-ITS) Laboratory. The system was evaluated in two different types of tests. The Anaheim Special Event Test assessed the surveillance trailers in an application that transmitted video imagery in support of arterial traffic control during a special event. The Interstate-5 (I-5) Test examined the use of the mobile surveillance and ramp meter trailers to transmit video imagery and data in support of freeway ramp metering.

The primary tasks of the surveillance trailer are to acquire video imagery and traffic data, transmit metering rates to the ramp meter trailer, and transmit traffic flow data and imagery to the relay site. The major components of the surveillance trailer are a video image processor (VIP); two pan and tilt black-and-white cameras; one pan, tilt, and zoom color camera; one fixed black-and-white security camera; a 170 controller; wide and narrow bandwidth spread spectrum radios (SSRs) for video and data transmission; a telescoping 30-foot (9.1-meter) mast; a security system; and a propane-powered electrical generator and power supply system. The ramp meter trailer retransmits the metering rates to portable signal heads on the ramp and controls the meter-on sign. The major components of the ramp meter trailer are two traffic signal heads, a ramp meter-on sign, narrow band SSRs for data reception, and solar-powered electrical recharging systems for one signal head and the meter-on sign. The relay site on the Union Bank Building in Santa Ana, CA supports trailer locations along the I-5 reconstruction zone in Orange County, CA. Video imagery and data received at the relay site are retransmitted to the TMCs and to the UCI-ITS Laboratory.

Perhaps the biggest issue faced by the project was the schedule delay. This was mainly attributed to deficiencies in the planning and procurement processes and the changes in scope that persisted well into the procurement and integration phases of the project. Allowing the primary contractor a more direct method of parts procurement, perhaps through a project credit card, for items costing less than some predetermined amount would have been helpful. Closely related to the planning issues was the conflict over whether the FOT was developing prototypes or completely developed equipment that could support normal transportation management operations.

Three issues that affect the portability of the mobile surveillance and communications system became apparent. First, the size of the trailers limits where they can be placed in a construction zone. Second, since the configuration of a construction zone may change weekly or daily, the trailer is subject to frequent moves that are exacerbated by their size. Third, the current existence of only one relay site limits the areas in which the trailers can be deployed. Subgrade placement is not possible because of line-of-sight restrictions. Two recommendations based on these findings are that: (1) road construction contractors be made aware early in the planning process for the need to allocate sites for the surveillance, and perhaps ramp meter, trailers in the construction zones; (2) additional or supplemental relay sites be designed and deployed in areas from which Caltrans desires video and VIP data.

The item that most impacted the start of the I-5 Test once the trailers were deployed was the initial lack of ramp signal synchronization with vehicle demand and control commands from the surveillance trailer. The problem was remedied by reducing the transmission rate of the commands.

The most prevalent problem uncovered during the I-5 Test was frequent discharge of the surveillance trailer battery. After the FOT was completed, an extensive redesign of the generator, batteries, charging system, and power distribution architecture was completed. The new power system was installed in the six surveillance trailers, but was not evaluated as a part of the FOT.

Once the cameras and communications links were operational, camera control and picture quality were consistent from each test venue. Exceptions occurred when strong winds moved the antennas or the mast accidentally dropped because the locking pins were not fully extended.

The average percent differences between the permanent inductive loop detector (ILD)- and VIP-measured mainline total volume and average lane occupancy were –22 and 8, respectively, based on data gathered in the fourteen runs completed in the I-5 Test. These accuracies appear adequate for the rush-hour ramp-metering application as shown by the tracking of the metering rates produced by the ILD and VIP data. These errors were tolerable because a more restrictive metering rate (namely zero) than the prestored time-of-day (TOD) rate was calculated by the metering algorithm from the ILD and VIP real-time data. Therefore, the algorithm reverted to the less restrictive TOD rate for both sets of data.

The larger mainline volume measured by the VIP as compared to the ILD may lead to the reporting of erroneous levels of service on the mainline. This potential problem is caused by the VIPs over estimating the volume by as much as 53 percent or under estimating it by as much as 14 percent. It is more likely that the VIP will overcount when the camera is mounted as it was in this evaluation. Therefore, a method of compensating for vehicle overcount by the VIPs is needed in order to report valid mainline traffic volumes.

The ramp signals responded properly to vehicle demand an average of 85 percent of the time. This is not good enough for ramp-metering operation. A possible method to increase this average is to position the surveillance trailer, and hence the camera, closer to the ramp. This may provide a better perspective of the vehicles on the ramp and perhaps modify the camera’s field of view to allow even more VIP detection zones to be created upstream of the ramp stop bar. The multiple detection zones can then be connected with OR logic to increase the probability that a stopped vehicle will be detected by the VIP.

The most likely estimate of LPG consumption by a surveillance trailer is approximately 0.00522 tank/hr or 0.460 gallon/hr. With an LPG cost of $1.75/gallon, the estimated cost of fuel is $0.80/hr for surveillance trailer operation.

Table of Contents

Tables

Figures

1. Objectives and Project Organization

1.1 Introduction

Traditional inductive loop detectors and landline communications can be costly to maintain, are subject to damage and removal during construction, and generally cannot provide cost-effective surveillance and communications at special events or remote locations where these detectors and communications systems are not already in place. In the Mobile Surveillance and Wireless Communication Systems Field Operational Test (FOT), the California ITS partners designed, built, and evaluated a mobile trailer system that provides closed-circuit television surveillance, video image processing, inductive loop emulation, ramp metering, and communication of data and video imagery to transportation management centers and research facilities. The mobile system consists of surveillance and ramp meter trailers, a retransmission or relay site, and data reception facilities. The salient features of the system are:

- Mobile trailers that can be deployed to locations that have line-of-sight communications with a relay site;
- A color camera that provides surveillance of traffic conditions, two black-and-white cameras that supply imagery to a video image processor (VIP), and a black-and-white camera used for trailer security;
- Video image processing of freeway mainline and onramp traffic to detect vehicles, control metering rates, and extract traffic volume, lane occupancy, and vehicle speed at construction areas, special events, or any other site where permanent vehicle detection systems are not installed or operating;
- Inductive loop emulation by the VIP to facilitate the incorporation of data into existing traffic management systems;
- Wireless spread spectrum radio (SSR) communications between surveillance and ramp meter trailers and between the trailers, traffic management centers, and research facilities.

The mobile surveillance and wireless communication system was tested under real traffic conditions on Orange County, CA freeways and Anaheim, CA arterial roadways in two tests. The Anaheim Special Event Test evaluated the ability of the surveillance trailers to provide video imagery in support of traffic management on arterial streets during a preplanned event. In the Interstate-5 (I-5) Test, the surveillance and ramp meter trailers were used to provide local-responsive ramp metering. During these tests, the wireless communication system transmitted traffic flow data and imagery to the California Department of Transportation (Caltrans) and California Highway Patrol (CHP) District 12 (Orange County) Transportation Management Center (TMC), the City of Anaheim TMC, and the University of California at Irvine Institute of Transportation Studies (UCI-ITS) Laboratory.

The Final Report was developed in conformance with the FHWA Intelligent Vehicle Highway Systems Operational Test Evaluation Guidelines of November 1993. The Executive Summary contains the objectives of the FOT, summaries of the notable features of the mobile surveillance and wireless communication system, descriptions of other portable traffic management systems, evaluation findings, conclusions, and recommendations.

1.2 Goals and Objectives of the Mobile Surveillance and Wireless Communication Systems FOT

The goals and objectives for the Mobile Surveillance and Wireless Communication Systems FOT were derived from those of the National ITS Program, namely:

- Improve the safety of the Nation's surface transportation system;
- Increase the operational efficiency and capacity of the surface transportation system;
- Reduce energy and environmental costs associated with traffic congestion;
- Enhance present and future productivity;
- Enhance the personal mobility and the convenience and comfort of the surface transportation system; and
- Create an environment in which the development and deployment of ITS can flourish.

These program goals are expanded in ITS America's *Strategic Plan for Intelligent Vehicle-Highway Systems* and in the U.S. Department of Transportation's *IVHS Strategic Plan*.[1]

The overall goal of this FOT was to assess the application of traffic monitoring and management systems that utilize transportable surveillance and ramp meter trailers, video image processors, and wireless communications. This goal is consistent with the national objectives described above. For example, the FOT tested and evaluated technology that is designed to increase the operational efficiency of the freeway system by providing a ramp-metering system suitable for temporary deployment in construction zones. The FOT was conducted within the California ITS Test Bed, an area in Orange County containing both freeways and surface streets that has been specified by Caltrans for the development and evaluation of ITS products. Therefore, the FOT occurred in an environment that was designed for the development and deployment of intelligent transportation systems.

1.2.1 Anaheim Special Event Test Objectives

The Anaheim Special Event Test had five objectives:

1. Examine the portability of the surveillance and ramp meter trailers for installation in a city pre-planned special event setting within range of the communications relay site;

---

1. *Strategic Plan for Intelligent Vehicle-Highway Systems in the United States*, Final Draft (First Version), ITS America, Washington, D.C., March 25, 1992.

2. Demonstrate that the surveillance and ramp meter trailers are effective in supporting pre-planned special event traffic management where traditional traffic monitoring systems are not otherwise available;

3. Assess the relative impact of additional video surveillance with respect to special event traffic management;

4. Examine the institutional issues, benefits, and costs associated with sharing resources between agencies in a special event setting;

5. Examine the institutional issues, benefits, and costs associated with sharing information between allied agencies.

1.2.2 I-5 Test Objectives

The I-5 Test had the following four objectives:

1. Examine the portability of the surveillance and ramp meter trailers for installation in a freeway setting within range of the communications relay site;

2. Demonstrate that the surveillance and ramp meter trailers are effective in that they may be used for freeway traffic management where permanent traffic surveillance and control systems may be disabled or not otherwise available;

3. Examine the institutional issues, benefits, and costs associated with surveillance and ramp meter trailer deployment in a freeway setting;

4. Examine the institutional issues, benefits, and costs associated with information sharing in a freeway setting.

1.3 FOT Design

The FOT deployed surveillance and ramp meter trailers to selected locations and transmitted data and video imagery from multiple sites, in real-time, to TMCs and the UCI-ITS Laboratory. The FOT evaluated the operational effectiveness of the trailers for real-time traffic management on freeways and in special event settings that required traffic control on city arterials.

1.3.1 Anaheim Special Event Test Design

In the Anaheim Special Event Test, three surveillance trailers were placed on streets that fed traffic into the Arrowhead Pond in Anaheim, indicated on Figure 1-1. Only camera imagery was of interest in this test. The video was transmitted to the Anaheim and Caltrans District 12 TMCs during evenings when the Anaheim Mighty Ducks were involved in hockey playoff games. Anaheim had primary control of the trailer locations and cameras during this test as the emphasis was on controlling traffic ingress and egress operations to and from the streets and parking lot areas near the Pond.

1.3.2 I-5 Test Design

In the I-5 Test, surveillance and ramp meter trailers were located at six evaluation sites along a 7-mi (11.3-km) length of I-5 between State Route (SR)-22 and Culver Drive in Orange County, CA as shown in Figure 1-1. Video images of traffic flow and traffic flow data were transmitted to the Caltrans District 12 TMC, Anaheim TMC, and the UCI-ITS Laboratory. Caltrans had primary control of the cameras during the I-5 Test. Emphasis was on weekday, peak-period traffic operations.

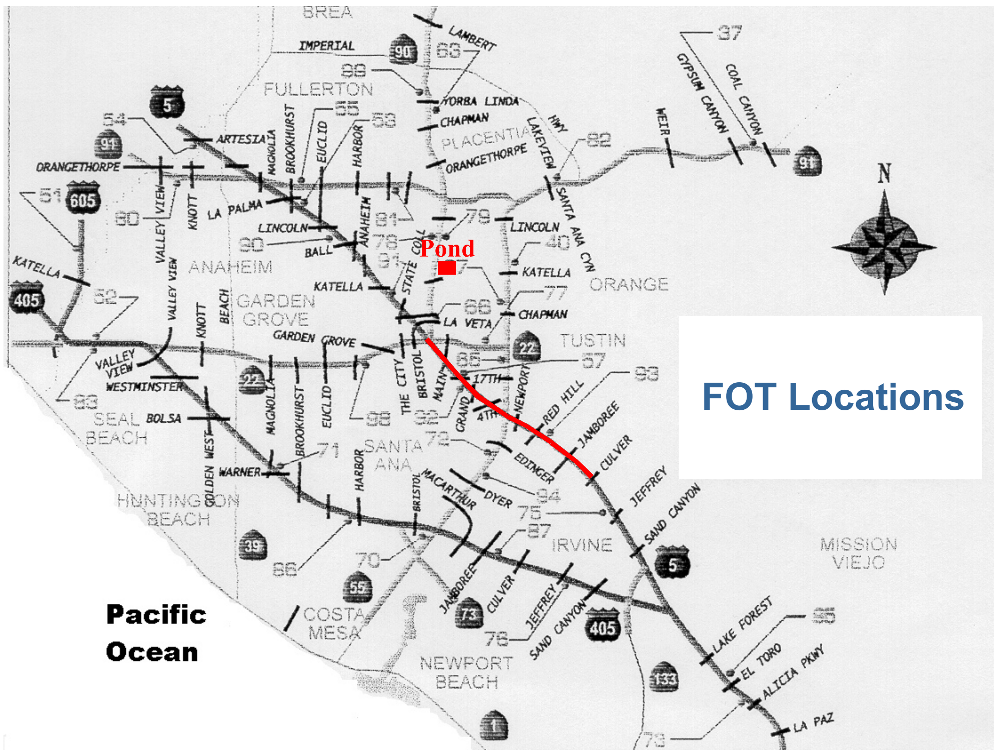


Figure 1-1. FOT locations

All six surveillance trailers and all three ramp meter trailers were used in this test. Three surveillance trailers were paired with ramp meter trailers at three onramps along the freeway. These surveillance trailers used SSRs to transmit camera imagery and VIP-generated traffic flow data to the TMCs and UCI. They also used SSR to transmit metering rates to the ramp meter trailer, which in turn controlled the ramp signals and the meter-on sign. The remaining three surveillance trailers were placed at other strategic venues along the freeway. These trailers transmitted only imagery to the TMCs and UCI.

1.4 Mobile Surveillance and Wireless Communication System Design and Operation

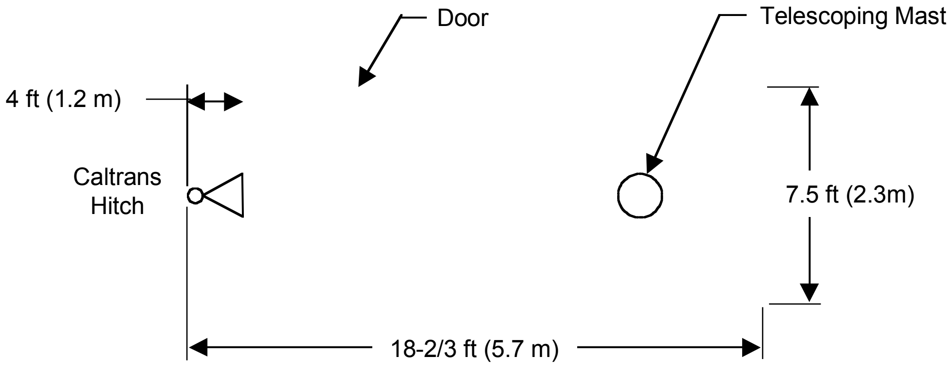
The mobile surveillance and wireless communication system consists of surveillance and ramp meter trailers, a video and data retransmission or relay site, and video and data reception facilities at TMCs and the UCI-ITS research laboratory. Six surveillance and three ramp meter trailers were assembled as part of the FOT. Figure 1-2 shows a surveillance trailer. Its major components are a video image processor; two pan and tilt black-and-white cameras; one pan, tilt, and zoom color camera; one fixed black-and-white security camera; a 170 controller; wide and narrow bandwidth spread spectrum radios for video and data transmission; a telescoping 30-foot (9.1-meter) mast; a security system; and a propane-powered electrical generator and power supply system.

Figure 1-2. Surveillance trailer at First Street overlooking I-5 Freeway

Figure 1-3 shows a ramp meter trailer. Its major components are two traffic signal heads, a ramp meter-on sign, narrow band SSRs for data reception, and solar-powered electrical recharging systems for one of the signal heads and the meter-on sign.

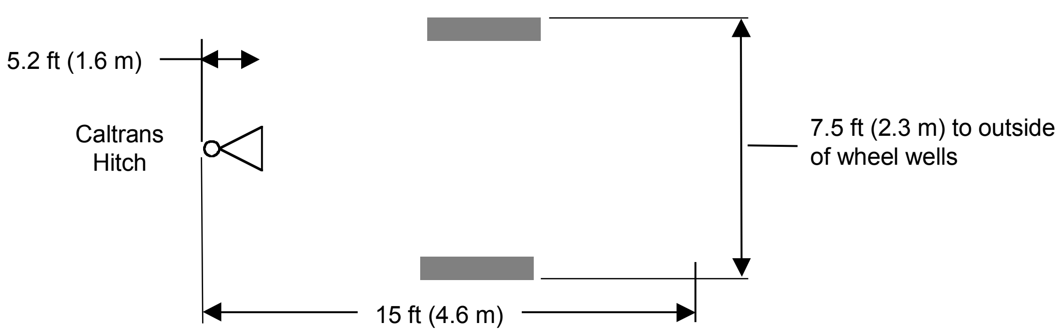
Figure 1-3. Ramp meter trailer at Grand Avenue alongside I-5 Freeway

Trailer dimensions are displayed in Figure 1-4. The surveillance trailers can operate autonomously of the ramp meter trailers and thus be used in applications that do not require ramp metering. Each surveillance trailer can support two ramp meter trailers. However, in this FOT the surveillance trailers were programmed to operate only one ramp meter trailer.



A fully-extended mast is 30 ft (9.1 m) high.
Since the floor of a surveillance trailer is approximately 2 ft (0.6 m) above the ground, the top of a fully-extended mast is approximately 32 ft (9.8 m) above the ground.
The roof of the surveillance trailer is 8-2/3 ft (2.6 m) above the ground.
The railing on the surveillance trailer roof is 3 ft (0.9 m) high.

(a) Surveillance trailer dimensions



(b) Ramp meter trailer dimensions

Figure 1-4. Trailer dimensions

The primary tasks of the surveillance trailer are to acquire traffic video imagery and data, transmit metering rates to the ramp meter trailer, and transmit traffic flow data and imagery to the relay site. The ramp meter trailer retransmits the metering rates to the signal heads and controls the meter-on sign. The primary signal head is connected by cable to the ramp meter trailer; the secondary signal head receives its commands via SSR from the ramp meter trailer. The meter-on sign receives its commands via an FM radio transmitter/receiver pair.

The relay site receives traffic flow data and imagery from the trailers and retransmits them to the state and city TMCs and the UCI-ITS Laboratory. The relay site on the Union Bank Building in Santa Ana, CA supports trailer locations along the I-5 reconstruction zone in Orange County, CA providing line-of-sight transmission exists.

Depending on their equipment, the TMCs and UCI may have remote surveillance trailer control, remote camera control, and remote VIP calibration control. Remote surveillance trailer control includes trailer selection, power-up, power-down, mast-extend, and mast-retract control. Remote camera control includes image selection for display at the TMC and pan, tilt, and zoom control of the surveillance camera. Remote VIP calibration control includes video detection zone configuration and the ability to receive VIP data.

The Caltrans District 12 TMC is the only facility that can exercise all remote control options, namely remote trailer, camera, and VIP control. The Anaheim TMC has remote trailer and camera control, but lacks remote VIP control. The UCI-ITS Laboratory does not presently have any remote control capability. While researchers at UCI are able to view camera images, they must contact either the Caltrans District 12 TMC or the Anaheim TMC for assistance in selecting a particular image or scene transmitted by the SSR system. However, the UCI-ITS Laboratory can also receive imagery and data over a separate fiber optics backbone connected to Caltrans.

Table 1-1 lists the SSRs used in the mobile system to facilitate communications between surveillance and ramp meter trailers, the relay site, and the TMCs and UCI. The various video and data transmission paths are illustrated in Figure 1-5.

Table 1-1. Spread spectrum radios used in the mobile surveillance and wireless communications system

Manufacturer and Model	Qty	Spectrum	Bandwidth/ Channel	Location	Information
Cylink 19.2 ALM	1	902-928 MHz	1.5 MHz	Surveillance trailer	Metering and control data
Cylink 64 ALSM	1	2.4-2.48 GHz	5.1 MHz	Surveillance trailer	Data
Cylink 256 NSPALS	1	2.4-2.48 GHz	20.5 MHz	Surveillance trailer	Video
Cylink 19.2 ALM	1	902-928 MHz	1.5 MHz	Ramp meter trailer	Control data
Digital Wireless WIT915	2	902-928 MHz	1 MHz	Ramp meter trailer	Signal light control
Cylink 64 ALSM	2	2.4-2.48 GHz	5.1 MHz	Relay site	Data
Cylink 256 NSPALS	3	2.4-2.48 GHz	20.5 MHz	Relay site	Video
Cylink ALT1	1	5.725-5.850 GHz	125 MHz	Relay site	Data and video
Cylink ALT1	1	5.725-5.850 GHz	125 MHz	District 12 TMC	Data and video
Cylink 64 ALSM	1	2.4-2.48 GHz	5.1 MHz	Anaheim TMC	Data
Cylink 256 NSPALS	1	2.4-2.48 GHz	20.5 MHz	Anaheim TMC	Video
Cylink 64 ALSM	1	2.4-2.48 GHz	5.1 MHz	UCI-ITS	Data
Cylink 256 NSPALS	1	2.4-2.48 GHz	20.5 MHz	UCI-ITS	Video

The two pan and tilt black-and-white cameras on each surveillance trailer supply imagery to the VIP. In freeway operations, one camera is usually pointed at the mainline and the other at an onramp. For arterial applications, each camera can be pointed at a different approach to an intersection. Once the detection zones are calibrated, the black-and-white cameras are not repositioned. In fact, the control cables are removed from the pan and tilt units for these cameras to prevent accidental camera movement once the VIP is operational.

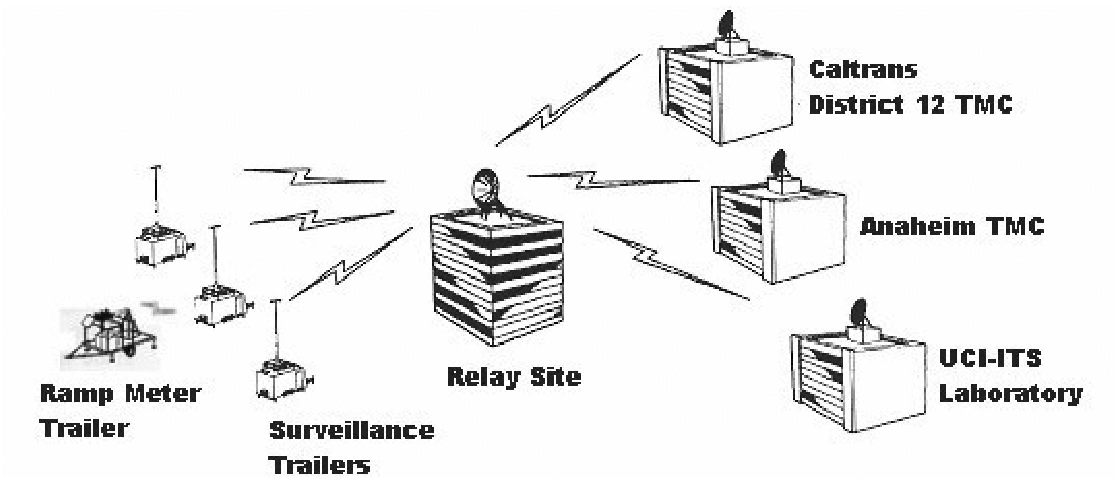


Figure 1-5. Transmission of video and data among trailers, relay site, TMCs, and UCI

(Adapted from *System Information Manual, Mobile Video Surveillance Communications System*, Hughes Aircraft Company, Feb. 1998)

The pan, tilt, and zoom color camera is used for traffic flow surveillance. The fixed position black-and-white security camera is pointed at the surveillance trailer door to enable TMC personnel to observe trailer entry. The surveillance trailers contain a security system that is connected to the Caltrans District 12 TMC. Up to two cameras from among a total of twenty-four (four at each of the six surveillance trailers) can be selected by the District 12 TMC to simultaneously transmit and display video imagery. Imagery from one camera can be selected for display by the Anaheim TMC. This concept is shown in Figure 1-6.

Figure 1-7 contains photographs of the two racks of equipment found in each of the surveillance trailers. The rack on the left contains the power distribution system, spread spectrum radios that transmit data to the ramp meter trailer and relay site, wide-area communications controller, AutoScope 2004 VIP, and the170 controller that processes the VIP data. The rack on the right contains a monitor, controls for selectively displaying the imagery from the color surveillance camera or the black and white VIP cameras on the monitor, digital video encoder, spread spectrum radio that transmits compressed video imagery to the relay site, pan-tilt-zoom camera controls, generator auto start/battery recharge system, and the automatic mast retraction circuit.

The video image processor analyzes the images of mainline and ramp traffic and provides traffic flow volume, lane occupancy, and vehicle speed to the 170 controller located in the surveillance trailer. The format of the VIP data is the same as that produced by permanent inductive loop detectors. Therefore, the VIP data are compatible for utilization by existing traffic control systems.

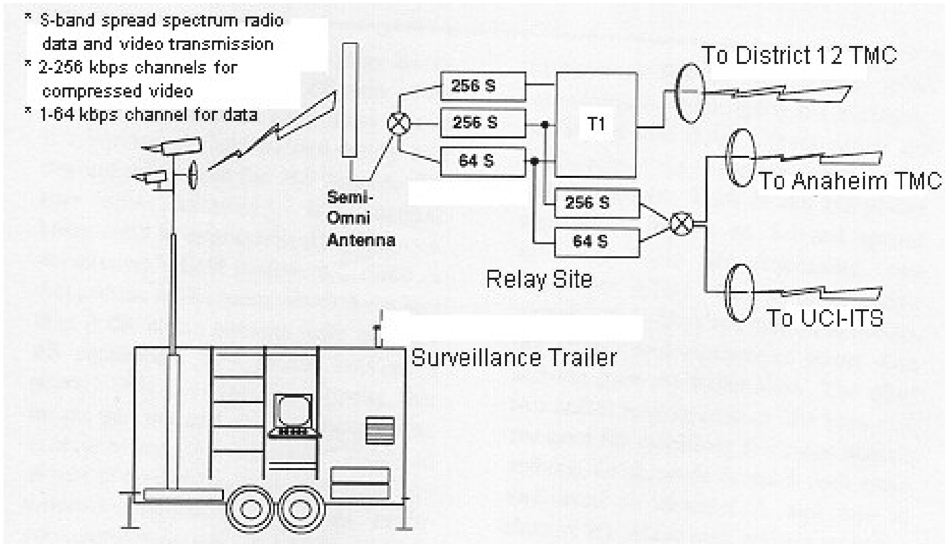
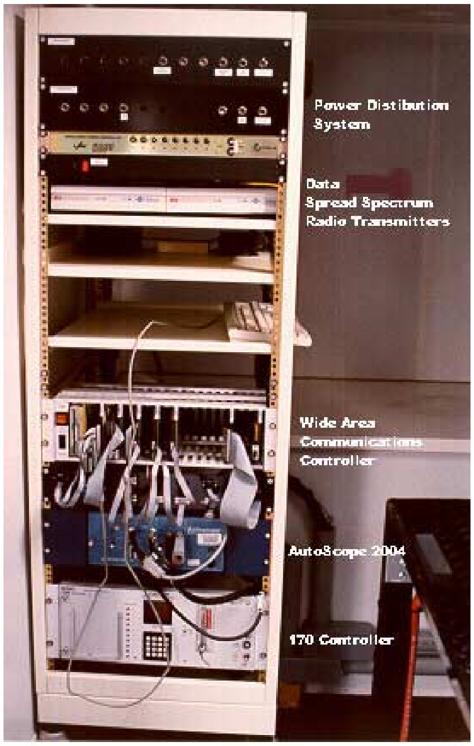


Figure 1-6. Selection of video images for transmission from surveillance trailers to TMCs and UCI. Video images from two cameras on any of the six surveillance trailers reach the District 12 TMC, while one camera image is transmitted to the Anaheim TMC and UCI.
(Adapted from *System Information Manual, Mobile Video Surveillance Communications System*, Hughes Aircraft Company, Feb. 1998)

Since the surveillance and ramp meter trailers are self-powered and use wireless communications, they can be located where normal electric power and landline communications are not available. Thus, the equipment can replace in-pavement loop systems temporarily rendered inoperative at construction sites and supplement existing traffic control systems at special pre-planned events or at long-duration emergencies. The system can also provide data for traffic management research. The trailers and relay site operate without human operator intervention. As such, the surveillance and ramp meter trailers can be programmed to turn on and off automatically using the 170 controller. Outside of designated metering times, the associated surveillance trailers can be turned on and off remotely from the TMCs as needed.

1.5 Project Management

The FOT was a cooperative effort among the test partners. The Federal Highway Administration (FHWA) and Caltrans sponsored the FOT. Other partners included California PATH, University of California at Irvine, Hughes Aircraft Company (now Raytheon Systems Company), City of Anaheim, the California Highway Patrol, Pacific Polytechnic Institute (PPI), and Lawrence A. Klein, Consultant (LAK). The partners were arranged into three teams: the Project Management Team, the Evaluation Team, and Technical Review Team. While each team had responsibilities that were distinct, the three teams worked as a group to support the objectives of FOT.



(a) Left equipment rack

(b) Right equipment rack

Figure 1-7. Surveillance trailer equipment racks

The Project Management Team (PMT), which included Caltrans, Hughes, FHWA, Anaheim, and UCI, was responsible for conducting the FOT. As such, they deployed and operated the surveillance and ramp meter trailers, assisted in test design, and collected test data. The PMT also provided the Evaluation Team with written reports on test activities, technology issues, institutional issues, and costs.

The Evaluation Team, which included PPI (later LAK), PATH (later UCI), and FHWA, was responsible for performing an independent evaluation of the FOT. PPI performed the independent evaluation from April 1994 through June 30, 1997. A contract to complete the independent evaluation was issued to Lawrence A. Klein for the September 1, 1997 through April 30, 1999 period. PPI and LAK were the members of the Evaluation Team responsible for coordinating the collection of test data and preparing test procedures and reports. In this role, PPI and LAK provided the PMT with comments about the test design, observed test activities, analyzed test data, interviewed test participants, and prepared the final reports. California PATH served as evaluation manager, through a contract with Caltrans, when PPI was the evaluator. UCI-ITS served as the evaluation manager, also through a contract with Caltrans, when LAK was the evaluator. FHWA and its contractor, Booz-Allen & Hamilton, reviewed and approved test plans and reports. UCI retained Hughes to provide engineering services for the design, installation, and systems integration of the equipment.

The Technical Review Team (TRT), which included Caltrans and Anaheim, was responsible for reviewing technical issues related to the planning, design, and execution of the FOT. Members of the TRT were selected for their ability to assist in evaluating project objectives, plans, and evaluation procedures.

1.6 Evaluation Focus

Remote traffic surveillance by itself does not result in direct operational benefits. Traffic flow measurements and video surveillance produce benefits to freeway traffic management only when freeway operations personnel use the information appropriately. In the Caltrans District 12 TMC, Caltrans and CHP operators review all available incident and traffic information, coordinate activities with allied personnel, and refer to standard operating procedures in order to initiate traveler advisories and other traffic management decisions. The objective of their actions is to help preserve freeway safety and expedite the movement of freeway traffic.

The FOT partners focused the FOT evaluation on functions that are unique to the mobile surveillance and ramp meter trailers, wireless transmission of data and imagery, and the relay site. As such, the evaluation did not investigate the benefits of providing traffic surveillance video and data to operations facilities, nor did it explore the benefits of ramp metering or a comparison of VIP and inductive loop detector accuracies. Rather, the focus was on features such as transportability, self-contained power, wireless communications, and the ability to provide video and data that are of sufficient accuracy to support local-responsive ramp metering and the arterial traffic management goals of the FOT. Other issues explored dealt with the sharing of real-time video and data among traffic operations and research facilities.

1.7 Other Portable Traffic Management Systems Designed for Temporary Use in Construction Areas

Two other mobile traffic management systems have been developed in recent years. FHWA and the Minnesota Department of Transportation sponsored the first and the Iowa DOT and FHWA sponsored the second.

1.7.1 Portable Traffic Management System

The Portable Traffic Management System (PTMS) application for a Smart Work Zone was developed by MnDOT with support from FHWA.[2] The project partners also included the University of Minnesota, ADDCO, ISS, Vano Associates, BRW, and SRF Consulting Group. The PTMS integrates existing, off-the-shelf, and emerging traffic management technologies into a wireless, portable traffic control system. It operates in a work zone and provides traffic engineers with speed, volume, and incident detection data that are communicated to the traveling public so that they may make informed travel decisions.

As developed for the work zone application, the PTMS consists of portable skids that contain a machine vision system, variable message sign (VMS), central processing unit (CPU), and spread spectrum radio communications. The skids are placed in strategic locations in the work zone and, when linked to one another by the spread spectrum radio, form nodes in the PTMS network. The nodes can include both vehicle detection devices and driver information devices. Figure 1-8 shows the PTMS skid deployed in the work zone with both types of devices installed. The inset in Figure 1-8 shows a close up of the top of the PTMS tower. The CPU and related components are housed in the cylindrical enclosure.

The PTMS consists of four subsystems: vehicle detection and surveillance, traffic control center, driver information, and communications. The vehicle detection and surveillance subsystem contains cameras and a video image processor. Video cameras placed at strategic locations in the work zone provide real-time traffic flow information to traffic management personnel. The video image processor analyzes the camera imagery to produce traffic volume, speed, incident detection, and alarms that indicate vehicle intrusion into the work zone. The camera is mounted at the top of the tower as illustrated in the left side of the inset in Figure 1-8.

The data from the vehicle detection and surveillance subsystem are transmitted to the traffic control center at the MnDOT Traffic Management Center. After review, operators use the data to make decisions regarding traffic control that are intended to improve traffic flow through the work zone. The traffic control changes are implemented by relaying messages to the motorist through the driver information subsystem that consists of full-size portable, variable message signs and smaller work zone portable variable message signs. The information can also be made available to the public on a World Wide Web page via the Internet.

2. *Portable Traffic Management System Smart Work Zone Application Operational Test Evaluation Report*, SRF Consulting Group, Report Number 0942089.7/11, May 1997.

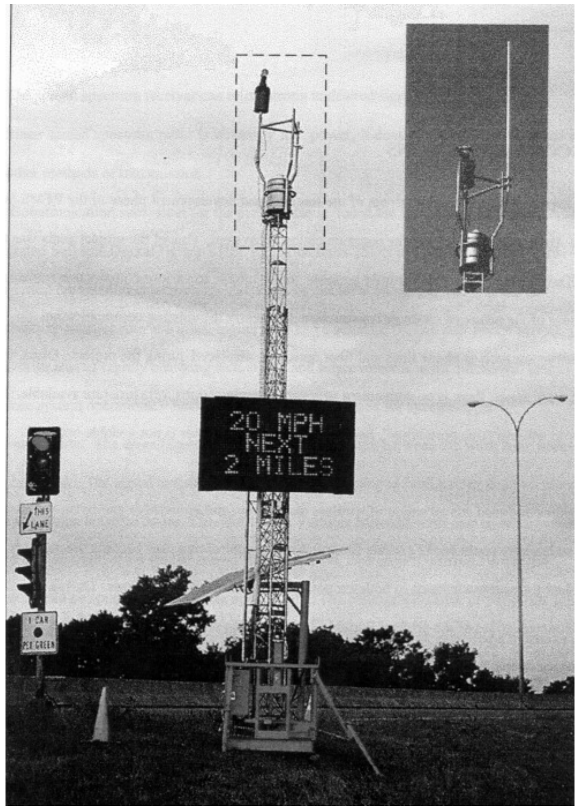


Figure 1-8. PTMS deployed on a skid
(From *Portable Traffic Management System Smart Workzone Application, Final System Design Report*, MnDOT, May 1997)

The communications subsystem utilizes spread spectrum radio, cellular telephone, and the Integrated Services Digital Network (ISDN). The spread spectrum radio antenna is mounted at the top of the tower as shown on the inset in Figure 1-8. Each of the communication devices is used for specific links. This subsystem will eventually include a master controller and a radio link to the traffic control center.

The costs for the PTMS are summarized in Table 1-2. The minimum configuration for a PTMS requires the basic system, base station, and landline communications and control packages. The cost for this configuration is $75,850.

1.7.2 Rural Smart Work Zone

During the 1997 Interstate-80 reconstruction in Iowa, traffic engineers acted to mitigate the impact of traffic incidents in the work zone and reduce the number of secondary traffic accidents. The increased incidents and secondary accidents were caused by reduced work zone capacity, which combined with peak period demand to create traffic backups that brought about the accidents. Prior to the development of the Rural Smart Work Zone, traffic monitoring was provided by a single person in a roving vehicle who monitored traffic and responded to observed incidents. The single roving vehicle technique, by itself, was inadequate for the large reconstruction area.

Table 1-2. Portable Traffic Management System costs (MnDOT project)

System	Cost
Basic System containing skid mount platform and 40-foot (12.2-meter) tower; CCTV camera, enclosure, pan, tilt, zoom assembly; video compressor and control processor; 900 MHz SSR communications; 600 W tilt and rotate solar panel with 3520 amp-hour battery	$59,850
Base Station, Landline Communications, and Control System containing solar powered pole mount relay and termination; two ISDN routers, ADDCO Base Station Software	$16,000
Optional systems:	
3 x 6 foot, 24 x 48 pixel LED message sign	$9,800
AutoScope with field upgrade kit	$21,700
Speed (Doppler) radar	$2,000
Skid trailer assembly	$4,000

The Rural Smart Work Zone consists of an incident detection unit (IDU) equipped with a Whelen microwave Doppler sensor to measure vehicle speed and a camera to acquire images of the traffic flow.[3] When speeds drop below 35 mi/h (56.3 km/h), the IDU automatically places a series of four cellular telephone calls, three to activate Automated Traveler Information System (ATIS) devices [namely, two mobile changeable message signs (CMS) and a highway advisory radio (HAR)] and one to notify the roving vehicle. The camera operates independently of the speed sensor. The images from the camera can be viewed (for example, at the TMC) by calling the camera via cellular telephone. The images are transmitted by cellular communications as well. The viewer can select the image refresh rate up to a maximum of once every 2 to 3 seconds. Cellular communications was used because of the required transmission distances. CMS #1 is two miles from the IDU, CMS #2 is 10 miles (16.1 km) from the IDU, and the HAR is 20 miles (32.2 km) from the IDU.

The camera and its interface to the cellular communications system were provided by Denbridge Digital of San Leandro, California. The Iowa DOT reports that the camera portion of the IDU has performed well. The Doppler sensor with its link to the cellular system was provided by Display Solutions (the CMS supplier). The sensor-cellular system fails whenever there is a temporary disruption in traffic flow. The problem arises because it takes a certain amount of time for the telephone to place the four cellular calls. If traffic clears [speeds rise above 35 mi/h (56.3 km/h)] before all four calls are completed, the system locks up. Iowa is attempting to remedy this problem. However, Display Solutions may have decided to discontinue their participation in the sensor market and may not support the product further. No formal evaluation was required or performed.

3. S.J. Gent, "Rural Smart Work Zone," *ITE Journal*, p. 18, Jan. 1998.

2. Test Result Summary

During the Anaheim Special Event Test, three surveillance trailers were placed at intersections near Arrowhead Pond in Anaheim. Emphasis was on management of hockey playoff game traffic ingress and egress from parking lots. The video image quality and camera control were monitored at hourly intervals at the Anaheim TMC and the Caltrans District 12 TMC to assess benefits to special event traffic management. Interviews with TMC operators and traffic control personnel provided additional information about the effectiveness of the trailers.

For the I-5 Test, surveillance trailers were placed at six onramp or offramp sites along I-5. Ramp meter trailers were deployed at three of the sites. Emphasis was on weekday, peak-period traffic operations. Data were gathered at hourly and daily intervals along the freeway and at the TMCs to evaluate image quality and camera control, vehicle detection performance by the VIP, and the local-responsive metering function. The ramp meter trailers were turned on and off at the beginning and end of the ramp metering periods by the 170 controller in the surveillance trailer. The response of the ramp signal sequence to vehicle demand was monitored by the evaluator to determine if the ramp meter signals were operating properly.

2.1 Measures of Performance

Trailer portability was assessed by measuring the time required to deliver and setup the trailers at the test sites. Quantitative measures of performance included the number of minutes required to hitch, transport, set in place, and activate the trailers. Qualitative measures included identifying specific transport preparations and the level of effort (number of personnel and time) required for each step.

Trailer effectiveness was assessed by evaluating the primary system functions. Quantitative measures included the percent of time images, camera control, VIP vehicle detection, and turn-on of ramp meters and meter-on signs occurred properly. Qualitative measures included characterizing video image quality and identifying technical problems, severity, and remedies.

The major portion of the VIP quantitative assessment focused on whether the VIP data were of sufficient accuracy to support local-responsive ramp metering. This assessment had two parts. The first compared the ramp meter rates calculated by the 170 controller that processed VIP mainline occupancy and volume data with the rates calculated by the 170 controller that processed data provided by the permanent inductive loops. If the resulting ramp meter rates were similar, the VIP data were deemed adequate to support the ramp meter function. The second part of this quantitative assessment examined the percent of the vehicles detected by the VIP at the ramp stop bar. The quantitative data were recorded by laptop computers connected to the 170 controllers. The laptops simulated the polling and data capture features of the Caltrans computer system, which was not available during the FOT.

Institutional issues were assessed by noting the advantages, disadvantages, and costs associated with shared use of the trailers and the video among the partner agencies.

These mobile systems are unique in that a city agency or UCI can borrow them from Caltrans to support a short-term event or research project. Furthermore, wireless communications allow the video to be viewed at each of the agencies. The assessments were made through observations of the evaluators and by conducting interviews with TMC and university personnel.

2.2 Portability Issues

During the Anaheim Special Event Test, one class of portability issues dealt with identifying sites large enough to accommodate the surveillance trailers that also provided an acceptable view of traffic flow and adequate signal strength. The large size of the trailers prevented them from being parked on city sidewalks or overpasses. Therefore, a four-step site survey process was developed, namely:

1. Confirm the identified property is available. Parking lots adjacent to the streets are ideal, except they are generally private property. Therefore, permission for their use must be obtained.

2. Confirm adequate space for parking the surveillance trailers. Several parking spaces are required to accommodate the trailer. Additional space is required to maneuver.

3. Confirm proper camera placement. Close placement to the road does not necessarily guarantee a usable view of traffic flow in the direction required for traffic management because of obstruction by trees, other foliage, power poles and transmission lines, buildings, or other structures.

4. Confirm signal strength at the relay site. The signal received at the relay site must be of adequate strength to allow retransmission to the TMCs and UCI-ITS Laboratory.

Several weeks and multiple personnel were required to survey the region, select the sites, perform signal-strength testing, secure the necessary permits, and determine the best way to maneuver the trailer into position. Ultimately, it took about an hour to transport the trailer a few kilometers and set it up at a predetermined site. As in the I-5 Test, the Anaheim Special Event Test demonstrated that once a trailer had been delivered to a particular special event site, subsequent installations were more easily executed. The major portability issues uncovered during the I-5 Test involved the trailer power system and learning that occurred with each trailer deployment.

The ease of trailer transportation and setup improved as Caltrans maintenance personnel gained experience with the procedures. The hitch times were less than 10 minutes when the trailers were functioning properly and all of the parts required for the operation were at hand. The set in place times were larger when the ramp meter trailers were part of the deployment. Time was needed to unload the signal heads and meter-on sign from the trailer and erect them at the desired locations. Usually a boom truck and a crew of at least five were required to unload and assemble the signal heads.

2.3 Effectiveness Issues

2.3.1 Power System

The most prevalent problem during the I-5 Test was frequent discharge of the surveillance trailer battery. This occurred because the automatic generator start system was not turning on and off at the preset battery voltages specified in the design of the charging system. Consequently, the trailer battery had to be jump started from an automobile battery. At other times, the generator could not be started at all and service personnel had to be called. The reliability of the Culver Drive trailer when operating on commercial power supported the conclusion that the generators and portable power system, in general, were the most troublesome part of the surveillance trailer system.

2.3.2 Camera Image and Control

Once the cameras and communications links were operational, camera control and picture quality were consistent from each venue. Exceptions occurred when strong winds moved the antennas or the mast accidentally dropped because the locking pins were not fully extended.

2.3.3 Effectiveness of VIP Data for Special Event Traffic Management

The additional video surveillance provided by the surveillance trailers assisted the event traffic manager in performing the traffic management function. The data suggest that the additional video may reduce the traffic egress time from a special event. However, this conclusion must be verified with additional testing for two reasons: (1) a limited amount of data was collected during the Anaheim Special Event Test and (2) the historical database, with which the data from the added video surveillance was compared, may not be accurate.

2.3.4 Effectiveness of VIP Data for Ramp Metering

Figure 2-1 shows the averages of the percent differences between the ILD- and VIP-measured lane occupancies and volumes for the fourteen rush-hour interval runs conducted during the I-5 Test. The data are from the Grand Avenue, Tustin Ranch Road, and Jamboree Road evaluation sites. Not all lanes reported valid data at each site according to the 170 controllers. At Tustin Ranch Road, for example, the 170 controllers flagged the Lane 1 and Lane 5 ILDs and the Lane 5 VIP detection zones for malfunctions or suspect data. At Jamboree Road, the Lane 2 ILDs and the Lane 5 VIP detection zones were flagged. Therefore, only the lanes reporting valid data at each site were included in Figure 2-1.

Lane 5, the lane closest to the shoulder, had the smallest percent difference in measured volume equal to –2.6 percent. The negative sign indicates that the VIP counted more vehicles than the ILD. Lane 3 had the smallest difference in occupancy measurement equal to 0.5 percent. The average percent differences in total volume and average occupancy over all lanes reporting good data were -22 and 8, respectively.

Two effects contribute to the less than optimal performance of the VIP compared with the inductive loops, especially in lanes further from the trailer location. Both effects are caused by the relatively low operational height of the VIP cameras above the road surface [approximately 32 ft (9.8 m)] as constrained by the height of the fully extended mast on the surveillance trailer. Tall vehicles, such as large commercial trucks, that project their image into adjacent lanes produce the first effect. The VIP detector zones in the adjacent lanes detect the truck as if it was actually traveling in those lanes. Depending on the location of the surveillance trailer with respect to the roadway, the tall vehicle can project its image into 1, 2, or 3 adjacent lanes. Thus, the VIP will overcount vehicles if this effect is present. The second factor that degrades VIP performance is blockage of shorter vehicles, such as passenger cars, in the lanes further from the camera by taller vehicles traveling in the lanes closer to the camera. This effect appears to be less prevalent than the detection of a tall vehicle in more than one lane.

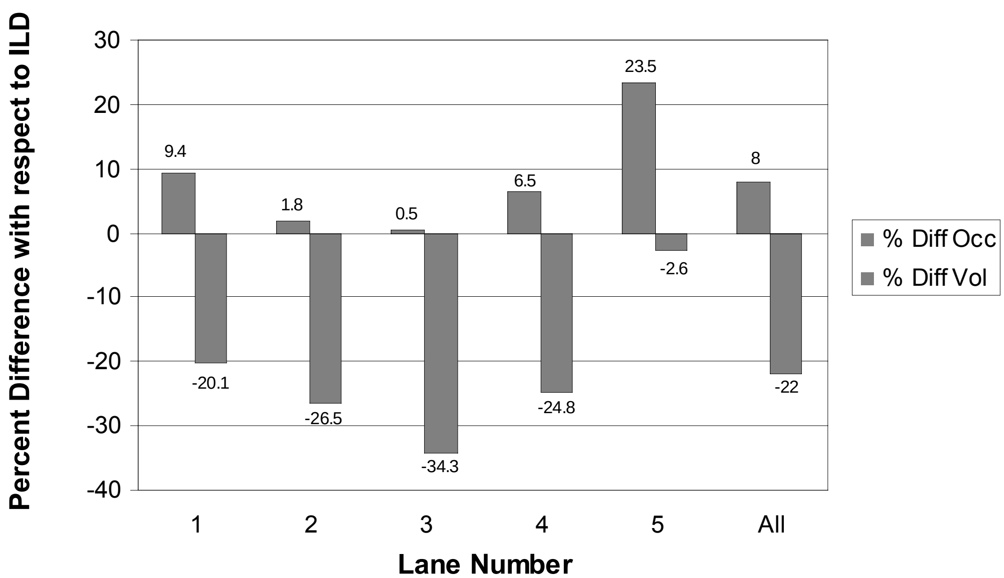


Figure 2-1. Average of the percent difference between average occupancies and total volumes over all I-5 Test runs as measured by the ILDs and VIP

Because of these two effects, it was anticipated that the vehicle counts and lane occupancies calculated by the VIP would be closest to the values calculated from the inductive loops in the lane nearest the surveillance trailer, i.e., the rightmost lane. In this lane, there would be no false images of tall vehicles or blockage of short vehicles by the taller ones. This premise is generally substantiated by the data in Figure 2-1.

Figure 2-2 compares the local-responsive meter rate computed from the ILD and VIP measurement data acquired at the Grand Avenue site during the afternoon rush hour interval on April 16, 1998. The ILD and VIP local-responsive rates are identical in the middle of the run. This is because a more restrictive metering rate (namely zero) than the prestored time-of-day (TOD) rate was calculated by the algorithm from the ILD and VIP real-time data. Therefore, the algorithm reverted to the less restrictive TOD rate for both sets of data. The differences in meter rates at the beginning and end of the data-recording period are attributable to initialization and data interruptions that occur during the start and end of a run.

When examining the data in Figures 2-1 and 2-2, a goal of the mobile surveillance and wireless communication system design should be recalled, namely that the surveillance trailers and mast height were not designed to maximize the accuracy of VIP data, but rather to acquire data that were accurate enough to support the ramp-metering function. The accuracy of the VIP data appears adequate for the rush-hour ramp-metering application. However, this conclusion must be verified with additional testing because only a limited amount of data were collected during periods when TOD metering did not override local-responsive metering.

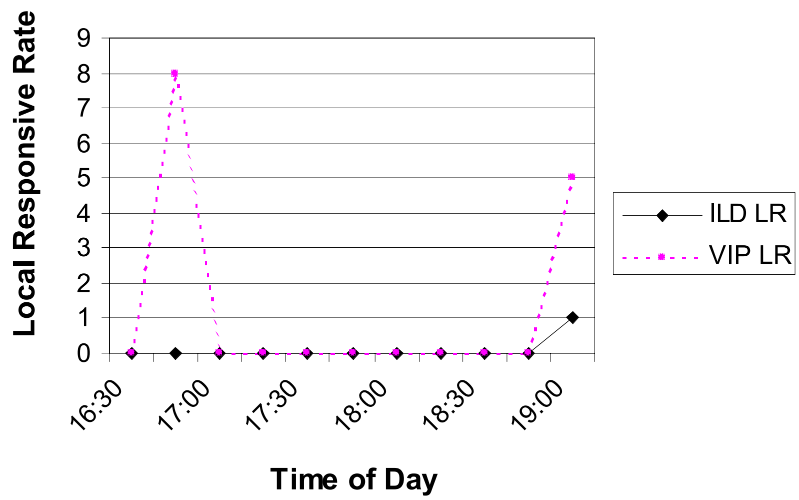


Figure 2-2. Local-responsive ramp meter rate (vehicles/minute) computed from ILD and VIP data at Grand Avenue during afternoon rush hours on 4/16/98

However, the larger percent differences between mainline volume measured by the ILDs and VIP may lead to the reporting of erroneous levels of service on the mainline. This potential problem is caused by the VIPs over estimating the volume by as much as 53 percent or under estimating it by as much as 14 percent. It is more likely that the VIP will overcount when the camera is mounted as it was in this evaluation.

2.3.5 Ramp Vehicle Presence Detection by VIP

The ramp signals responded properly to vehicle demand an average of 85 percent of the time at the three evaluation sites. This is not good enough for ramp-metering operation. A possible method to increase this average is to position the surveillance trailer, and hence the camera, closer to the ramp. This may provide a better perspective of the vehicles on the ramp and perhaps modify the camera's field of view to allow even more VIP detection zones to be created upstream of the ramp stop bar. All the detection zones can then be connected with OR logic, as they were during the FOT, to increase the probability that a stopped vehicle will be detected by the VIP. The 85 percent vehicle presence detection result is not surprising in light of the nonideal camera height mounting, i.e., 50 ft (15.2 m) or greater is recommended for the side-viewing geometry encountered in this application.

Other factors affected ramp meter control by the mobile system. These were: (1) daytime vehicle detection on ramps was sometimes affected by the relative color of a vehicle compared to the road surface; (2) nighttime vehicle detection on ramps was affected by the alignment of VIP detection zones with vehicle headlight beams; (3) ramp overflow detection by VIPs will most likely require an additional camera to detect vehicles at the ramp entrance. However, lack of overflow detection is not deemed a critical issue by Caltrans.

2.4 Institutional Issues

2.4.1 Liquid Propane Fuel Cost

The most likely estimate of liquid propane gas (LPG) consumption by a surveillance trailer is approximately 0.460 gallon/hr. With an LPG cost of $1.75/gallon, the estimated cost of fuel is $0.80/hr for surveillance trailer operation.

2.4.2 Ramp Meter Timing Plan Development

Caltrans ramp meter engineers are interested in using the surveillance trailers to support the development of ramp meter timing plans. To develop a ramp meter plan, the controlling bottleneck needs to be identified. This requires an analysis of traffic volume data that may not be available in some locations. Furthermore, manual traffic counts are labor intensive and, therefore, expensive. The surveillance trailers could be used to collect volume data that would otherwise be unavailable, thereby supporting the development of ramp meter plans. Some method of compensating for vehicle overcount by the VIPs would need to be developed in order to gather valid data.

2.4.3 Resource Sharing

Shared control of a surveillance camera by allied agencies at different facilities is not uncommon. This occurs whenever there is an incident within range of a shared camera. District 12 TMC personnel report that primary control typically goes to whichever agency has superior camera control capability. The Anaheim Special Event Test showed that security, permission to use private land, and liability concerns can be resolved if there is a desire to use the trailers. Perhaps the most serious disadvantage noted was that the benefits may not be commensurate with the amount of human, time, and fiscal resources that were expended. This concern may be ameliorated if a higher priority special event application for the trailers surfaces.

2.4.4 Information Sharing

The advantages of information sharing were recognized by Anaheim and Caltrans. The camera images allowed Caltrans to better manage freeway operations resulting from the traffic flow due to the special event. Personnel at both agencies learned more about the other’s operations. The disadvantages were overcome by arranging procedures to share the common video assets. The primary cost item for Anaheim was to provide personnel and space for the installation of the antennas and radios that receive the video imagery.

3. Conclusions

The conclusions below are those gathered from the planning and system development phase of the FOT and the Anaheim Special Event and I-5 Tests.

3.1 Planning and System Development

The FOT was able to assess the portability, effectiveness, and institutional issues relating to the mobile surveillance and wireless communication system using evaluation plans and test procedures developed during the FOT. The biggest issue addressed during the FOT was the schedule delay in building and deploying the trailers. This was in part due to deficiencies in the planning process, the multi-stage procurement process, and to requirements being added to the trailer design and operation, even as the design and assembly of the trailers, relay site, and TMC equipment was occurring. Closely related to the planning issues was the issue concerning whether the FOT was developing prototype equipment or operational equipment that could support normal transportation management functions. As the testing progressed, some modification of the test procedures was necessary because the 170-controller data calculated from VIP measurements could not be displayed or reliably updated on the graphical user interface at the Caltrans District 12 TMC.

Three issues that affect the portability of the mobile surveillance and communications system became apparent. First, the size of the trailers limits where they can be placed in a construction zone or to support a special event. Second, since the configuration of a construction zone may change weekly or daily, the trailer is subject to frequent moves that are exacerbated by their size. Third, since only one relay site has been built, the areas in which the trailers can be deployed are limited. Subgrade placement is not possible because of line-of-sight restrictions. Two recommendations based on these findings are that: (1) road construction contractors be made aware early in the planning process for the need to allocate sites for the surveillance, and perhaps ramp meter, trailers in the construction zones; (2) additional or supplemental relay sites be designed and deployed in areas from which Caltrans desires video and VIP data.

Institutional issues, such as sharing of video and data and paying for trailer transportation and setup, were raised and satisfactorily resolved. Other issues, such as liability for accidents that occur while a trailer is on private property or accidents that occur while Caltrans equipment is used by another jurisdiction, were also resolved satisfactorily.

Additional conclusions from the planning and system development phase are summarized below.

3.1.1 Planning

The execution of the FOT would have benefited from planning that acknowledged that additional requirements and tests could possibly emerge as the FOT progressed. Had the possibility for additional requirements been considered and formally communicated to the partner agencies and companies earlier in the planning cycle, some of the encountered delays could have been better accommodated or reduced.

3.1.2 Project Schedule

Allotting more time in the schedule for each increase in scope in the trailer's design or function would have allowed Hughes to adequately design, fabricate, and test each component of the trailer system. Furthermore, changes in scope should have been limited. Some date on the schedule should have been chosen as a cut-off after which no further design changes were permitted. Belated design modifications aggravated the already difficult task of systems integration and delayed some subsystems tests. Lack of early testing prevented early discovery of some problems and, subsequently caused the schedule to slip, thereby creating delays for other FOT tasks.

3.1.3 Procurement Process

The procurement process had a significant impact upon the project schedule as much of the FOT focused on trailer systems integration. The procurement was many faceted. Hughes researched and recommended items for purchase, Caltrans approved the items, and UCI purchased the approved items for Hughes to assemble and integrate into the trailers, TMCs, UCI, or relay site. This process became cumbersome at times, thereby contributing to project delay. Difficulties included misconceptions regarding the division of procurement responsibility and mid-project changes to technical specifications. The problems with the procurement process were compounded by some vendors who were unable to supply items in a timely manner. Allowing the primary contractor a more direct method of parts procurement, perhaps through a project credit card, for items costing less than some predetermined amount would have been helpful.

3.1.4 Prototype Equipment Versus Operational Equipment

There appeared to be a conflict between the desire of Caltrans to have completely developed operational equipment upon completion of the FOT and the FOT objective to develop and build a prototype unit for evaluation purposes, which could be improved upon if necessary. This issue sometimes resulted in conservative specifications, such as the need for the surveillance trailer to withstand a 70-mi/h (113-km/h) wind. On the other hand, there was a desire to save money that led to purchasing equipment that failed to fulfill requirements, such as the original radio transmitter/receiver pair to control the meter-on sign.

3.1.5 Cost Centers and Personnel Year (PY) Allocations

Funds and personnel were not initially provided to the Caltrans or Anaheim maintenance or electrical departments for FOT planning and routine trailer maintenance. Consequently, personnel supervisors in these departments resisted requests to allocate time and resources for these tasks. This continued to impact the utilization of the trailers until funds were allocated for their upkeep and transport. Therefore, special cost centers should be created and funded early in the program to facilitate design, maintenance, and transportation during and after the FOT.

3.1.6 Trailer Hitch Redesign and Replacement

The design requirements for the trailers failed to specify the Caltrans hook-and-pintel trailer hitch. Consequently, the originally installed ball hitches had to be replaced. A mechanism for raising and lowering the hitches on the trailers was also needed to accommodate the different heights of the tow vehicles. The project delays caused by installation of an improper hitch could have been avoided if Caltrans maintenance was invited to review and approve the trailer design.

3.1.7 Charging and Maintenance of Batteries

One of the major contributors to test delays once the trailers were deployed was the poor performance of the analog control system that maintained the charge in the primary trailer batteries. The analog control did not provide repeatable turn-on and turn-off of the generator and, hence, failed to maintain the battery voltage. The analog control system was replaced with a microprocessor-based system that corrected the lack of repeatability in generator control and battery charge. After the FOT was completed, an extensive redesign of the generator, batteries, charging system, and power distribution architecture was completed. The new power system was installed in the six surveillance trailers, but was not evaluated as a part of the FOT.

3.1.8 Automatic Mast Retraction

The decision to modify the surveillance trailer mast to include automatic mast retraction caused significant delays and introduced logistical challenges. Introduction of this modification after the trailers were already assembled and deployed delayed its implementation and impacted the FOT schedule.

3.1.9 Data Capture

Polled 170-controller data from the surveillance trailers were not fully integrated with the District 12 TMC software to allow their display on a workstation graphical user interface (GUI). The evaluators also observed that the polled 170-controller data from the permanent inductive loops were not always updated in a periodic manner. Another issue that affected the transmission of 170-controller data to the TMC was based on a Caltrans observation that the wide area communications controller crashed intermittently and then rebooted itself. This behavior was more frequent as the number of surveillance trailers online increased from one to six. Remedies were attempted, but the VIP data remained unavailable from the GUI for the duration of the FOT. Consequently, the I-5 Test Evaluation Plan was modified to bypass this interface. Two laptop computers were used instead to poll and record data from the 170 controllers in the surveillance trailers (VIP data) and roadside cabinets (ILD data).

3.1.10 Shared Camera Selection and Control Among Agencies

The original design of the communications network was not fully compatible with the desire to allow several agencies to share and control their own access to real-time traffic information. Consequently, the video switching and control system was modified midway through the project to add video control by the Anaheim TMC.

3.1.11 Relay Site

Establishing the relay site became a critical path task, as it was an integral part of the wireless communications system used to transmit video and data from the trailers to the TMCs and UCI-ITS Laboratory. Site development required multiple steps beyond determining the best location. These included negotiating access to space, securing liability coverage, taking responsibility for any possible increase in property taxes, and providing reasonable upkeep to the site and equipment.

The current relay site limits trailer deployment to the 5-mi (8-km) radius surrounding the Union Bank building in Santa Ana, CA. Caltrans has been presented with five options for extending the communications area. A determination should be made as to which option is most suitable and that option should be implemented.

3.1.12 Trailer Security System

Operation of the security system presented challenges during the initial stages of the project. Early communication between project staff and the CHP was incomplete. Consequently, the responsibility and actions required of CHP officers to trailer security alarms was unclear and the exact locations of some of the surveillance trailers was unknown to them. Perhaps the most serious problem identified with the security system was the initial procedure by which the TMC operators were detecting and responding to alarms. The TMC "attention" tone would sound dozens of times each day simply because a status notification was being transmitted. It required no immediate action, as would an intruder-initiated security alarm. Consequently, the TMC staff lost interest and stopped checking the security system output. This problem was remedied by suppressing the alarm when normal status was reported.

3.1.13 Technical Training

The partners failed to reach an early understanding regarding the level and amount of training that would be provided to Caltrans and Anaheim personnel. Some personnel nominated for training could not obtain permission to attend because training time could not be afforded. Some personnel available for training did not get adequate advance training and thus became heavily dependent upon on-the-job training. Many of those that did receive advance training required refresher courses because the initial training was completed many months prior to the first trailer deployment and, hence, the first opportunity to apply the skills they had learned.

3.1.14 Trailer Transport and Setup

Trailer transport and setup became more efficient as personnel gained experience working with the trailers. A major issue uncovered early in the FOT was the need to better contain trailer functional requirements. Imposing additional requirements (e.g., adding eight stabilizing plates to support the signal heads and meter-on sign on the ramp meter trailer) added weight that increased the ramp meter trailer load to the point where it exceeded the maximum design load. A solution may be to equip the ramp meter trailers with larger tires or dual tires.

3.1.15 Equipment Costs

The equipment costs for the surveillance and ramp meter trailers, Caltrans District 12 TMC, Anaheim TMC, ITS laboratory at UCI, and the relay site are summarized in Table 3-1. Prices for some equipment, such as the security system telephones and security alarm receiver and printer located in the Caltrans District 12 TMC, were not available. The cost for the winch and hydraulic crane that were used to service the generators is shown on the District 12 TMC equipment list, although it is a service item. Figure 3-1 illustrates the relative contributions of the six surveillance trailers, three ramp meter trailers, District 12 and Anaheim TMCs, UCI-ITS Laboratory, and the relay site to the total equipment expenditure. The six surveillance trailers represent 70 percent ($749,778) of the total equipment cost, the three ramp meter trailers 16 percent ($171,540), the District 12 TMC 5 percent ($50,552), the Anaheim TMC 2 percent ($23,654), the UCI-ITS Laboratory 2 percent ($24,399), and the relay site 5 percent ($57,109). One surveillance trailer and its associated equipment therefore cost approximately $125,000 and one ramp meter trailer and its equipment approximately $57,000.

Table 3-1. Equipment cost summary

Item		**Unit Cost**	**Quantity**	**Total**
Surveillance Trailers				
Trailer, Generator, Mast, etc.		$48,403	6	$290,418
Equipment		$76,560	6	$459,360
	Subtotal	$124,963	6	*$749,778*
Ramp Meter Trailers				
Trailer, Generator, Signals, etc.		$40,334	3	$121,002
Equipment		$16,846	3	$50,538
	Subtotal	$57,180	3	*$171,540*
Caltrans District 12 TMC		$50,552	1	*$50,552*
Anaheim TMC		$23,654	1	*$23,654*
UCI-ITS Laboratory		$24,399	1	*$24,399*
Relay Site		$57,109	1	*$57,109*
Grand Total				**$1,077,032**

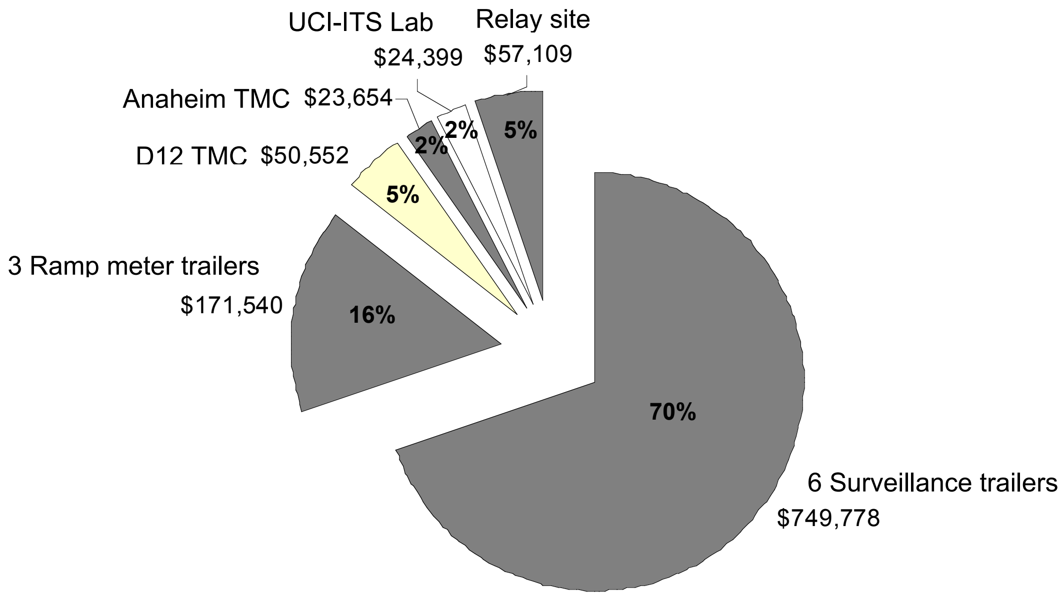


Figure 3-1. Relative contributions of the six surveillance trailers, three ramp meter trailers, District 12 and Anaheim TMCs, UCI-ITS Laboratory, and relay site to total equipment expenditure

3.2 Anaheim Special Event Test

The Arrowhead Pond hockey games provided an opportunity for testing the functionality and effectiveness of the mobile surveillance trailers in a special event setting. The trailers were placed in strategic locations near traffic signals to assist traffic officers and TMC operations personnel during the traffic egress period that followed each game. The Anaheim Special Event Test showed that there was value in deploying the surveillance trailers to a special event location. The operators at the Anaheim TMC found the imagery of traffic flow from streets normally without video cameras an asset in controlling the phases of traffic signals. Caltrans received information about traffic approaching freeways in advance of it entering the freeway.

The objectives of the test were satisfied as shown by the findings below.

3.2.1 Objective 1: Portability

3.2.1.1 Transportation

After the trailers were initially transported to the special event sites, subsequent moves were more easily accomplished. Site selection procedures required substantial time to survey the region, locate potential sites, perform signal testing, secure the necessary permits and permissions, and determine the best way to maneuver the trailer into position. It took about an hour and twenty minutes to transport the trailer a few miles, set it in place, and make it operational at a previously selected site.

3.2.1.2 Trailer Readiness

The trailers required frequent maintenance of propane fuel, battery water, oil, and other expendables. When routine maintenance is neglected, the trailers become unusable. The myriad of complex equipment in each of the trailers requires detailed maintenance procedures such as those recommended by Hughes. They are found in Appendix B of Volume 3 of the Final Report. Down time can be reduced by placing each trailer on a revolving maintenance schedule. Such a procedure will ensure that no two trailers are off line for maintenance during the same period. Construction of future trailers should incorporate features that support easy maintenance by field personnel, such as improving access to components that require maintenance (such as the batteries).

3.2.2 Objective 2: Effectiveness of Trailers for Special Event Management

The trailers perform well in a city special event setting when site survey and site selection are performed properly. Carefully positioned trailers produced imagery that was valuable to event traffic managers. Once a camera was operating, its control and image quality remained constant from day to day. Darkness had a detrimental effect on the clarity of the image from the color surveillance camera. However, higher sensitivity color cameras can be purchased to upgrade the system. If trailer placement is suboptimum, the view may be unsatisfactory due to improper camera angle or distances to the areas of interest. The large size of the trailers may lead to less than optimum trailer placement.

3.2.3 Objective 3: Benefits of Additional Surveillance

The additional video surveillance provided by the surveillance trailers assisted TMC personnel in performing traffic management functions. The data suggest that the additional video may reduce the traffic egress time from a special event. However, this conclusion must be verified with additional testing for two reasons: (1) a limited amount of data was collected during the Anaheim Special Event Test and (2) the historical database, with which the data from the added video surveillance was compared, may not be accurate.

3.2.4 Objective 4: Resource Sharing Institutional Issues

The advantages, disadvantages, and costs associated with resource sharing between Anaheim and Caltrans were evaluated. The surveillance trailers provide tactical, strategic, and historical data to aid in traffic management. Tactical data are obtained in real time from the cameras and aid in controlling signal timing. The trailers serve as a strategic asset since they can be incorporated into plans that are developed for special event traffic management. Finally, the data obtained from the trailers can be stored in a database for later recall. Most, if not all, of the institutional disadvantages can be overcome with planning. Budgets can be provided for personnel who transport and operate the trailers. The Anaheim Special Event Test showed that security, permission to use private land, and liability concerns can be resolved if there is a desire to use the trailers. Perhaps the most serious disadvantage noted was that the benefits may not be commensurate with the amount of human, time, and fiscal resources that were expended. This concern may be ameliorated if a higher priority application for the trailers surfaces.

3.2.5 Objective 5: Information Sharing Institutional Issues

The advantages of information sharing were recognized by Anaheim and Caltrans. The camera images allowed Caltrans to better manage freeway operations from the traffic flow due to the special event. Both agencies learned more about the other's operations. The disadvantages were overcome by arranging procedures to share the common video assets. The primary cost item for Anaheim was to provide personnel and space for the installation of the antennas and radios that receive the video imagery.

3.3 I-5 Test

The I-5 Test demonstrated that mobile surveillance and ramp meter trailers can be deployed along freeways to control ramp-metering rates during rush hours and transmit video imagery to TMCs and research facilities. The most troublesome technical issue during the I-5 Test was the reliability of the portable power generation system. It was eventually redesigned toward the end of the FOT. Two items impacted the start of the test once the trailers were deployed. They were (1) the initial lack of ramp signal synchronization with vehicle demand and control commands from the surveillance trailer and (2) the failure to communicate the requirement for displaying a long yellow signal before the initial red ball when the ramp meter is first turned on. The first problem was remedied by reducing the transmission rate of the commands. The second was fixed when the requirement was finally communicated to and understood by the software developer. A problem that persists, however, is the lack of 100 percent detection of all vehicles at the VIP ramp demand detector. This issue should be investigated further. Perhaps the problem can be solved by adding an even greater number of detection zones before the stop bar. The multiple detection zone technique is used for VIP presence detection at arterial traffic signal stop bars.

The reliability of the ramp meter hardware and software improved substantially during the course of the evaluation once data transmission timing problems were identified and remedied. Although there are issues concerning the accuracy of the VIP mainline data as compared to the data from the permanent ILDs and the requirement to detect all vehicles at a ramp signal stop bar, the VIP mainline data do appear accurate enough to control local-responsive ramp meter rates during rush hours. One drawback may be the larger mainline traffic volume measured by the VIP and its impact on the level of service that is reported. Therefore, a method of compensating for vehicle overcount by the VIPs is needed in order to report valid results. If the ramp-metering function is to become operational, then a technique to ensure vehicle presence detection approaching 100 percent must also be found.

The objectives of the I-5 Test were satisfied as shown by the findings below.

3.3.1 Objective 1: Portability

3.3.1.1 Power System

The most prevalent problem uncovered during the I-5 Test was frequent discharge of the surveillance trailer battery because the automatic generator start system that sensed the battery voltage was not functioning properly. Consequently, the generator had to be jump started from an automobile battery. At other times, the generator could not be started at all and service personnel had to be called. The reliability of the Culver Drive trailer when operating on commercial power supported the conclusion that the generators and portable power system, in general, were the most troublesome part of the surveillance trailer system. The power generation and distribution system was redesigned and new power system components installed in all the surveillance trailers upon completion of the FOT. However, the new power generation system was not evaluated as part of the FOT.

3.3.1.2 Ramp Meter Signal Synchronization with Commands

Loss of ramp meter signal synchrony with vehicle demand on the ramp and with the synchronizing signal from the surveillance trailer delayed the start of the I-5 Test. The problem was fixed by reducing the transmission rate used to send commands between the surveillance and ramp meter trailers. Another change that alleviated this problem was to decrease the delay in sending commands to the ramp trailer to 100 milliseconds from 5 seconds.

3.3.1.3 Ramp Signal Sequence at Turnon

Another design issue that delayed the start of the I-5 Test was due to a misunderstanding between Caltrans and the system designers as to how the ramp meter signal sequence must operate when it first turns on. The Caltrans requirement to have a relatively long yellow phase follow the initial green ball was initially not conveyed to or understood by the system integrators.

3.3.1.4 Transportability

The ease of trailer transportation and setup improved as the maintenance personnel gained experience with the procedures. The hitch times were less than 10 minutes when the trailers were functioning properly and all of the parts required for the operation were at hand. The set in place times were larger when the ramp meter trailers were part of the deployment. Time was needed to unload the signal heads and meter-on sign from the trailer and erect them at the desired locations. Usually a boom truck and a crew of at least five were required to unload and assemble the signal heads.

3.3.2 Objective 2: Effectiveness of Trailers for Traffic Management

3.3.2.1 Camera Image and Control

Once the cameras and communications links were operational, camera control and picture quality were consistent from each venue. Exceptions occurred when strong winds moved the antennas or the mast accidentally dropped because the locking pins were not fully extended.

The stops on the surveillance camera should be adjusted during trailer setup to ensure that the camera can rotate to provide imagery of the mainline upstream and downstream traffic flow.

Higher sensitivity color surveillance cameras should be sought to provide better imagery on poorly lighted roads.

The pan and tilt unit for the surveillance camera should be upgraded to a model that can support more weight. The manufacturer reduced the weight limit on the selected unit after it was purchased. The tests showed it couldn't raise the combined weight of the camera and enclosure if the loaded unit was tilted near its lower limit.

To prevent vandalism to the security camera's video and power cables, the cables should be protected, e.g., by placing them in conduit. When the trailers are left unattended at a remote site for an extended period, they are more likely to be vandalized as evidenced by thefts that occurred after the FOT was completed.

3.3.2.2 Comparison of VIP and ILD Data

Since the District 12 Automated Traffic Management System software was not polling the 170 controllers in all of the trailers, or not polling them consistently, the VIP data percent up time at the District 12 TMC was low, approaching zero. Therefore, two laptop computers connected to the 170 controllers in the surveillance trailers and roadside cabinets were used to acquire data to compare VIP- and ILD-measured volumes and occupancies at the ramp meter evaluation sites.

The average percent differences between the ILD- and VIP-measured mainline volume and average lane occupancy are –22 and 8, respectively, based on data gathered during the fourteen runs completed in the I-5 Test. These accuracies appear adequate for the rush-hour ramp-metering application as shown by the tracking of the local-responsive metering rates produced by the ILD and VIP data. This is because a more restrictive metering rate (namely zero) than the prestored TOD rate was calculated by the metering algorithm from the ILD and VIP real-time data. Therefore, the algorithm reverted to the less restrictive TOD rate for both sets of data. To verify that the VIP data are sufficient to support local-responsive metering, additional data should be gathered during periods of lighter mainline traffic when the local-responsive algorithm will not clamp at the TOD limit.

The larger percent differences between mainline volume measured by the ILDs and VIP may lead to the reporting of erroneous levels of service on the mainline. This potential problem is caused by the VIPs over estimating the volume by as much as 53 percent or under estimating it by as much as 14 percent. It is more likely that the VIP will overcount when the camera is mounted as it was in this evaluation. Some method to compensate for the overcount should be developed.

ILD-produced local responsive metering rates for the afternoon runs at the Tustin Ranch Road and Jamboree Road sites appear erratic. The same behavior was not observed during the morning runs at these sites or at the morning or afternoon runs at the Grand Avenue site. This “afternoon effect” bears further investigation.

3.3.2.3 VIP Control of Ramp Signals

The ramp signals responded properly to vehicle demand an average of 85 percent of the time. This is not good enough for ramp-metering operation. A possible method to increase this average is to position the surveillance trailer such that the camera’s field of view (FOV) allows additional VIP detection zones to be created upstream of the stop bar and then connecting all the zones with OR logic. Another way to increase the camera’s FOV is by installing a wider FOV lens. This solution may, however, decrease the imaged size of the ramp on the monitor and thus make it more difficult to create multiple detection zones.

Daytime vehicle detection on ramps is sometimes affected by the relative color of a vehicle compared to the road surface.

Nighttime vehicle detection on ramps is affected by alignment of VIP detection zones and vehicle headlight beams.

Ramp overflow detection by VIPs will most likely require an additional camera to detect vehicles at the ramp entrance. However, lack of overflow detection is not deemed a critical issue by Caltrans District 12 engineers.

3.3.3 Objective 3: Freeway Deployment Institutional Issues

3.3.3.1 LPG Fuel consumption

The most likely estimate of LPG consumption by a surveillance trailer is approximately 0.00522 tank/hr or 0.460 gallon/hr. With an LPG cost of $1.75/gallon, the estimated cost of fuel is $0.80/hr for surveillance trailer operation.

3.3.3.2 GUI Trailer Location Updates

Each time a trailer is moved to a new freeway location, the field device database on the GUI at the District 12 TMC must be updated to reflect the new trailer location. If this task is not performed, the trailer icon on the TMC map display does not reflect the actual trailer location. However, if the trailer location icon is updated, the data gathered at the previous trailer location are automatically removed from the database. This may present a problem if it is necessary to retrieve the previous data for later use. A solution may be to add alpha characters or in some other way modify the trailer name each time the trailer is moved. In this manner, the computer program will think a new trailer has been added to the array. The drawback with this approach is that the display will eventually become cluttered with icons that represent nonexistent trailers.

3.3.3.3 GUI Trailer Cluster Icons

The trailer location icon cluster on the GUI consists of many closely spaced camera and detector icons. District 12 TMC personnel report difficulty in selecting the one icon they need from among the many in the cluster. It has been suggested that a single icon representing the trailer replace this cluster of icons. A mouse click to the new icon would trigger the image from the pan-tilt-zoom surveillance camera on the trailer. Buttons on this initial video window would then allow the other cameras and detector stations to be selected.

3.3.3.4 Traffic Management Plan

Each construction project is accompanied by a formal traffic management plan. If the surveillance trailers are included as part of a future construction zone traffic management plan, the contractor would be obligated to accommodate the trailer and protect it. However, there are not any current plans to use the surveillance trailers in future or ongoing projects.

3.3.3.5 Ramp Meter Trailers

There has been no experience to date using the ramp meter trailers in construction zones. There appears to be no current interest at District 12 in using the ramp meter trailers for a temporary ramp meter installation. One Caltrans engineer explained that Caltrans would prefer a permanent ramp meter installation to a temporary installation in order to ensure driver acceptance and compliance. It has been suggested that the ramp meter trailers be used to meter parking lot egress at special events.

3.3.3.6 Ramp Meter Timing Plan Development

Caltrans ramp meter engineers are interested in using the surveillance trailers to support the development of ramp meter timing plans. To develop a ramp meter plan, the controlling bottleneck needs to be identified. This requires a thorough analysis of traffic volume data that may not be available in some locations. Furthermore, manual traffic counts are labor intensive and, therefore, expensive. The surveillance trailers could be used to collect volume data that would otherwise be unavailable, thereby supporting the development of ramp meter plans.

3.3.4 Objective 4: Information Sharing Institutional Issues

3.3.4.1 Video Sharing

Shared control of a surveillance camera by allied agencies working from different sites is not uncommon. This occurs whenever there is an incident within range of a shared camera. District 12 TMC personnel report that primary control typically goes to whichever agency has superior camera control capability.

3.3.4.2 Research

The UCI-ITS laboratory is also interested in using the surveillance trailers to fill gaps in the available inductive loop database. To date, research personnel have not used the trailers to gather data. The current surveillance trailer design uses a 170 controller to poll the VIP for data at 30-s intervals. Therefore, data at less than 30-s intervals (of interest in some research projects) are not presently available.

4. Recommendations

The major recommendations of the evaluators have been grouped into three categories as summarized below.

4.1 Planning and Policy

1. Road construction contractors be made aware early in the planning process for the need to allocate sites for the surveillance, and perhaps ramp meter, trailers in the construction zones;

2. Additional or supplemental relay sites be designed and deployed in areas from which Caltrans desires video imagery and VIP data;

3. Contractors working on projects similar to this FOT be allowed a more direct method of parts procurement, perhaps through a project credit card, for items costing less than some predetermined amount;

4. Schedules in future programs reflect the possibility for some added requirements and for testing of all subsystems prior to system integration;

5. Cutoff dates be established after which further requirements are not permitted to be added;

6. A clear delineation between the goals for a concept validation program versus a program to develop operational equipment be established;

7. Cost centers be created for all stakeholders to participate in the design and execution of future programs;

8. A regular trailer maintenance schedule be established and executed;

9. Additional personnel, especially engineers, be trained in operating and diagnosing causes of problems in the electrical and mechanical equipment in the trailers and TMC.

4.2 Technical

10. Problems with polling 170-controllers in the surveillance trailers and displaying their output data on TMC workstations be resolved;

11. A method of compensating for mainline vehicle overcount by the VIPs be developed in order to report valid mainline traffic volumes and levels of service;

12. A technique to ensure onramp vehicle presence detection approaching 100 percent be found.

4.3 Hardware Upgrades

13. The pan and tilt assembly used for the color surveillance cameras be replaced with a model that can support more weight;

14. Cables and wires that are associated with the security camera be enclosed in metal conduit;

15. Higher sensitivity color cameras be purchased for any future surveillance needs.

4.4 Optimization of Existing Equipment

16. Stops on the surveillance camera be adjusted during trailer setup to ensure that the camera can rotate to provide imagery of the mainline upstream and downstream traffic flow;

17. Camera sun shields be moved as far forward as possible to minimize sun glint and rain from interfering with camera operation.