U.S. Department
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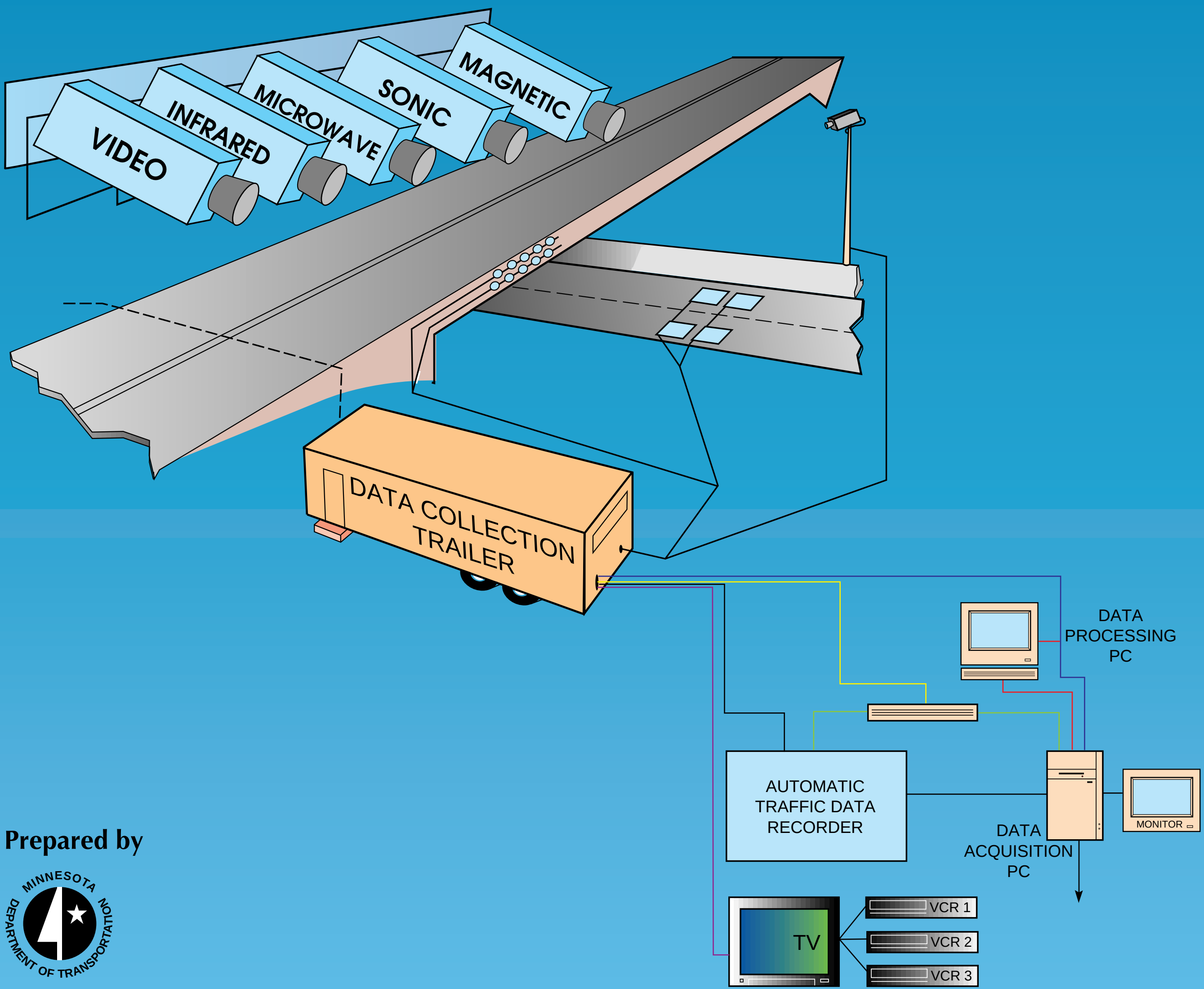
FIELD TEST OF MONITORING OF URBAN VEHICLE OPERATIONS USING NON-INTRUSIVE TECHNOLOGIES

Final Report



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FIELD TEST OF MONITORING OF URBAN VEHICLE OPERATIONS USING NON-INTRUSIVE TECHNOLOGIES FINAL REPORT

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<u>Note on Video Images</u>

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Field Test of Monitoring of Urban Vehicle Operations Using Non-Intrusive Technologies: Final Report

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EXECUTIVE SUMMARY

I. INTRODUCTION

This report documents the activities and results of a 2-year test of non-intrusive traffic detection technologies. The test was initiated by the Federal Highway Administration (FHWA) and conducted by the Minnesota Department of Transportation (Mn/DOT) and SRF Consulting Group, Inc. (SRF). The main goal is to provide practitioners with useful information about the performance of non-intrusive technologies and specific devices within each technology. The capabilities and limitations are analyzed under a variety of conditions. However, because of the complexities involved in selecting a device for a particular application, such as data needs, mounting locations, traffic and weather conditions, and cost, this report does not make specific recommendations or rank devices. Rather, this report provides basic information on which technology is most suitable for various specific data collection needs.

II. BACKGROUND

The collection of historical traffic data in urban areas is essential in making well-informed transportation planning decisions. Until recently, however, the methods for collecting historical traffic data were limited to fixed counting locations using inductive loop detectors, or temporary counting locations using road tubes or manual counts. Each of these methods has limitations, such as disruption of traffic flow, that make urban traffic data collection a significant challenge. These limitations have spurred the development of products that use non-intrusive technologies to detect traffic.

Evaluation of each technology's data collection capabilities covered both the quality and types of data collected. Emphasis was placed on urban traffic conditions, such as heavy congestion, and locations that typify temporary counting locations, such as 48-hour or peak hour counts. The evaluation also focused on the ease of system setup and use, general system reliability, and system flexibility. The performance of the technologies was evaluated under the extreme weather conditions found in Minnesota over the year. The technologies were evaluated at both freeway and intersection locations to provide a variety of traffic conditions.

Non-intrusive detection technologies, as defined for the purposes of this test, are those technologies where deployment causes minimal disruption to normal traffic operations and installation can be done more safely than conventional methods. Based on this definition, non-intrusive technologies are represented by devices that do not need to be installed in or on the pavement but can be mounted overhead, to the side, or beneath the pavement by "pushing" the device in from the shoulder.

The eight technologies evaluated in this project are listed below:

1. Passive Infrared
2. Active Infrared
3. Passive Magnetic
4. Radar
5. Doppler Microwave
6. Pulse Ultrasonic
7. Passive Acoustic
8. Video

III. PROJECT OUTLINE

The project was divided into four tasks. The first task, the Initial Technology Review, included interviewing representatives from 11 state transportation agencies around the country to determine what research would be most useful to the transportation community. Also, a search of related research on traffic data collection practices was done. Finally, a list of the non-intrusive devices available in the United States market was developed. Twenty-one vendors were contacted for information on 21 devices.

In the next task, 11 non-intrusive vehicle detectors were tested in an Initial Field Test. All devices, except for the magnetic probes, were mounted on a bridge over Interstate 394 near downtown Minneapolis, Minnesota. The magnetic probes were installed under the pavement. Inductive loops carefully groundtruthed and used to provide baseline data.

In the third task, the Extended Field Tests, performance of the technologies and devices was evaluated over a 1-year period in a variety of environmental, traffic and mounting conditions. Devices were tested at both the freeway and a nearby intersection. As new devices became available they were added to the project.

The final task involved the preparation of the Final Report. This report summarizes the findings of the entire project, analyzing the performance potential of each type of technology as well as the performance of specific devices.

IV. RESULTS

Data were collected in both 24-hour and multiple week continuous test periods. When evaluating the various technologies it is important to examine the specific test conditions because the test periods included multiple mounting locations and test conditions over the year. Analysis of the potential for each technology to detect traffic under optimal conditions is given below. Refer to the Results section of the report for specific information on each device and the problems encountered.

1. Passive infrared technologies have good potential for detecting traffic at both intersection and freeway applications.

2. Active infrared technology was only tested at the freeway, where it exhibited good potential for vehicle detection.

3. Passive magnetic technology mounted in a conduit under the pavement has the potential for accurately detecting traffic, however, reliability problems were encountered during testing of the devices. This was probably due to the specific device tested or to cabling problems, not the technology itself. The installation of the magnetic probes under the freeway was much more involved than installation of the above-ground devices tested.

4. At the freeway test site doppler microwave technologies have good potential for detecting traffic and measuring the speed of moving vehicles. Data collection performance at the intersection test site was poor.

5. Radar technology was only tested at the freeway test site where it exhibited good potential for detecting traffic and measuring vehicle speed. The technology also has the advantage of being mounted from a sidefire location, perpendicular to the direction of traffic.

6. Pulse ultrasonic technologies have good potential for detecting traffic at both intersection and freeway applications.

7. Passive acoustic technologies have moderate potential for detecting traffic at the intersection and freeway test sites.

8. Video requires extensive installation and setup time and is not as accurate as other technologies, but it has the advantage of offering a wide variety of traffic data. They also have the advantage of sidefire mounting and can offer surveillance information.

V. CONCLUSIONS

The following factors must be considered when evaluating the non-intrusive devices tested in this project.

- Level of expertise required and time spent installing and calibrating a device,
- Reliability of a device,
- Number of lanes a device can detect,
- Mounting options such as overhead, sidefire and height,
- Ease of installation and moving from one location to another,
- Capability for remote adjustment of calibration parameters and trouble shooting,
- Wireless communication to simplify the data retrieval process,
- Solar powered or battery powered devices for temporary counts in locations without an accessible source of power,
- Type of traffic data provided,
- Performance in various weather and traffic conditions, and
- The intended use for a particular device; a device used to actuate a signal must meet a different set of performance criteria than a device used to collect historical traffic data. Some devices are also designed to offer real time information for ITS applications.

The following lists the major conclusions from the test:

- Most of the devices tested in this project are well-suited for temporary counting situations. Ease of installation and flexibility in mounting locations and power supplies are important elements in selecting a device to install quickly and move from location to location.
- The devices that use doppler microwave, active infrared, and passive infrared technologies have a simple "point-and-shoot" type of setup.
- Passive magnetic, radar, passive acoustic and pulse ultrasonic devices require some type of adjustment once the device is mounted. In most cases this adjustment must be performed over a serial communication line.
- Video devices require extensive calibration over serial communication lines and are not well-suited for temporary counting.
- Extensive installation work is required for video and passive magnetic devices, making them less suitable for temporary data collection.
- From an overhead mounting location at the freeway test site, the video and passive acoustic devices have been found to count to between 4 and 10 percent of baseline volume data.

- Pulse ultrasonic, doppler microwave, radar, passive magnetic, passive infrared, and active infrared have been found to count within 3 percent of baseline volume data.
- The count results are more varied at the intersection test site. The pulse ultrasonic, passive acoustic, and video devices were generally within 10 percent of baseline volume data while one of the passive infrared device was within 5 percent.
- Speed data were collected from active infrared, passive magnetic, radar, doppler microwave, passive acoustic and video devices at the freeway test site. In general, all of the devices were within 8 percent of the baseline data. Radar, doppler microwave, and video were the most accurate technologies at measuring vehicle speeds.
- Video and radar devices have the advantage of multiple-lane detection from a single unit. Video has the additional advantage of providing a view of the traffic operations at the test site.
- Weather variables were found to have minimal direct affect on device performance, but snow on the roadway caused some vehicles to track outside of their normal driving patterns, affecting devices with narrow detection zones.
- Lighting conditions were observed to affect some of the video devices, particularly in the transition from day to night.
- Extremely cold weather made access to devices difficult, especially for the magnetic probes installed under the pavement.
- Urban traffic conditions, including heavy congestion, were found to have little affect on the device performance.
- In general, the differences in performance from one device to another within the same technology were found to be more significant than the differences from one technology to another.
- It is more important to select a well designed and highly reliable product than to narrow a selection to a particular technology.

There are ongoing developments in non-intrusive vehicle detection technologies. Devices are now available that incorporate multiple technologies within a single device. Developments in other technologies, such as passive millimeter microwave and infrared video, will produce additional entries into the market. At the same time, existing technologies are continually being improved upon.

FIELD TEST OF MONITORING OF URBAN VEHICLE OPERATIONS USING NON-INTRUSIVE TECHNOLOGIES

FINAL REPORT

I. INTRODUCTION

A. Project Overview

Collection of historical traffic data is essential in making well-informed transportation planning decisions. In urban areas, existing methods for collecting wide area historical traffic data often are not always adequate because they can require disruption of traffic flow and can expose staff to unsafe conditions. The limitations of existing methods have spurred the development of products that use non-intrusive technologies to detect traffic.

A 2-year test of the available non-intrusive traffic detection technologies was initiated by the Federal Highway Administration (FHWA) and conducted by the Minnesota Department of Transportation (Mn/DOT) and SRF Consulting Group, Inc. (SRF). The main goal was to evaluate the capabilities of non-intrusive technologies to detect vehicles under a wide variety of conditions. A secondary goal was to assess the performance of the specific devices within each type of technology.

The devices tested utilize magnetic, sonic, ultrasonic, microwave, radar, infrared and video technologies. The project was intended to provide an analysis of device capabilities in a wide variety of weather and traffic conditions. The Minnesota test site provided an excellent location for exposing devices to relatively large temperature extremes, rain, sleet, snow and high winds.

The testing was conducted in two phases. Phase I, running from November 1995 to January 1996, consisted of a basic test of the functionality of all available devices. Phase II, running from February 1996 to January 1997, tested all available devices in a variety of conditions. The technologies were evaluated at both freeway and intersection locations to provide a variety of traffic conditions.

B. Background Of Traffic Data Collection In Urban Areas

Comprehensive information on the use of transportation facilities in urban areas provides the basis for many of the decisions made regarding the transportation infrastructure. Generally, the traffic data needed to support the decision-making process and the design process are traffic volume counts, vehicle classification, average speeds, lane occupancy or density, and axle counts. The accuracy of the traffic data collected is extremely important because it affects funding priorities and the design of highway improvement projects. Yet, until the last decade, the methods for collecting historical traffic data over a wide area were essentially limited to a mixture of fixed counting locations using inductive loop detectors, road tube counts and manual counts. Each of these methods has limitations that make urban traffic data collection a significant challenge.

Fixed counting locations with inductive loop detectors can provide a baseline for traffic data collection. However, there are not sufficient resources available for enough fixed counting stations to provide all of the traffic counts needed in an urban area. Also, there are counts, such as turning movement counts, complex weaving section movements, and vehicle occupancy counts, where fixed inductive loop detectors typically cannot provide the data needed.

Road tubes present problems in staff safety, traffic disruption and data collection performance. Staff safety is a concern when road tubes must be set where traffic volumes are high during peak periods and relatively high during off-peak periods. Disruption of traffic flow typically occurs when setting road tubes on moderate or high-volume roadways because temporary closure of traffic lanes may be needed to provide safety for personnel. Performance of road tube counters is often hampered by complex roadway geometrics, multiple lane roadways and adverse weather conditions.

Manual counts present safety and operational problems. Manual counts can place staff at risk if they must be exposed to vehicular traffic during counts. Another safety problem results from personnel being located in areas where crime presents a threat to personal safety. In very high or low temperatures the ability to use manual counts is limited. Also, in some cases, the presence of counting staff can affect the traffic flow on very high-volume roadways.

These problems have resulted in a number of new technologies being employed in devices for collecting traffic data in urban areas. These technologies are considered to be non-intrusive because they can be deployed without the need to close lanes to traffic or to expose staff to unsafe conditions. Even though traffic detection devices using these non-intrusive technologies have been available for several years, there are still many uncertainties regarding their appropriate application and performance. Traffic engineers and technicians have not had a comprehensive comparison between non-intrusive and conventional traffic detection technologies. This study, conducted by the Mn/DOT and SRF for the FHWA, seeks to address this need.

Non-intrusive devices that can monitor traffic in both permanent and portable installations were considered in the project. However, emphasis was given to portable systems that can support wide area traffic data collection, such as 48-hour monitoring sessions used to obtain coverage counts and/or classification data on the Highway Performance Monitoring System and the National Highway System. The ability of a device to collect accurate historical data was emphasized over the ability to monitor real time traffic operations. Traffic data collection in urban conditions, such as heavy congestion, was also emphasized. This project identifies the strengths and weaknesses of each technology and discusses practical issues in their implementation.

C. Description Of Non-Intrusive Technologies

Non-intrusive detection devices, as defined for the purposes of this test, are those devices that cause minimal disruption to normal traffic operations and can be deployed more safely than conventional detection methods. Based on this definition, non-intrusive devices are devices that do not need to be installed in or on the pavement but can be mounted overhead, to the side, or beneath the pavement by "pushing" the device in from the shoulder.

The basic principles of each non-intrusive technology evaluated in this project are described as follows:

1. Passive Infrared

Passive infrared devices detect the presence of vehicles by comparing the infrared energy naturally emanating from the road surface with the change in energy caused by the presence of a vehicle. Since the roadway may generate either more or less radiation than a vehicle depending on the season, the contrast in heat energy is what is detected.

2. Active Infrared

Active infrared devices detect the presence of vehicles by emitting a low-energy laser beam(s) at the road surface and measuring the time for the reflected signal to return to the device. The presence of a vehicle is measured by the corresponding reduction in time for the signal return.

3. Magnetic -- Passive and Active

Passive magnetic devices measure the change in the earth's magnetic flux created when a vehicle passes through a detection zone. Active magnetic devices, such as inductive loops, apply a small electric current to a coil of wires and detect the change in inductance caused by the passage of a vehicle.

4. Microwave -- Doppler, Radar and Passive Millimeter

Doppler microwave devices transmit low-energy microwave radiation at a target area on the pavement and then analyze the signal reflected back to the detector. According to the Doppler principle, the motion of a vehicle in the detection zone causes a shift in the frequency of the reflected signal. This can be used to detect moving vehicles and to determine their speed. Radar devices use a pulsed, frequency-modulated or phase-modulated signal to determine the time delay of the return signal, thereby calculating the distance to the detected vehicle. Radar devices have the additional ability to sense the presence of stationary vehicles and to sense multiple zones through their range finding ability. A third type of microwave detector, passive millimeter, operates at a shorter wavelength than other microwave devices. It detects the electromagnetic energy in the millimeter radiation frequencies from all objects in the target area.

5. Passive Acoustic

Passive acoustic devices consist of an array of microphones aimed at the traffic stream. The devices are passive in that they are listening for the sound energy of passing vehicles.

6. Ultrasonic -- Pulse and Doppler

Pulse devices emit pulses of ultrasonic sound energy and measure the time for the signal to return to the device. Doppler devices emit a continuous ultrasonic signal and utilize the Doppler principle to measure the shift in the reflected signal.

7. Video

Video devices use a microprocessor to analyze the video image input from a video camera. Two basic analysis techniques are used: tripline and tracking. Tripline techniques monitor specific zones on the video image to detect the presence of a vehicle. Video tracking techniques employ algorithms to identify and track vehicles as they pass through the field of view. The video devices use one or both of these techniques.

D. Project Outline

The project was divided into four tasks. The first task was an initial technology review, the second the Initial Field Test, the third the Extended Field Tests and the fourth the publication of all test results in the Final Report.

1. Initial Technology Review

The initial technology review and selection process was completed in April 1995. First, a list of non-intrusive traffic data collection devices was developed. This list was based on devices tested in other related projects, information obtained from interviews with other agencies, a review of professional journals, and information provided by the FHWA and Project Team members. A total of 26 devices representing 21 different vendors were identified.

The next step was to determine which devices would be considered for the Initial Field Test. The Project Team determined that non-intrusive vehicle detection devices should at a minimum conform to the following set of criteria:

- The device must cause either no disruption or very minimal disruption to normal traffic operations and must be capable of deployment with improved safety when compared to conventional detection methods. The device can be mounted overhead, to the side or beneath the pavement as long as cutting into the pavement is not required.

- The device must provide at least one of the following traffic measures: volume count, occupancy, density, speed or vehicle classification.
- The device must be currently available as either a final product or in the form of a fully developed prototype (including all necessary hardware and software) and must have been successfully field tested by either the vendor or an independent agency.
- The device may be applicable to either portable or permanent installation, but use in a portable installation (e.g., for a 48-hour count) will be emphasized.
- The device must have output that is "reasonably" compatible with existing data collection programs and devices. Output should be capable of being loaded into a database without significant manual manipulation or manual data input.

Vendors having devices with the potential to meet the criteria were contacted. Vendors provided additional technical details for each of their products, status of each product (commercially available, fully developed prototype or in initial development stage) and their general level of interest in participating in the test. After devices were identified as candidates for the Initial Field Test, vendors were contacted to initiate contract negotiations to procure the devices.

2. Initial Equipment Field Test

In the Initial Field Test, all of the non-intrusive vehicle detectors were simultaneously tested on Interstate 394 at Penn Avenue in Minneapolis, Minnesota. Before installation, each device was first bench tested for basic operation. Devices were then installed on a mounting fixture affixed to the Penn Avenue Bridge. The installation and significant points in the testing process were videotaped.

The Initial Field Test identified the capabilities of each device. This included the types of data collected and general level of accuracy of the data provided. The test was also used to identify the initial reliability of the various detector systems.

The devices were identified by type but not by manufacturer or model designation. This was done to focus the test on the performance of each type of technology rather than focusing on the performance of individual devices. The identity of the devices has been revealed in the Final Report after all testing is finished in order to provide a complete picture of the performance of the devices.

The Initial Field Test was originally intended to be a screening process from which the best representative of each technology was selected for inclusion in the Extended Field Tests. However, some of the technologies included devices that represented a significantly different approach to vehicle detection using the same basic technology. In these cases, it was determined that no single device adequately represented the technology. In addition, new devices were being developed and became available throughout the testing periods. It was decided that these devices should be included as they became available to ensure that the latest information could be included in the final analysis of the various technologies. Therefore, rather than selecting representative devices from the Initial Field Test for the Extended Field Tests, all of the devices initially tested were carried into the Extended Field Tests and some additional devices were included as they became available.

3. Extended Field Tests

In the Extended Field Tests the devices underwent approximately 1-year of field testing. The testing established the performance of each technology and of each device in a wide variety of environmental and traffic data collection conditions. As in the Initial Field Test, installation and significant points in the testing process were videotaped. The devices tested included all devices from the Initial Field Test as well as several devices that were added to the project.

The number of vendors and devices participating in the project grew as the project proceeded, in part because some of the vendors initially contacted were interested in participating but did not yet have devices fully developed. Where the Project Team determined that the additional devices met the test criteria (production unit or prototype having completed substantial testing), and testing the device would provide additional information about the technology, the devices were added to the test. This ensured that the Final Report would provide results reflecting a comprehensive and up-to-date evaluation of each technology.

Another reason for the increased number of devices was the relatively widespread coverage received by the interim reports. Some vendors not identified in the initial search contacted the Project Team to inquire about possible participation. Also, additional devices and vendors were identified through traffic engineering literature, ITS literature and advertisements.

The conditions under which the detector systems were tested included the following:

- Extreme high and low temperatures
- Exposure to high winds
- Precipitation in the form of rain, freezing rain, snow and fog
- Lightning
- Direct sunlight
- Early morning and late afternoon sunlight facing detection devices
- Simultaneous direct sunlight and shadows on roadway
- Full range of vehicle classes
- Variety of speeds and congestion levels
- Departing and oncoming traffic
- Difficult geometric conditions
- Freeways
- Signalized intersections

The performance of the detector systems under these various environmental and traffic data collection conditions were analyzed. The primary focus was the feasibility of installing the devices in temporary counting locations to provide historical traffic data including volume, speed and vehicle classification. The typical temporary application is for 48-hour traffic counts and peak hour counts. The secondary focus was on the feasibility of installing the devices in permanent counting station applications and using them to provide additional real time traffic data for use in traffic signals, ramp metering and ITS applications.

Evaluation of the devices' data collection capabilities covered both the quality and types of data collected by each device in comparison to the baseline data. Emphasis was placed on urban traffic conditions such as heavy congestion. The evaluation also focused on the ease of system setup and use, system reliability, and system flexibility. System flexibility included an analysis of how sensitive devices are to different mounting, environmental, and traffic conditions. Finally, the equipment, installation and operational requirements were documented

4. Final Report

The Final Report summarizes the findings of the entire project and addresses all of the issues discussed in this section. The performance potential of each type of technology is discussed based on the results from the Initial and Extended Field Tests. Also, the specific devices are identified and the test results for each device are presented.

E. Vendor Participation and Description of Devices

1. Initial Vendor Contacts

All of the vendors of devices identified as meeting the criteria for the test were contacted to explain the basic intent of the project and to determine whether they were interested in participating. The initial contact was made by telephone and was followed by sending each vendor a detailed description of the test purpose, plan and schedule of the project. All vendors were contacted again to discuss their participation. Those expressing interest were kept informed of the status of the project as the Initial Field Test site was prepared for testing.

Several vendors elected not to participate in the project for a variety of reasons while others with products currently being developed asked to be included later in the project, when the product met the prototype or production criteria. The next step was to enter into more formal contract negotiations to obtain the devices for testing.

2. Vendors Contacts and Devices Considered

The vendors contacted and the devices considered for inclusion in the test are listed in Table 1. The devices that ultimately were tested are identified.

Table 1 Summary of Vendor and Device Information

TECHNOLOGY	VENDOR	CONTACT	PHONE / FAX	PRODUCT	COST (1)	PARTIAL LIST OF STATED CAPABILITIES (2)
Passive Infrared	Eltec Instruments, Inc.	Doug Armstrong	P: (800) 874-7780 F: (904) 258-3791	Model 833* Model 842*	$820 $1,210	Presence (incl. stopped veh.), speed, loop emulation, max. speed model 833 (100 mph) & 842 (45 mph)
Passive Infrared	ASIM Engineering LTD.	Bertrand Steinbach Walter Kuster	P: +41-55-282-41-00 F: +41-55-282-31-51	IR-222/IR 223 IR-224*	$980 $1,300	Volume, presence, loop emulation or RS 232 serial output (222&223) plus avg. speed w/ 2 x relay or 2 x optocoupler loop emulation or RS 232 serial output (224)
Passive Infrared	SANTA FE Technologies,Inc./Titan	Jerry Musnitsky	P: (505) 243 - 4100 F: (505) 842 - 1999	SmartLOOK	Contact Vendor	Volume, presence, class, speed, and acceleration.
Active Infrared	Schwartz Electro-Optics, Inc.	Brian Domian	P: (407) 298-1802 F: (407) 297-1794	Autosence I* Autosence II Autosence III	$6,500 $10,000 $15,000	(I) - presence (incl. stopped veh.), speed, density and class (veh. Height), loop emulation and RS 232 serial outputs (II) - same plus 3D measure of veh., tow bar detection and separation of closely spaced vehicles (III) - same plus covers 2-3 lanes depending on mounting height
Active Infrared	Spectra Systems (Manufactured by MBB Business Development GmbH, Germany)	Margit Weir	P: (561) 998 - 3160 F: (561) 998 - 3166	TOM (Traffic Observation Module) SAM (Sensing and Activating Module)	Contact Vendor	TOM - volume, presence, turning movements, speed, acceleration, delay, queue length, classification, lane changes, travel time and headway. SAM - same as above
Magnetic	Safetran Traffic Systems, Inc.	John Satcher	P: (719) 599 - 5600 F: (719) 599 - 3853	IVHS Sensor 232E* 231E Probe*	$700 $90/Each	Volume, speed and occ. for 1 lane, loop emulation and RS 232 serial outputs / 232E supports two probes
Magnetic	3M, Intelligent Transportation Systems	Doug Henderson	P: (612) 737 - 1581 F: (612) 737 - 1055	Non-Invasive Microloop	$125/ Probe	Volume, occ., and speed (with 2 sensors)
Magnetic	Nu-Metrics, Inc.	John Cavalier	P: (412) 438 - 8750 F: (412) 438 - 8769	NC-30X / NC-40 NC-90A / G-1 G-2 / G-2WX	$275 / $595 $975 / $1,075 $1,895 / $1,995	Volume, presence, speed, class, headway, and/or occ. (depending on model) in one detection zone (periodic data download)
Radar	EIS (Electronic Integrated Systems)	Dan Manor	P: (800) 668 - 9385 F: (416) 785 - 9332	RTMS X1* RTMS X2	$3,300	Presence (incl. Stopped veh.), volume, speed, class, headway and occ. for up to 8 lanes with loop emulation and RS 232 serial outputs
Doppler Microwave	Microwave Sensors, Inc.	G. Dan Sutton Don Johnston	P: (800) 521 - 0418 F: (800) 847 - 5762	TC-20 TC-26B*	$629 $735	TC-20 - motion detection in one single or multi-lane zone TC-26B - long/short-range motion detection (max. 200' for cars, 350' for trucks) in one single or multi-lane detection zone
Doppler Microwave	Peek Traffic, Inc.	Bill Ippolito	P: (800) 245 - 7660 F: (301) 945 - 3558	PODD (Peek Overhead Doppler Detector)*	$600	Vehicle detection in one single or multi lane detection zone with loop emulation
Doppler Microwave	Whelen Engineering Co.	Philip Kurze	P: (800) 637 - 4736 F: (860) 526 - 4784	TDW-10* TDN-30*	$995 $995	TDW-10 - speed in multiple lanes (no lane or vehicle isolation), RS 232 serial data and loop emulation, wrong way flow and incident detection TDN-30 - single lane volume and speed, RS 232 serial data and loop emulation wrong way flow and incident detection
Pulse Ultrasonic	Novax Industries Corp.	Doug Grubbe	P: (604) 525 - 5644 F: (640) 525 - 2739	Lane King™*	Contact Vendor	Volume and presence via loop emulation and volume with RS 232 serial output
Pulse Ultrasonic	Microwave Sensors, Inc.	G. Dan Sutton Don Johnston	P: (800) 521 - 0418 F: (800) 847 - 5762	TC-30* TC-30C	$475 $559	Presence in one loop emulation zone
Pulse Ultrasonic	Sumitomo Electric USA, Inc.	Takehiko Barada	P: (408) 737 - 8517 F: (408) 737 - 0134	SDU 420	$2,200 (estimate)	Presence in one detection zone, classes (2), 8 detector heads for 8 zones per one processing unit.

Table 1 Summary of Vendor and Device Information (continued)

Passive Acoustic	IRD (International Road Dynamics)	Rod Klashinsky	P: (306) 653 - 6600 F: (306) 242 - 5599	Smartsonic™ TSS-1*	$2,500 (one lane) $7,000 (four lane)	Presence (incl. stopped veh.) in 2 zones with loop emulation, volume, speed, occupancy, class (3 lengths); zone size 6 to 8 ft. in direction of traffic and provides 1-2 lane selectable zone sizes in the cross lane direction; one lane per sensor and 4 sensors per controller
Video	Eliop Trafico	Luis Lopez Ramon Garcia	P: 011-34-1-383 01 80 F: 011-34-1-383 04 02	EVA 2000 S* EVA DAI	$7,000 - $17,000 $8,000 - $18,000	2000 S - incident, volume, speed, density, occ. and headway in 1-4 lanes (depends on height), loop emulation and RS 232 outputs DAI - same as above but designed for congested urban traffic conditions.
Video	Image Sensing Systems	Lisa Dumke	P: (612) 642 - 9904 F: (612) 603 - 7795	Autoscope 2004* Autoscope 2004 Lab	$24,000 $9,990 (Univ.)	2004 - volume, occ., speed, turn movements, 3 classes, incidents, and headway in 48 detection zones from max. of 4 cameras with 32 relay loop emulations and RS 232 serial outputs 2004 Lab - same as above with one camera input.
Video	Rockwell International	Greg McKhann	P: (714) 762 - 8804 F: (714) 762 - 1750	TraffiCam™ - S* TraffiCam™ - I	$5,000 $5,000	I - presence and visual image with loop emulation in 8 detection zone pairs and RS 232, RS 422, or RS 485 serial outputs S - same as above plus volume, speed and occupancy data.
Video	Peek Traffic - Transyt Corporation	Scott Meyerhoff	P: (904) 562 - 2253 F: (904) 562 - 4126	Video-Trak - 900™*	$18,000	Classes (5), presence, speed, occ., density, headway, delay, length, volume, and incident detection with loop emulation and RS 232 outputs in up to 32 zones per camera and 256 zones per unit (8 camera detection unit)
Video	Computer Recognition Systems, Inc.	Salvatore D'Agostino	P: (617) 491 - 7665 F: (617) 491 - 7753	TAS2 (Traffic Analysis System)	$15,000 - $25,000	Volume, speed, occ., density, queue length, dwell time (intersection), classes (4), incident detection with multiple zone loop emulation and RS 232 serial data.
Video	Sumitomo Electric, USA, Inc.	Takehiko Barada	P: (408) 737 - 8517 F: (408) 737 - 0134	IDET 100	$15,000 (Estimate)	Presence, volume, classes (2), speed, queue length, detection in up to four lanes of two-way traffic.
Video	Automatic Signal / Eagle Signal	Arnold McLaughlin	P: (512) 837 - 8425 F: (512) 837 - 0196	Eagle Vision, P/N EV1000	$15,000 (Processor) $3,000 (Cameras)	Presence, dwell time, incidents with 32 zones per processor, 8 zones per camera
Video	Condition Monitoring Systems, Inc.	Kay Dermer	P,F: (310) 438 - 4875	Mobilizer	$3,000 - $5,000	Volume, presence, occ., turning movements, speed, accel., delay, class, lane changes and headway with RS 232 serial output
Video	Nestor, Inc., Intelligent Sensor Division	Laurent Meilleur	P: (401) 331 - 9640 F: (401) 331 - 7319	Traffic Vision	Contact Vendor	Presence, volume, occ., speed, queue length, headway, lane changes, class (13-level FHWA), link travel time between camera sights, pedestrian and bicycle detection

* Indicates devices which were used in testing.

(1) Cost is the manufacturers suggested retail price.

(2) Summary of capabilities; see Appendix A for additional details.

3. Vendor Contract and Negotiation Process

Mn/DOT entered into more detailed discussions with the vendors to outline the proposed arrangements for obtaining the devices for the test period. Individual negotiations were carried out with each vendor to reach agreement on the method of procurement, loan, lease or purchase. The individual negotiations were conducted rather than a single procurement method because of the varied nature of the products to be tested. They ranged from relatively low cost devices that have been in production to higher cost devices that are either in the late prototype or initial production run phase. In each case, the products were available from the time of procurement through the final test period and the vendors were reimbursed for their expense to visit the site up to a maximum amount. Cost of additional visits were borne by the vendors.

4. Stated Device Capabilities and Costs

Table 1 presents the suggested retail price and a brief summary of the stated capabilities, provided by the vendors, for the devices considered for inclusion in the test. A detailed vendor and product list is also presented in Appendix A. This appendix provides more detailed descriptions of the device capabilities.

F. Project Team Description

The Project Team is composed of individuals from the following groups: Minnesota Department of Transportation (Minnesota Guidestar, Management Data Services, and Electrical Services Section), the City of Minneapolis Traffic Department, and the consulting firm of SRF Consulting Group, Inc. Project Team members include the following:

- William Grush, FHWA -- FHWA representative
- Stephen Bahler, Mn/DOT Guidestar Office -- Mn/DOT Project Manager
- Curt Dahlin, Mn/DOT Management Data Services -- Project Team Member
- Mark Flinner, Mn/DOT Management Data Services -- Project Team Member
- Rod Heuer, Mn/DOT Management Data Services -- Project Team Member
- Len Palek, Mn/DOT Metro Division Freeway Operations Section -- Project Team Member
- Dallas Hildebrand, Minneapolis Traffic Department -- Project Team Member
- Marlin Reinardy, Mn/DOT Electrical Services Section -- Project Team Member
- Tim Bangsund, Mn/DOT Electrical Services Section -- Project Team Member
- Dave Long, Mn/DOT Electrical Services Section -- Project Team Member
- Jim Kranig, SRF Consulting Group, Inc. -- SRF Project Manager
- Erik Minge, SRF Consulting Group, Inc. -- Project Team Member
- Carla Jones, SRF Consulting Group, Inc. -- Project Team Member

II. REVIEW OF STATE AGENCIES' EXPERIENCES AND RELATED NATIONAL RESEARCH

A. Interviews With State Agencies

Eleven state transportation agencies were interviewed to gather information concerning the current practices, needs and problems in the area of traffic data collection. The list of 11 states was developed to reflect the various areas of the country. The list includes states that have significant urban development and states that are known to have conducted tests of non-intrusive traffic data collection devices and Intelligent Transportation Systems (ITS) sensors. The resulting list included California, Connecticut, Florida, Georgia, Illinois, Michigan, New Jersey, New Mexico, New York, Ohio and Pennsylvania. In addition to the information from these states, input was received from the three Project Team members from the Mn/DOT Management Data Services.

The interviews were used to identify the current traffic data collection efforts of each state. The methods used and the problems encountered were discussed to determine the additional needs of each state. The interviews also identified the experience each state has had with non-intrusive traffic data collection devices. Interviewing the state agencies gave insight into the practical issues faced in data collection. Surveying the current data collection practices improved the utility of this project.

The state transportation agencies interviewed have had a wide variety of experiences in data collection. Some state agencies have small data collection departments and do little beyond the minimum required by the FHWA. They primarily use road tubes and inductive loops. At the other end of the spectrum, some states are doing extensive research with and collecting data with non-intrusive vehicle detection technologies. Most agencies, however, primarily use traditional methods of collecting data. These data fulfill both the FHWA requirements and their own collection needs for planning, accident analysis, etc. To be widely accepted, any new data collection methods must support these needs.

Interviewees generally felt that substantial benefits could be found with alternative counting methods once the technologies mature. Benefits include portability, cost, safety during installation, and reliability. Drawbacks include mounting difficulties, lack of information on what is available, and difficulties in learning a new data collection system.

The interviews were conducted in January 1995, and some of the information provided may now be out of date. A summary of the interviews is provided in this section. Note that this is a summary of the responses from the states and not the conclusions of this project. This project independently evaluated the benefits and limitations of non-intrusive technologies.

1. Types of traffic data collected and the methods for collecting.

a. Data Collected and Method

Data Collected	Traditional Collection Method
Count	Loops, road tubes, piezos, manual
Speed	Loops, road tubes, piezos, radar
Classification	Loops, road tubes, piezos, axle counters, manual
Weigh in motion	Loops, portable capacitance mats, weigh in motion stations

In addition to these methods, traffic data may also be available as a byproduct of other transportation activities. For example, the loops used at intersections to actuate traffic signals can also be configured to collect count data, transportation management centers can collect data through their surveillance cameras and loop detectors, and automatic vehicle identification or electronic toll collection technologies can provide many types of data. While it is physically possible to collect data through these methods, many jurisdictional, privacy and other issues limit their deployment at this time.

b. Counts and speed

The state transportation agencies identified two primary methods for collecting count and speed data. Inductive loops are used in permanent and some temporary count locations and road tubes are used in most of the other count locations.

Drawbacks to loop use include their reliability, safety, and installation difficulties. Loops require a lane closure for saw cutting into pavement, making for a permanent installation. Other technologies offer temporary placements. Quality control during the installation of loops is very important. Loops have the advantage of being very accurate when operating correctly.

Drawbacks to road tubes are numerous as they require intrusion onto the roadway for initial setup. This exposes personnel to traffic that cannot always be avoided in areas with high-volumes both night and day. Road tubes are also susceptible to weather conditions. Some use an adhesive that does not adhere well to pavements that are wet from snow or rain.

Piezo axle counters laid directly on the pavement are used to collect classification data. They have similar advantages and drawbacks to road tubes.

c. Classification

Classification is often difficult to obtain and much is manually collected. A non-intrusive device that can classify automatically would be very useful.

2. Types of physical conditions that cause problems.

a. Environmental

Environmental conditions such as rain or snow cause wet pavement that inhibits the use of road tubes. Any device that is placed on the pavement, such as magnetometers, piezos or road tubes, are susceptible to being damaged by snow removal equipment or street sweepers. Low temperatures also hamper tube and weigh-in-motion accuracy and shorten battery life. Solar panels are less effective in winter months. Personnel place themselves at risk due to reduced sight distance in foggy weather. Environmental conditions also affect non-intrusive detectors. For example, snow and fog were mentioned as problems for video detection systems.

b. Freeway Geometrics

Horizontal curves create a safety hazard for field personnel if the curve reduces stopping sight distance. Road tubes may double count if the vehicles strike them at an angle. Loops can be a problem if vehicles do not track in the center of the lane. If a vehicle travels to the right or left of the center it may be double counted because the influence area of a loop extends beyond the physical dimensions of the loop. Vertical curves pose a problem for sight distance during installation and for weigh-in-motion because a vehicle's weight may be misread when climbing or descending a grade. Speed studies are also not representative on grades. Weaving sections also present a problem because some vehicles may be double counted or missed altogether. Straight, level and basic freeway sections are generally selected for data collection.

c. Arterial Geometrics

Arterial geometrics that are difficult to count are primarily multiple lane roads where road tubes must be laid across more than one lane. Road tubes are also difficult to use on roads with curb and gutter.

d. Congestion

Congested or stop-and-go traffic can lead to poor data collection. Road tubes have trouble operating with vehicle speeds of less than 20 mph, and can misread when a vehicle stops over them. Stationary vehicles can be detected using new technologies even if they do not move for several minutes. Short headways can lead to miss-counting and miss-classification. Classification equipment must be set to the correct traffic speed and stop-and-go traffic introduces error.

e. Other

Vehicle types such as motorcycles are frequently miscounted. Vehicles traveling at high speeds may avoid detection.

3. Non-intrusive technology research by the agencies.

When the survey was conducted in January 1995, Caltrans and the California Polytechnic State University were conducting an evaluation of video and infrared detection. Pennsylvania was evaluating various non-intrusive devices for the I-95 reconstruction in Philadelphia. Ohio is doing research with the University of Cincinnati. Georgia will collect data on I-75 and I-85 for the 1996 summer Olympics. Refer to the section on review of related research for more information. Most data collection departments are not involved in non-intrusive technology research. This type of research is usually done by a separate ITS branch.

4. Non-intrusive technologies used by the agencies.

Few states have used non-intrusive technologies extensively. Magnetometers were frequently mentioned but not used extensively. Local agencies may have more experience with these types of devices. Also, many of the agencies were interested in testing video detection as well as some other technologies.

5. Comparison of non-intrusive technologies to traditional technologies.

State agencies surveyed stated that many new technologies offer the advantage of being easier to install, less expensive, and more portable than traditional data collection methods. Drawbacks cited include accuracy, cost and interference from environmental conditions such as fog and snow.

6. Agency plans for incorporating non-intrusive technologies.

Many states expressed interest in non-intrusive technologies but had no plans for implementing them.

7. Type of research that would be most useful to agencies.

Practical information on detectors would be most useful to those interviewed. Specific information on portability, reliability, flexibility, capabilities, remote access, maintenance, and installation were mentioned. Other comments included an interest in a system that can provide data for many links to obtain information for an entire region.

8. Other comments.

a. <u>History</u>

Non-intrusive technologies were used as early as the 1940s with magnetic sensors. By the 1960s, ultrasonic and microwave were also commercially available. Inductive loops have become more common and have replaced these alternatives.

b. Safety

All intrusive technologies have safety problems. For example, on very congested freeways and arterials volumes may be high 24 hours a day, not providing a window for safe installation. Non-intrusive technologies offer a very real benefit by avoiding intrusion onto the roadway. In some instances, side mounted detectors are better than overhead because there is no risk of dropping something onto the traffic below.

c. Security

Traffic counters and solar panels have been stolen from the field.

9. Summary

State agencies must meet both the federal data collection requirements and their local state level data collection needs. Whatever data collection method is used must support these needs. A new technology must prove itself before it will be selected over an established technology.

B. Published Test Reports And Papers

The literature search summarized here was conducted in the spring of 1995 in the early stages of this project, and it is likely that more recent reports detail testing of non-intrusive traffic detection technologies. However, this list represents the research that was available when the plan for this project was developed.

1. Hughes Aircraft

The Hughes Aircraft Company conducted the most extensive test of non-intrusive detectors to date in its study, *Detection Technology for IVHS.* Tests were conducted at eight different locations representing three geographic areas, namely Minnesota, Florida and Arizona. The different regions were selected to represent varying environmental operating conditions. The technologies tested included video, ultrasonic, sonic, infrared, microwave and radar. The purpose of the test was to study the application of non-intrusive technologies to Intelligent Transportation Systems (ITS). While the Hughes Aircraft test considered the application of these technologies to data collection, it did not focus on this function.

2. California Polytechnic State University

California Polytechnic State University conducted two research projects through Caltrans and California Partners for Advanced Transit and Highways (PATH). The first project field tested commercially available video traffic detectors. It included both video tracking systems and video systems using user-defined detection zones. The second research project is an ongoing study to test infrared detectors. The infrared sensors themselves, not the traffic data collection performance, are being studied.

3. National Test Center

In 1996, a National Test Center for Traffic Monitoring Devices was proposed by the Southwest Technology Development Institute (SWTDI) at New Mexico State University. The funding for the full test center has not yet been secured. As an interim, a Vehicle Detector Clearinghouse is being established by SWTDI to provide information on the capabilities of commercially available vehicle detectors by gathering, organizing and sharing product test and evaluation results.

4. Bolt Beranek and Newman, Inc. (BBN) Study

A Comparative Study of Non-intrusive Traffic Monitoring Sensors examines the different types of non-intrusive technologies. It focused on the fundamental advantages and limitations of each technology. The test was done with inexpensive sensors developed exclusively for the project. A data acquisition workstation capable of receiving data from many different devices was also developed with the project.

5. University of Nebraska-Lincoln

"Traffic Data Collection Using Video-based Systems" examined capabilities of video sensors. The Autoscope 2003 was the only sensor tested.

6. University of California-Berkeley

"Detectors for Freeway Surveillance and Control" examined the application of ultrasonic devices to traffic data collection. Field tests were conducted.

7. Ohio University, Athens

"Automatic Turning Movement Counter" examined the application of ultrasonic sensors to obtain intersection turning movements.

8. Texas University at Austin

"Infrared Sensors for Counting, Classifying, and Weighing Vehicles" examined the application of infrared sensors to traffic data collection. The project was conducted in a series of five field tests.

9. Texas Transportation Institute

"Development of an Overhead Vehicle Sensor System" examined the use of infrared and ultrasonic sensors for traffic data collection.

10. Center for Transportation Research (CTR) at Virginia Tech

The CTR has a program to evaluate vehicle detection technologies. It has an interim test facility that offers a variety of physical conditions and will test at the Smart Road when it is completed. The ability of detector systems to both collect data and offer real-time information for ITS applications will be studied. The Center is working to develop a standard for sensor technologies based on established measures of effectiveness.

III. FIELD TEST DESCRIPTION

A. Field Test Site Selection

1. Initial Field Test Site Selection

The objective of the Initial Field Test was to determine whether the devices could perform basic data collection functions under relatively simple traffic, geometric and environmental conditions. The site for the Initial Field Test required a location providing a variety of traffic flow conditions and the capability for both overhead and sidefire mounting options. Several sites were investigated to determine which provided all of the attributes needed for the Initial Field Test.

Interstate-394 immediately east of the Penn Avenue interchange in Minneapolis was selected for the Initial Field Test site (see Figure 1). This site was initially considered because it was one of the test sites used by Hughes Aircraft in *Detection Technology for IVHS*. It offered the opportunity to monitor traffic in freeway lanes and in the reversible high occupancy vehicle lanes of I-394. It also has a bridge that could be used for overhead mounting and luminaire poles for sidefire mounting of devices. The traffic conditions vary from low-volume free flow to high-volume congested flow. An additional benefit was the presence of six inductive loops installed for the Hughes test that could be used as a data collection baseline.

2. Extended Field Test Site Selection

The intent of the Extended Field Tests was to test the technologies under a variety of difficult geometric, environmental and traffic conditions. The initial test site was well suited to testing the technologies in conditions that simulated freeway and mid-block arterial roadway traffic. The typical weather conditions in Minnesota throughout the year provided the weather extremes desired for the test, including high winds, rain, fog, sleet, snow and a wide range of temperatures. This site offered a significant range of traffic conditions as it has high traffic volumes throughout the day with recurring congestion in both the morning and afternoon peak periods and lower volumes with free flow conditions in the evening and on weekends. The site also provides a variety of lighting conditions depending on the time of year because I-394 is aligned in an east/west direction. This alignment causes low angle sunlight when the sun is on the horizon in the summer, cross roadway shadows in the winter, and bridge shadows year-round. These conditions provided the challenging conditions needed for testing the various detection technologies.

The adjacent intersection of Penn Avenue with the I-394 south ramps provided a good intersection location for testing the technologies (see Figure 2). It also provided the obvious advantage of being located near the data collection trailer, which allowed simultaneous testing at the freeway and the intersection. The site is also well suited because it has multiple-lane approaches, unusual geometric characteristics and congested morning and afternoon peak periods. To prevent interference between devices that use the same technology, two approaches of the intersection were used for testing the devices. Significant traffic levels are present at the northbound approach, where ramp meters at the nearby on-ramp regularly send queues back into the approach's right turn lane. The second location selected for testing is the eastbound approach where traffic is exiting the freeway. Both of these approaches have loop detectors that are being used to collect baseline data. Both approaches also have traffic signal poles, luminaries, or camera surveillance poles that offer convenient device mounting locations.

B. Field Test Site Preparation

1. Initial Field Test Site Preparation

The various activities needed to prepare the initial test site are described in the following

Sections.

a. Utilities

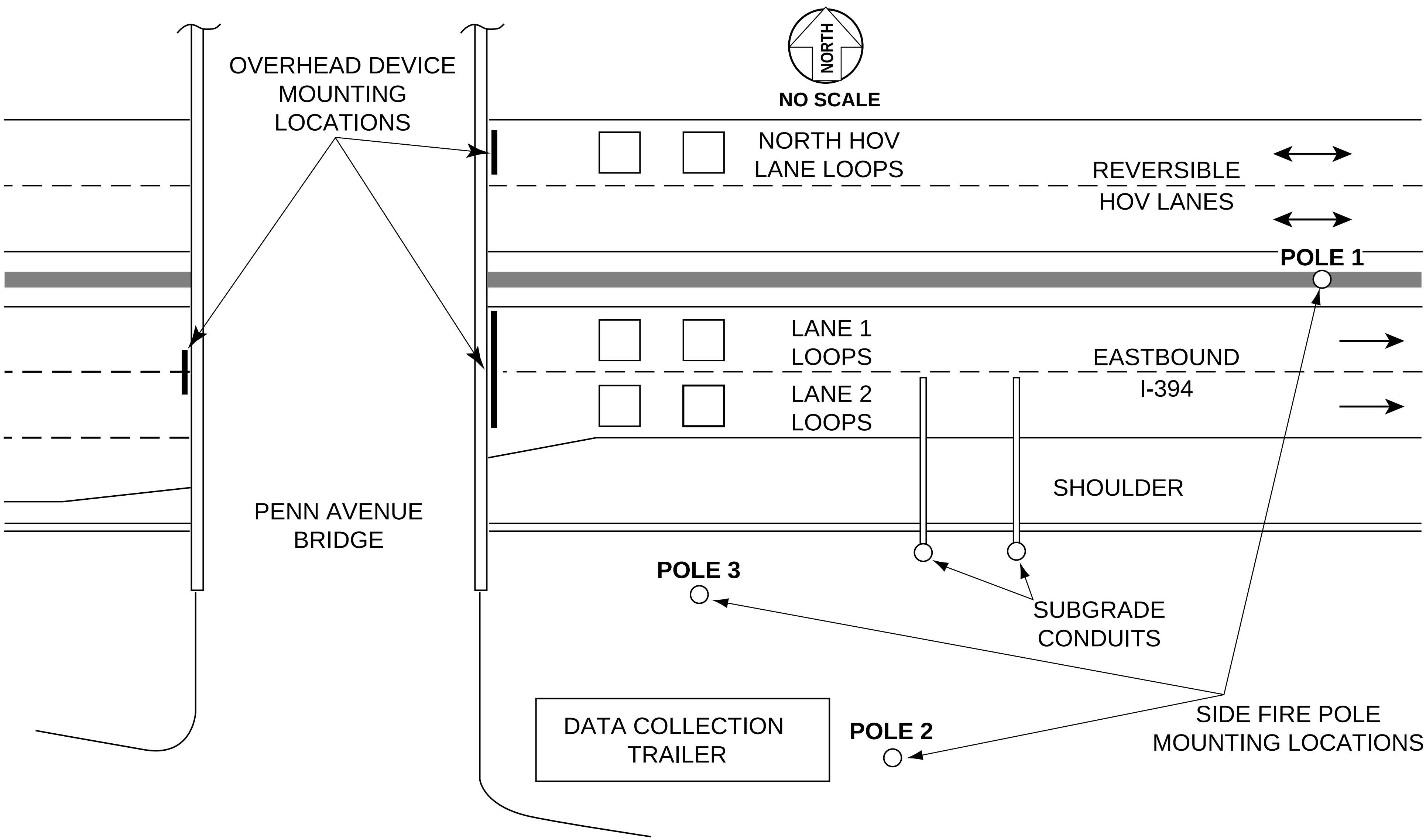
The first step in preparing the field test site was to determine the location of utilities in the area. Since the installation of magnetic detectors required boring a hole and pushing a 3-inch (8 cm) conduit under the roadway, it was necessary to make sure there would not be any subgrade conflicts. After examining utility plans for the area, the only nearby utility identified was the local drainage system. A location was selected away from the drainage system yet close to the detection zones used by the other devices.

b. Baseline Loops

The outputs from the six inductive loops installed for the Hughes' Project were examined and found to function properly. This test utilized the six loops to provide baseline data against which the performance of all devices was measured. The loops and the overall initial test configuration for the freeway site are shown in a field test site schematic in Figure 3. Only the bridge mounting locations were used in the Initial Field Test.

a. Device Mounting Structure –Video Clip 1

Mn/DOT Electrical Services Section designed and built the mounting structures for the devices. Two mounting trusses were fabricated in the Mn/DOT shop from 2-inch (5 cm) steel pipes. The larger of the two trusses spans the two lanes of eastbound I-394 east of Penn Avenue while the smaller truss is mounted over the northern high occupancy vehicle (HOV) lane. Both trusses were designed to be bolted to the bridge. Figure 4 shows the device mounting structure and the location of some of the devices in the Initial Field Test.



Minnesota Department of Transportation

SRF NO. 0942006

FIGURE 3
FREEWAY TEST SITE SCHEMATIC

FHWA Field Test of Monitoring of Urban Vehicle Operations Using Non-Intrusive Technologies

d. Data Acquisition Trailer

In order to implement the data collection plan (described in Section E), several logistical steps had to be completed before actual data collection could begin. It was decided that a construction trailer located at the test site would be best for collecting data because it would facilitate easy connection to equipment and enable direct observation of traffic. An 8 by 20 foot (2 by 6 m) trailer with heating and air conditioning was selected. After the trailer was rented and located between the eastbound on-ramps and I-394, Mn/DOT personnel wired phone and electrical connections. Power was supplied from the Mn/DOT power system in the area. Figure 5 shows the overall field test site schematic including the data acquisition trailer.

e. Security System

A security system was installed in the trailer. The system included a motion sensor, a door contact sensor with automatic phone connection to the local police, a long-range radio transmitter (to prevent disarming by cutting phone lines) and two exterior motion lights.

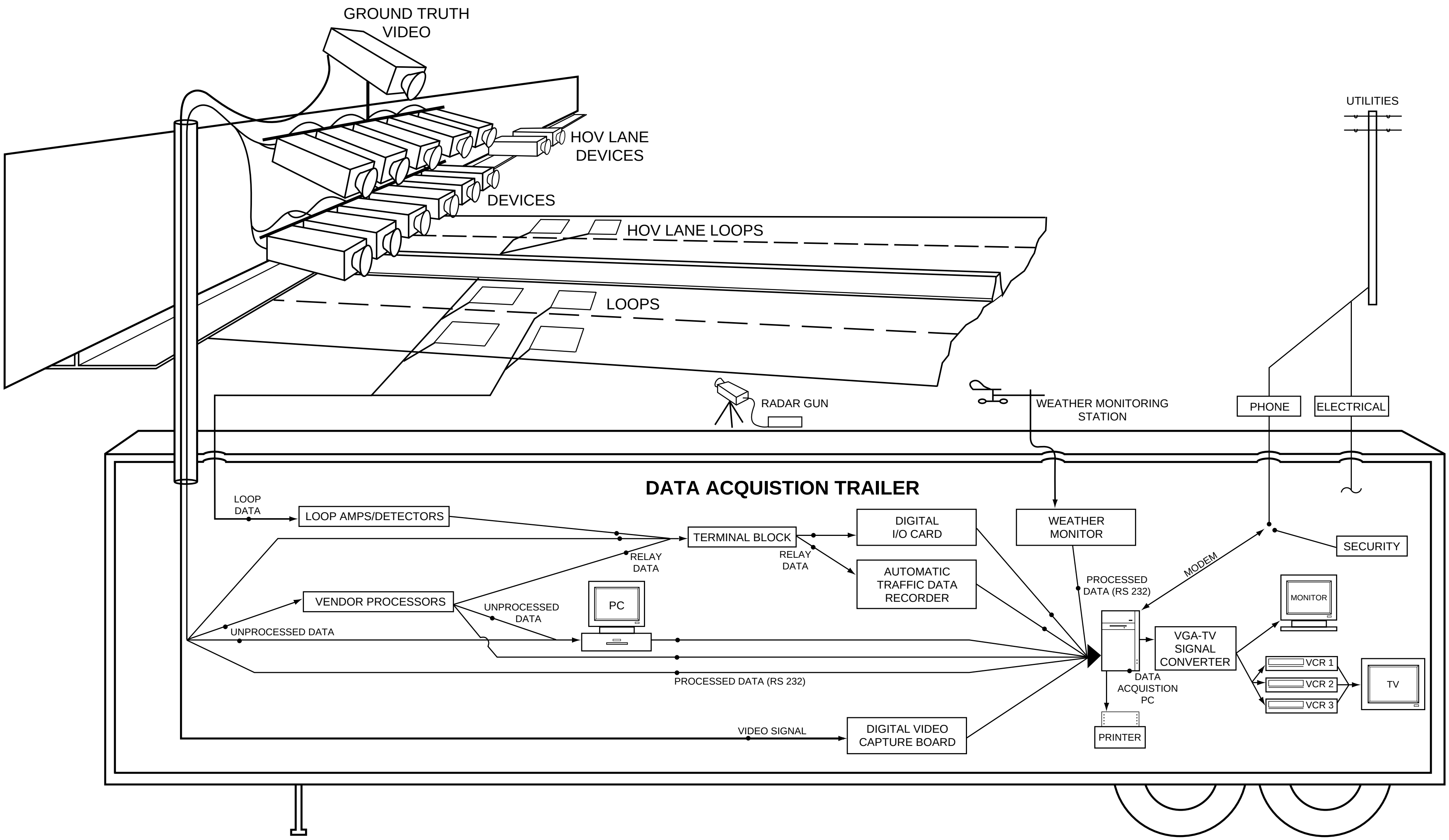
f. Weather Monitoring Station Installation

A weather monitoring station was installed near the data collection trailer. This included a rain gauge, temperature sensor, humidity sensor, wind vane and anemometer. In addition, Mn/DOT Electrical Services personnel placed markers on the concrete barrier in the detection area. These markers can be used to measure the visibility.

2. Extended Field Test Site Preparation

At the freeway test site little preparation was necessary because testing activities were ongoing between the Initial and Extended Field Tests. In addition to mounting devices on the Penn Avenue Bridge, several sidefire poles were used as well. A luminaire pole in the median of the freeway was used to mount video cameras and a passive acoustic device. Cabling to this pole was run along a span wire mounted between the Penn Avenue Bridge and the luminaire, a distance of 100 feet (30 m) downstream. In addition, two sidefire poles were used to mount the radar device. One is located approximately 100 feet (30 m) from the freeway and the second pole, which was installed specifically for the project, is about 35 feet (11m) from the freeway. Refer to Figure 3 for the location of these poles and to Figure 6 for photographs of the devices mounted for the Extended Field Tests.

At the intersection test site a total of four poles were used to mount devices. At the eastbound approach, a traffic signal pole and a traffic camera surveillance pole were used. The traffic signal pole is 10 feet (3 m) from the edge of the lane and 5 feet (1.5 m) downstream of the stop bar. It is identified as Pole 1 in Figure 7. The camera surveillance pole is 14 feet (4 m) from the edge of the lane and 5 feet (1.5 m) upstream of the stop bar. This is Pole 2 in Figure 7. Typical device locations at the intersection are shown in Figure 8. Both poles are visible in the "view facing west" in Figure 2.



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MINNESOTA DEPARTMENT OF TRANSPORTATION

FIGURE 5
FIELD TEST SITE SCHEMATIC

FHWA Field Test of Monitoring of Urban Vehicle Operations Using Non-Intrusive Technologies

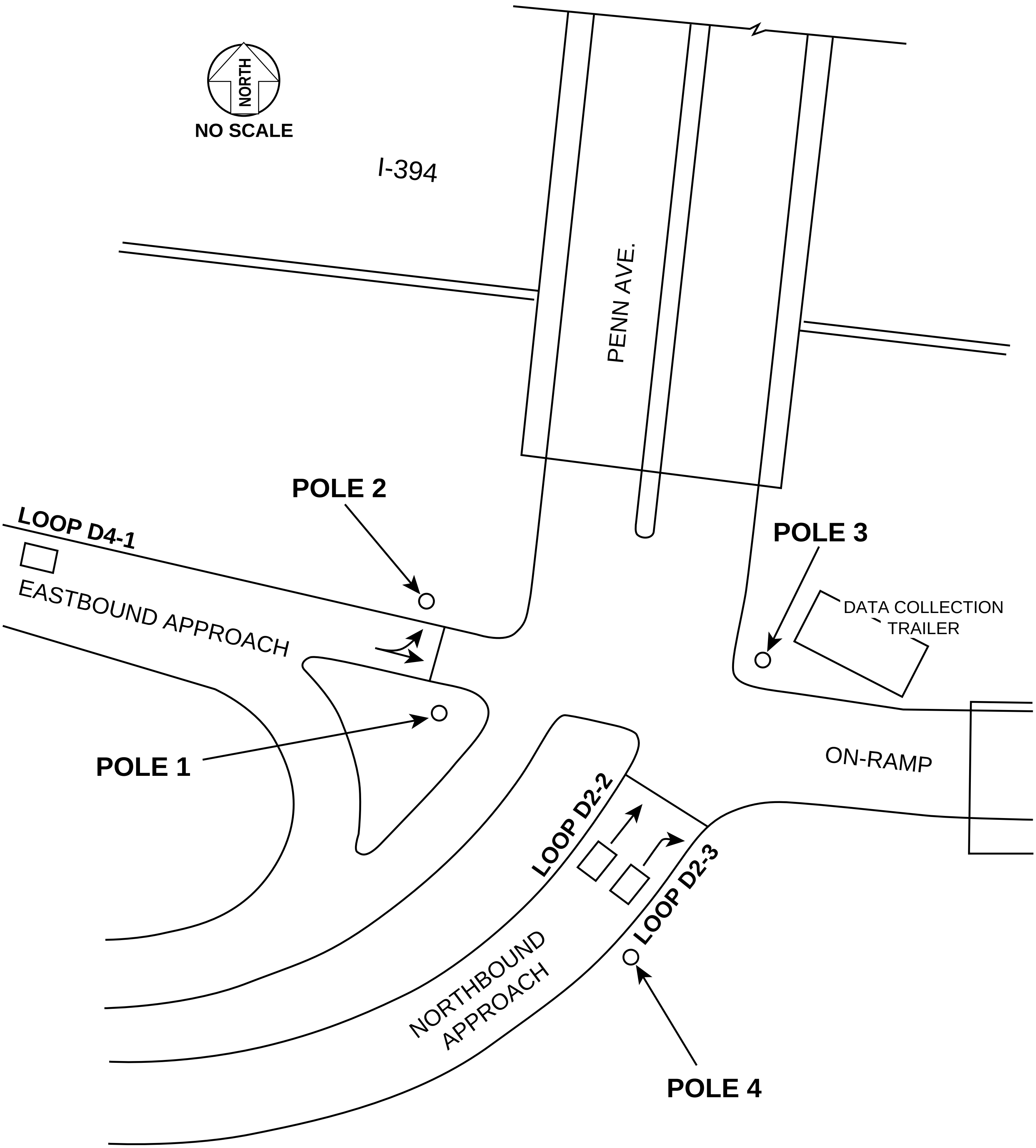

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FIGURE 7
INTERSECTION TEST SITE SCHEMATIC

FHWA Field Test of Monitoring of Urban Vehicle Operations Using Non-Intrusive Technologies

The loop for eastbound approach is 165 feet (50 m) upstream of the stop bar. Cabling between these poles and the trailer was mostly run through segments of in-place traffic signal conduit with reserve capacity. In addition, a 20-foot (6 m) section of flexible conduit was installed to provide connection between a handhole and surveillance pole and another 10-foot (3 m) section between a handhole and the data collection trailer.

At the northbound approach, a traffic signal pole and a luminaire pole were used for mounting devices. The traffic signal pole was used for mounting the video cameras. This pole is located 65 feet (20 m) downstream of the stop bar and is roughly aligned with the lanes in the northbound approach. This is Pole 3 in Figure 7. The luminaire pole was used for sidefire devices on the northbound approach. The pole is located 12 feet (3.7 m) from the edge of the right turn lane and 30 feet (9.1 m) upstream of the stop bar. Devices mounted on this pole detected traffic in the right turn lane only. Since this pole is located on a curve, the traffic in the right turn lane was observed to travel in different parts of the lane. While most vehicles travel in the center of the lane, some tend to travel more toward the through lane. This may cause some devices to undercount vehicles. The loops in both the right turn and through lanes are about 4 feet (1.2 m) upstream of the stop bar. Cabling from the trailer to the luminaire pole was run along a span wire mounted between the luminaire and the traffic signal pole. Wiring from the traffic signal pole to the trailer was run through in-place traffic signal conduit.

The City of Minneapolis gave permission to tap into the traffic signal cabinet in order to access the outputs from the inductive loops used to actuate the traffic signal system. These outputs were brought back to the trailer located 10 feet (3 m) away and incorporated into the data acquisition system.

C. Device Installation

1. Initial Field Test Device Installation

This section describes the installation of the devices tested in the Initial Field Test.

a. Boring Contractor Selection

The magnetic devices included in this project are designed to be placed in conduits under the roadway. These conduits must be pushed into holes bored under the pavement. Several boring contractors were solicited and one was selected to perform this work.

b. Device Bench Tests

Before the actual on-site installation, the devices were bench tested in the Mn/DOT Electrical Services shop. Power supply requirements varied from 12 VDC to 120 VAC. All of the devices were checked to ensure that they were functioning properly and were ready for installation.

c. Installation Logistics

In preparation for the actual installation, several activities were coordinated. First a check of major events in the western Minneapolis/St. Paul metropolitan area was made to insure that traffic would not be impacted by detouring eastbound I-394. The highway patrol and proper Mn/DOT authorities were notified of the detour. Necessary trucks and personnel were then scheduled for the night of the installation, including the boring operation. Mn/DOT Video Services was notified so they could tape the installation.

d. Overhead Device Installation

The installation took place the night of July 19, 1995. Mn/DOT maintenance personnel closed both lanes of eastbound I-394, routing traffic to the south ramps at Penn Avenue. The closure allowed trucks unrestricted access to I-394 for mounting the two trusses. The larger of the two racks was hoisted above the eastbound lanes with a bucket truck. Workers in separate buckets maneuvered the rack into place and bolted it to the overpass. Next the smaller rack was similarly installed over the HOV lane. Cabling conduits were also mounted to the overpass and routed to the trailer. Due to the number of devices being tested in this project the freeway had to be closed in order to install the mounting system. For a typical device installation, however, a lane closure would not be required.

Once the trusses were installed, the devices were mounted to them. On the first night, most of the devices were mounted and the cabling run back to the data collection trailer. The remainder of the devices were mounted over the next few days. In addition, some devices were re-aimed in accordance with their vendor's recommendation. This device mounting could be performed from a truck with a long extending bucket without closing the freeway. Working over live traffic, however, required extra caution to avoid dropping devices or tools.

Most of the devices have flexible mounting systems that allow them to be attached to the mounting truss's 2-inch (5 cm) horizontal steel pipes. One device and the ground truth video camera required a vertical mount. Special tools were not required to mount any of the devices. The mounting truss provided mounting conditions similar to what is available from a typical overhead sign mounting structure. Smaller and lighter devices were generally easier to mount than larger and heavier devices. The latter required more elaborate mounting to secure them in place against their greater weight and wind loads. One device was accidentally dropped from a bucket truck and had to be replaced at the project's expense. Some vendors supplied enough cable to allow a direct connection to the data collection trailer. Others were spliced in a junction box mounted on the truss.

The test site was developed to provide flexibility for installing additional devices as they became available. Adequate capacity was provided on the device mounting structure and in conduits leading to the trailer. Devices were added or adjusted using a Mn/DOT cantilever bucket truck without any lane closures.

e. Under the Pavement Conduit Installation – Video Clip 2

Boring for conduit installation began the same night as the overhead device installation. Using directional boring techniques, the contractor bore two holes under the pavement. After the holes were bored 10-foot (3 m) sections of conduit were pushed in place. One conduit was 3-inches (8 cm) in diameter and the other 2-inches (5 cm). The larger conduit was selected to allow room for the installation of devices of unknown size. Problems were encountered with large aggregates, the size of the hole required for the 3-inch (8 cm) conduit, and the boring equipment. At one point a section of conduit was trapped in the hole and had to be worked around. It took several nights to complete the work. Handholes were installed where the conduits terminated to facilitate the installation and removal of the magnetic probes. After the installation the pavement over the conduits appeared slightly elevated.

f. Cabling Installation

Cabling for the overhead devices was run back to the trailer through 2- and 3-inch (5 and 8 cm) PVC conduits mounted to the Penn Avenue overpass. Cabling for the magnetic probes and inductive loops were run up the embankment to the trailer with 2-inch (5 cm) PVC. Inside the trailer the wiring terminates at the terminal panel. Twelve and 24-volt power supplies were built for those devices that cannot run off standard 120 volt AC current. Loop detector cards and similar cards for those devices that emulate loop detectors were mounted in a standard NEMA rack. A fuse panel provides circuit protection. All computer connections including RS 232 and RS 422 serial lines were wired to one of the three computers housed inside the trailer.

g. Device Inspection

Once all of the devices were installed and connected to computers they were checked for proper functioning. Several devices came with software interfaces that required setup. Devices were setup, calibrated, and initial data collected from them. Some devices required aiming while simultaneously viewing the data outputs. This process required communication between the device and trailer via cellular phone or hand signals. Some devices recommend access to the roadway to aid in calibrating the detection zones. All calibration was accomplished without accessing the roadway. Vendors were contacted regarding the preliminary results.

h. Devices Included in the Initial Field Test

Ten models of devices from eight vendors were tested in the Initial Field Test. These devices are listed below:

Technology	**Vendor**	**Device**
Passive Infrared	Eltec Instruments	Model 842 Sensor
Passive Magnetic	Safetran Traffic Systems	232E IVHS Sensor (2 devices)
Radar	Electronic Integrated Systems	RTMS
Doppler Microwave	Microwave Sensors	TC26B
Doppler Microwave	PEEK Traffic	PODD
Doppler Microwave	Whelen Engineering	TDW-10
Doppler Microwave	Whelen Engineering	TDN-30
Passive Acoustic	International Road Dynamics	SmartSonic™ (2 devices)
Pulse Ultrasonic	Microwave Sensors	TC-30C
Video	Rockwell International	TraffiCam S™

Three of these devices are not intended for the single-lane freeway application used in the Initial Field Test. The Eltec Model 842 Sensor is intended to detect vehicles traveling at speeds under 45 mph. The Microwave Sensors TC-26B is intended to detect traffic at an intersection; its hold time is too long to accurately detect high-density freeway traffic. The Whelen TDW-10 has a wide detection area and cannot be used to monitor just one lane of traffic. These devices were installed and checked for basic functioning at the Initial Field Test site but the data collected from them is not presented.

2. Extended Field Test Device Installation

a. Device Installation Methods

With the aid of a bucket truck, the video cameras, devices and junction boxes were mounted at the intersection poles. The junction boxes provide flexibility in moving devices from one location to another because the cabling to the trailer is terminated at the junction box, requiring only a pig tail connection between the device and junction box. Banding equipment was used to affix the devices and junction boxes to the poles. No lane closures were required for these installations.

At the freeway test site, devices and a junction box were mounted on the sidefire poles with banding equipment. Some of the cabling at these poles was brought back to the trailer in one continuous cable. Other cabling was tied into the junction box on the pole. No lane closures were required for these installations.

Many of the devices were moved to various locations during the Extended Field Tests. The specific locations are described for each device for each test period in Table 2.

b. Devices included in the Extended Field Tests

Nine additional devices from six vendors were added for the Extended Field Tests phase of the project. The 17 devices included in the Extended Field Tests are listed as follows:

Technology	Vendor	Device
Passive Infrared	Eltec Instruments	Model 833 Sensor
Passive Infrared	ASIM Engineering, Ltd.	IR 224 (2 devices)
Active Infrared	Schwartz Electro-Optics, Inc.	Autosense I™
Passive Magnetic	Safetran Traffic Systems	232E Sensor (2 devices)
Radar	Electronic Integrated Systems	RTMS
Doppler Microwave	PEEK Traffic	PODD
Doppler Microwave	Whelen Engineering	TDN-30
Passive Acoustic	International Road Dynamics	SmartSonic™ (2 devices)
Pulse Ultrasonic	Microwave Sensors	TC-30C
Pulse Ultrasonic	Novax	Lane King™
Video	Rockwell International	TraffiCam S™
Video	Image Sensing Systems	Autoscope 2004™
Video	ELIOP Trafico S.A.	EVA 2000 S
Video	Peek Transyt	Video-Trak 900™

D. Data Acquisition System

1. Data Acquisition Hardware

The data acquisition hardware included three personal computers, a television, three video cassette recorders and a standard hardware equipment rack. The rack was used to hold data acquisition components such as loop detectors, power supplies, an automatic data recorder and a terminal panel for device wiring. For these tests a PEEK ADR 3000 was used to collect all of the loop emulation relay output into a single database. This data acquisition system allowed for the collection of all data outputs simultaneously. During specific 24-hour data collection periods data were collected from the devices and baseline loops in 5- or 15-minute intervals. Some data outputs were in the form of a simple relay contact closure with the relay normally open and then closing when a vehicle was detected. Other data were supplied through a serial communication link to a personal computer housed in the data collection trailer. Some devices offer both data outputs. The Field Test Site Schematic in Figure 5 shows the general layout of the data acquisition hardware.

Table 2 Device Mounting Locations by Test Period

TECHNOLOGY / Device	Test Period (1): 24-Hour Test 1 Jan. 19, 1996	24-Hour Test 2 June 20-21, 1996	24-Hour Test 3 Aug. 7-8, 1996	24-Hour Test 4 Dec. 12-13, 1996	24-Hour Test 5 Jan. 22-23, 1997	Continuous Test 2 Jan. 24 - Feb. 26, 1996	Continuous Test 3 June 6-13, 1996	Continuous Test 4 June 22-26, 1996	Continuous Test 5 July 13-29, 1996	Continuous Test 6 Aug. 16 - Sept. 9, 1996	Continuous Test 7 Sept. 10-30, 1996	Continuous Test 8 Sept. 30 - Oct. 24, 1996	Continuous Test 9 Oct. 31 - Dec. 11, 1996	Continuous Test 10 Dec. 16, 1996 - Jan. 22, 19
PASSIVE INFRARED														
Eltec Model 833				NB P4	L1 BR								NB P4	L1 BR
Eltec Model 842	L1 BR					L1 BR								
ASIM IR 224 No. 1		L1 BR	L1 BR	EB P1	EB P1		L1 BR	L1 BR	L1 BR	L1 BR	L1 BR	EB P1	EB P1	EB P1
ASIM IR 224 No. 2			EB P2	L1 BR	L1 BR				EB P2	EB P2	EB P2	L1 BR	L1 BR	L1 BR
ACTIVE INFRARED														
Autosense I		L1 BR	L1 BR	L1 BR	L1 BR		L1 BR	L1 BR	L1 BR	L1 BR	L1 BR	L1 BR	L1 BR	L1 BR
MAGNETIC														
IVHS Sensor 232E	L2 UG	L2 UG	L2 UG	L2 UG	L2 UG	L2 UG	L2 UG	L2 UG	L2 UG	L2 UG	L2 UG	L2 UG	L2 UG	L2 UG
RADAR														
RTMS X1	L2 BR	L12 P2	L12 P2	L1 BR	L1 BR	L2 BR	L12 P2	L12 P2	L12 P2	L12 P3	L12 P3	L1 BR	L1 BR	L1 BR
DOPPLER MICROWAVE														
TC - 26B	L2 BR					L2 BR								
PODD	L1 BR	L1 BR			L1 BR	L1 BR	L1 BR	L1 BR		NB P4	NB P4			L1 BR
TDW - 10	L2 BR					L2 BR								
TDN - 30	L1 BR	L1 BR		EB P2	L1 BR	L1 BR	L1 BR	L1 BR	EB P2	EB P2	EB P2	EB P2	EB P2	L1 BR
PULSE ULTRASONIC														
Lane King No. 1				NB P4	EB P2					NB P4	NB P4	NB P4	NB P4	(2)
Lane King No. 2					L1 BR									L1 BR
TC - 30	L1 BR			EB P2	L1 BR	L1 BR				EB P2	EB P2	EB P2	EB P2	L1 BR
PASSIVE ACOUSTIC														
Smartsonic TSS - 1 No. 1	L1 BR	EB P2	EB P2	EB P2	EB P2	L1 BR	EB P2	EB P2	EB P2	EB P2	EB P2	EB P2	EB P2	EB P2
Smartsonic TSS - 1 No. 2	L2 BR	L2 BR	L2 BR	L1 P1	L1 P1	L2 BR	L2 BR	L2 BR	L2 BR	L1 P1	L1 P1	L1 P1	L1 P1	L1 P1
VIDEO														
EVA 2000 S		L12 BR	L12 P1	L12 BR	L12 BR		L12 BR	L12 BR	L12 P1	NB P3	NB P3	NB P3	L12 BR	L12 BR
Autoscope 2004		L12 BR	L12 P1	NB P3	L12 P1		L12 BR	L12 BR	L12 P1	NB P3	NB P3	NB P3	NB P3	(3)
TraffiCam - S	L2 BR	L12 BR	L12 BR	L12 BR	L12 BR	L2 BR	L12 BR	L12 BR	L12 BR	L12 BR	L12 BR	L12 BR	L12 BR	L12 BR
Video Trak-900		L12 BR	L12 P1	NB P3	L12 P1		L12 BR	L12 BR	L12 P1	NB P3	NB P3	NB P3	NB P3	(3)

LEGEND

Freeway Site
- L1 Lane 1
- L2 Lane 2
- L12 Lanes 1 and 2
- BR Bridge Mounted
- P1 Pole 1
- P2 Pole 2
- P3 Pole 3
- UG Underground

Intersection Site
- EB Eastbound Approach
- NB Northbound Approach
- P1 Pole 1
- P2 Pole 2
- P3 Pole 3
- P4 Pole 4

Notes:
(1) This table represents when and where devices were mounted, not all of the data from these time periods is presented.
(2) Lane King Ultrasonic moved from Northbound Pole 4 to Eastbound Pole 2 at the intersection on January 10, 1997.
(3) Video cameras for the Video Trak-900 and Autoscope devices were moved from intersection Pole 4 to freeway Pole 1 on January 2, 1997.

2. Data Acquisition Software

In addition to the automatic data recorder and serial outputs, it was desired to have a video image providing both the traffic being monitored and real-time vehicle detection of this traffic from each device. A data acquisition software interface for this purpose was developed by a systems integration sub consultant, Pioneer Technology. The interface consists of a real-time display of all relay contact closure inputs. Superimposed on this screen is a real-time video of the traffic in the test area. Refer to Figure 9 for a reproduction of this interface. During test periods this interface screen was recorded onto VCR tapes for later reference. By placing a record of each detection event next to a video of the traffic it was possible to perform a detailed analysis of each device. These tapes were offered to vendors for their use.

E. Data Collection Plan

1. Baseline Calibration

Six inductive loops previously installed for the Hughes' project, *Detection Technology for IVHS*, provided the baseline for the speed and volume data collected from devices mounted at the freeway test site. The loops are located in both lanes of eastbound I-394 and in the northern HOV lane. The loops are 6 by 6 feet (1.8 by 1.8 m) square with the leading edge of one loop 15 feet (4.6 m) from the leading edge of the next. Refer to Figure 3 for the location of the loops at the freeway test site and to Appendix F for a detailed description of the loop installation, materials and detector cards used.

To establish the accuracy of the loops at the freeway test site, the volume and speed outputs were checked against ground truth data collected by manual counts and speed observations. One-hour manual counts were conducted in 5-minute or 15-minute intervals on several different days and under different traffic conditions. At the same time, loop data were collected from each loop individually, allowing a comparison between the upstream and downstream loops in each lane. Each loop was found to agree well with the loop in the same lane.

Because the loops served as the baseline data, extra care was taken to ensure that they were precisely groundtruthed. In order to reduce counting fatigue, the manual counts were made from video tapes of traffic. This allowed the tape to be stopped every 5 or 15 minutes to accurately record numbers and allowed one lane to be counted at a time. The tapes from some time periods were counted multiple times to verify the accuracy of the manual counts. Refer to the detailed calibration results in Tables D-1 and D-2 in Appendix D.

The freeway baseline calibration found the loops in lane 1 to range from overcounting 0.5 percent to undercounting 1.4 percent compared to 1-hour manual counts. The loops in lane 2 ranged from overcounting 1.1 percent to undercounting 1.0 percent. Refer to Table 3, Loop Calibration Summary, and to Appendix D. Included in Appendix D are volume scatter plots with the loop volumes plotted on the y-axis and the manual count volumes plotted on the x-axis. Note that some data points represent 5-minute counts and others represent 15-minute counts.

Table 3 Loop Calibration Summary - Freeway

Freeway Lane One

Date / Period	Manual Counts	Adjusted Manual Counts (1)	Avg. of Loops 1A & 1B	Difference	% Diff.	Root Mean Square
09/28/95 pm peak	1025	1033	1031	-2	-0.2%	1.1
10/12/95 mid-day	568	573	565	-8	-1.4%	3.5
10/16/95 mid-day	878	885	888	3	0.3%	1.8
10/16/95 pm peak	2225	2236	2238	2	0.1%	1.8
11/02/95 am peak #1	2347	2354	2352	-2	-0.1%	0.6
11/02/95 am peak #2	2342	2350	2352	2	0.1%	1.0
01/19/96 am peak	1316	1321	1326	5	0.4%	1.5
09/27/96 am peak	1732	1732	1740	8	0.5%	3.7
11/06/96 am peak	1901	1907	1909	2	0.1%	1.3

Freeway Lane Two

Date / Period	Manual Counts	Adjusted Manual Counts (1)	Avg. of Loops 2A & 2B (2)	Difference	% Diff.	Root Mean Square
09/28/95 pm peak	1181	1189	1177	-12	-1.0%	3.0
10/12/95 mid-day	2297	2309	2287	-22	-1.0%	2.9
10/16/95 mid-day	1143	1152	1165	13	1.1%	3.9
10/16/95 pm peak	2330	2344	2346	2	0.1%	2.7
11/02/95 am peak #1	2299	2307	2311	4	0.2%	1.8
11/02/95 am peak #2	2301	2307	2311	4	0.2%	1.8
01/19/96 am peak	1387	1392	1394	2	0.1%	2.3
09/27/96 am peak	1742	1742	1747	5	0.3%	1.7
11/06/96 am peak	1494	1499	1495	-4	-0.3%	2.1

Freeway HOV Lane

Date / Period	Manual Counts	Adjusted Manual Counts (1)	Avg. of HOV Loops A&B	Difference	% Diff.	Root Mean Square
9/28/95 pm peak	156	158	148	-10	-6.3%	2.5
10/16/95 mid-day	181	182	182	0	0.0%	0.5
10/16/95 pm peak	818	822	817	-5	-0.6%	1.2
11/02/95 am peak	806	808	806	-2	-0.2%	0.9

Notes:
(1) The manual counts were adjusted by splitting the "mid lane" traffic between the corresponding adjacent lanes.
(2) In lane 2 the volumes from loops 2A and 2B were averaged for all but 10/12/95 and 9/28/95 because loop 2B was recalibrated after initial calibration checks.

Table 3 (Continued) Loop Calibration Summary - Intersection

Northbound Approach - Through Lane

Date/Period	Manual Counts	Loop D2-2	Difference	% Difference	Root Mean Square
06/03/96 am peak	109	112	3	2.8%	0.9
09/23/96 mid day	60	61	1	1.7%	0.5
09/23/96 pm day	256	263	7	2.7%	1.9
12/04/96 mid day #1	76	74	-2	-2.6%	2.2
12/04/96 mid day #2	71	74	3	4.2%	0.9
12/05/96 am peak #1	235	229	-6	-2.6%	5.2
12/05/96 am peak #2	228	229	1	0.4%	5.4
12/05/96 am peak #3	225	229	4	1.8%	4.2

Northbound Approach - Right Turn Lane

Date/Period	Manual Counts	Loop D2-3	Difference	% Difference	Root Mean Square
06/03/96 am peak	615	613	-2	-0.3%	1.7
09/23/96 mid day	248	249	1	0.4%	0.9
09/23/96 pm day	507	503	-4	-0.8%	2.7
12/04/96 mid day #1	198	201	3	1.5%	2.8
12/04/96 mid day #2	205	201	-4	-2.0%	1.7
12/05/96 am peak #1	556	577	21	3.8%	7.5
12/05/96 am peak #2	559	577	18	3.2%	8.5
12/05/96 am peak #3	562	577	15	2.7%	7.4

Eastbound Approach - Through / Left Turn Lane

Date/Period	Manual Counts	Loop D4-1	Difference	% Difference	Root Mean Square
06/03/96 am peak	95	94	-1	-1.1%	1.5
09/23/96 mid day	129	131	2	1.6%	0.7
09/23/96 pm day	142	142	0	0.0%	0.0
12/04/96 mid day	138	137	-1	-0.7%	0.5
12/05/96 am peak	106	104	-2	-1.9%	0.7

Baseline speed data were collected at the freeway test site with a pair of loops in each lane. Speed was calculated by measuring the time it took for a vehicle to travel from the upstream loop to the downstream loop, 15 feet (4.6 m) away. The automatic data recorder was used to calculate the speed and to aggregate the data. The speeds measured by the loops were calibrated with a combination of a radar gun and a probe vehicle. The speed calibration tests found the loops in lane 1 to consistently underestimate speed by 6.1 percent and lane 2 to underestimate by 2.1 percent. All of the baseline speed data were adjusted by these factors.

At the Penn Avenue and I-394 south ramps intersection test site, eight loops are in place to actuate the traffic signal. The loops are approximately 6 by 6 feet (1.8 by 1.8 m) square. The data from all eight loops were collected and compared to manual counts in 15-minute intervals. Based on these counts and considerations such as device mounting locations, two loops in the northbound approach, D2-2 and D2-3, and one loop in the eastbound approach, D4-1, were selected. Refer to Figure 7 for the location of these loops and to Appendix F for a detailed description of the loop detector cards used.

To establish the baseline volume data, the procedure used at the freeway location was repeated for the intersection. One-hour manual counts were conducted in 15-minute intervals on several different days and under different traffic conditions. Counts were done from videotape to provide more accurate results and to allow for multiple counts of the same time periods. At the northbound Penn Avenue approach, loop D2-2 in the through lane was found to range from over counting 4.2 percent to undercounting 2.6 percent and loop D2-3 in the right turn lane was found to range from over counting 3.8 percent to undercounting 0.2 percent. At the eastbound I-394 off-ramp approach, loop D4-1 in the shared through / left turn lane was found to range from over counting 1.6 percent to undercounting 1.9 percent compared to 1-hour manual counts. Speed data were not collected at the intersection test site. Refer to Table 3, Loop Calibration Summary, and to Appendix D where detailed baseline calibration results are presented.

2. Device Adjustments and Calibration

After devices were mounted and connected, they were checked for basic functioning. Some devices simply output relay contact closure outputs upon power up, not requiring any calibration. These outputs were compared to the outputs from the loops in the corresponding lanes. Most other devices require some degree of calibration. These devices were calibrated according to manufacture's instructions. Informal data collection was done with these devices to aid in calibration.

As in the Initial Field Test, devices were mounted and checked for basic functioning. Those requiring it were calibrated according to manufacture's instructions.

After this initial setup, data were collected and supplied to vendors for their comments. Additional calibration was conducted on the devices as required. Every effort was made to accommodate vendors' requests for mounting changes and calibration. Several vendors visited the test site to set up devices. In these cases, the calibration process was done by the vendors but observed by project personnel. It was decided by the Project Team that every effort would be made to calibrate the devices to ensure that the optimal performance of each technology could be determined. Except as noted, only the data from calibrated devices are presented in the Final Report.

3. Continuous Data Collection Tests Periods

In continuous data collection periods relay data and easily retrievable serial data were collected from each device for one or more weeks. A total of ten continuous tests were conducted over the course of the project. The results from all test periods, except for Continuous Test Number 1, which was used to calibrate the devices, are presented in the Final Report.

The data collection philosophy was to aggregate the continuous test results, typically into 15-minute intervals and daily percent differences, not perform a vehicle by vehicle real-time analysis of device performance. While an event by event level of analysis would provide useful information, it was outside the scope of the project. The data aggregation allows an easy analysis of long-term trends in device performance. The impact of environmental conditions can be readily examined. An aggregated analysis also presents the data in the same form encountered in real world data collection practices.

There are shortcomings to aggregating data. Every time data are aggregated some information is lost. While the effects of aggregation should be kept in mind, the aggregation to 15-minute intervals coupled with the large number of time periods still provides a good picture of device performance.

4. 24-Hour Data Collection Tests Periods – Video Clips 3-5

During specific 24-hour data collection periods, extensive data were collected from each device and baseline loops in 5- or 15-minute intervals. The data included counts, speed, and vehicle classification. The test site weather monitoring station located on the roof of the trailer provided hourly data on temperature, precipitation and wind speed. In addition, weather data from the National Climactic Data Center were used.

The data acquisition software interface consisted of a real-time display of all relay contact closure inputs, a real-time video of the traffic in the test area, and a digital clock with time and date. This allowed for a detailed manual analysis of the performance of each device to identify if there were any systematic problems with detection under specific conditions, such as heavy congestion, low light levels, shadows, etc. This display was recorded onto VCR tapes during 24-hour test periods. The video tapes provide an opportunity for vendors to analyze the performance of their device on a vehicle-by-vehicle basis.

F. Data Analysis

The results section of this report contains an overview of test results for each technology followed by a discussion of detailed test results for each device using that technology. The actual data are presented in Appendixes B through E. Appendix B contains data that have been prepared for special analyses. This includes graphs showing the impact of variables such as rain and lighting conditions. Appendix C contains detailed test results including extensive graphs and tables assembled for each test period. The five 24-hour test periods are presented first, followed by the nine continuous test periods. Several different types of graphs are used in Appendix C to present the detailed test results. It is important to examine all of the different graphs in order to gain an accurate picture of each device's performance. Appendix D contains detailed baseline calibration results. Appendix E contains summarized weather data.

1. Correlation Coefficient Calculation

The correlation coefficient is presented for each device in both the 24-hour and continuous test periods. The Pearson's product-moment correlation coefficient was selected for this calculation. It provides a measure of each device's variation from the baseline data from one time interval to the next. The closer the correlation coefficient is to 1.0 the more reliable the data are from one 15-minute period to the next.

A correlation coefficient of 0.999 was often obtained in counts at the freeway test site. In some test periods the majority of devices had correlation coefficients of 0.999 or higher. A correlation coefficient of less than 0.99 signifies a greater variance in data. Correlation coefficients calculate the linear nature of the data points seen on a scatter plot, not the deviation from the loops. A device that consistently under or overcounted proportional to the actual volume may have a high correlation coefficient but not be counting accurately.

2. Volume Scatter Plots

The volume scatter plots, shown for both the 24-hour and continuous test periods, provide a visual representation of the correlation coefficient. Each point on a scatter plot represents a 15-minute traffic volume as measured by the baseline loops on the horizontal axis and the device on the vertical axis. Data points falling on a linear 45-degree line represent perfect agreement between the loops and a device. Observations, such as the influence volume has on device performance, can be made by examining the patterns in the scatter plots. Note that the 24-hour test scatter plots have significantly fewer data points than the scatter plots from the continuous tests. As a result, a few outlying data points from a continuous test do not necessarily indicate a poor performance in a device that was in operation for several weeks.

3. Root Mean Square Calculation

The Root Mean Square (RMS) is a useful statistic for evaluating the deviation between device and baseline loop volumes. The RMS data presented in Appendix C were calculated for both the 24-hour and continuous test periods from the 5- or 15-minute volumes. Note that the RMS is sensitive to the relative volume of traffic being observed. The RMS for devices at the freeway test site cannot be directly compared to RMS values for devices at the intersection test site. Similarly, the RMS from one approach at the intersection cannot be compared to the RMS values from another approach. It is important to examine the percent difference, correlation coefficient, standard deviation and RMS when interpreting the results.

4. Percent Difference Graphs and Calculation

The percent difference between baseline loops and each device was calculated for each day of the continuous test periods. This information is provided in a table and in the daily percent difference graphs. In Continuous Test Numbers 6, 7, 8, 9 and 10 separate graphs are included for the freeway and intersection test sites. The daily percent difference graphs show long term patterns of device performance. However, the aggregation of data into daily totals can obscure the performance of a device that both under and overcounts, having compensating errors. Therefore, the daily percent difference should be used in conjunction with other statistical measures.

5. Count Accuracy / Speed Relationship Graphs

Device performance relative to traffic volumes does not provide a complete picture of the parameters that affect count accuracy. During peak periods, congestion can cause volumes to drop. When examining the volume scatter plots from the 24-hour test periods, the low-volume data cannot be differentiated from low-volume data found in free flowing off-peak periods. A separate analysis of the correlation between traffic speed and device performance distinguishes the impact of speed from the impact of volume levels. A scatter plot of the relationship between count accuracy on the vertical axis and average speed on the horizontal axis for each 15-minute period provides useful information on the performance of some devices. These graphs have been prepared for all 24-hour test periods except for 24-hour Test Number 4, which does not contain baseline speed data. Only data from 6:00 a.m. to 12:00 midnight were used to avoid including large percent differences caused by small sample sizes during extremely low-volume periods.

6. Statistical Analysis Graphs

A statistical analysis figure is included for each 24-hour test. This graph displays the standard deviation on the y-axis and the results from each of the devices on the x-axis. A separate graph is included for count and speed data. The figures are useful for portraying both the range in error and the overall percent difference. The graphs are generated by plotting the daily percent difference and then adding and subtracting one standard deviation. The standard deviation was calculated from the percent difference for each 5- or 15-minute time period. Time periods with fewer than 50 vehicles were removed from the data set in order to avoid excessively large percent differences. Similarly, time periods with no speed values were removed. The standard deviation, percent difference, correlation coefficient and RMS values are also tabulated.

7. Speed Scatter Plots

Speed scatter plots were prepared for each 24-hour test period. Similar to volume scatter plots, the speed scatter plots have the device speed on the y-axis and the baseline speed on the x-axis. Data points that cluster along a 45-degree line most closely agree with the baseline data. Also included are tables of detailed results from the 24-hour test periods. These data are provided in either 5- or 15-minute time intervals, depending on the test.

8. Classification Results

During 24-hour Test Numbers 2 and 3, classification data were collected at the freeway test site. Baseline classification data were provided by the inductive loops in each lane. The loops were checked against manual observations and found to have an approximate correlation. Since some obvious inaccuracies in the loop length data were observed, the loop data provide only a general guide. The loops classify vehicles based on length only. More accurate baseline classification would require an axle counter, which was not available for this test, or manual classification over the full testing period.

The two methods used to classify vehicles are based on length and height. The active infrared device classifies vehicles by height while the rest of the devices and loops classify by length. Some devices have fixed classification definitions while others allow flexibility to create user-defined classifications. These differences made the classification data difficult to compare from one device to another. None of the devices tested can count the number of axles. The number of axles is an important parameter for placing vehicles into the 13 classes used by the Federal Highway Administration. The classification results are presented in the end of Appendix B.

IV. RESULTS

This section presents detailed test results for each of the seven distinct technology groups evaluated. The first portion of each technology group is a discussion of the potential for that technology to perform under optimal conditions. This discussion is emphasized because the overall goal of the project is to examine the performance, capabilities, and potential of each technology as opposed to a device-by-device comparison from products within a technology. Next the test results are presented for each device, analyzed separately to allow for a more detailed description of each test setup and the various steps taken in calibrating devices.

The detailed analysis of each device includes information on where devices were mounted and how they performed under various mounting locations and environmental conditions, refer to Table 2 for a summarized description of device mounting locations for each test period. Also included is a discussion of the ease of device mounting, ease of calibration, cost, general indications of maintainability and reliability, and finally, the device's features. Refer to Table 3 for a summarized presentation of these factors. While every attempt was made to test the full capability of each device, some forms of data such as occupancy could not be groundtruthed and are not presented here.

In testing and presenting the results for these devices, emphasis has been placed on making the data easy to interpret for a diverse audience. For this reason, every attempt has been made to make the statistical analyses performed as straightforward and intuitive as possible. Most of the data were collected in 15-minute intervals and assembled into daily totals and daily percent differences from baseline data. The correlation coefficient, standard deviation, and root mean square are used to express the variation between device data and baseline data.

The emphasis in this project was to test devices in a real world environment rather than in a controlled laboratory setting. Whenever possible the most challenging conditions were selected, including unusual geometric conditions, heavy traffic, a variety of mounting locations, and a variety of environmental conditions. Also, whenever possible, the devices were mounted from existing structures and operated in conditions that would most commonly be experienced in the real world. Specific testing objectives -- such as determining the mean time between failures or a detailed analysis of the sensitivity to multiple mounting positions - were outside the scope of this project.

When evaluating the performance of these devices it is important to consider their intended applications. For example, if a device will be used to actuate a signal it is not necessary to obtain a highly accurate vehicle count. It is more important that the device detect the presence of every vehicle that approaches. In this case it may be acceptable for the device to double count some vehicles, or see multiple vehicles as one continuous vehicle, but it would not be acceptable to miss vehicles. Note that the focus of this project is to evaluate the ability of these devices to collect traffic data, not actuate signals or gather real-time traffic information.

In previous interim reports devices were only identified by the type of technology being used, not the product name. Now that the testing has been completed and all of the data analyzed, the results are considered final and the identity of each device is revealed.

The Final Report contains more data than were published in previous reports. In general, all data from calibrated devices are presented here, except as noted in this section. A device was considered calibrated when the setup and installation procedures were followed according to the vendor's specifications and the vendor had an opportunity to examine the data. In addition to data from non-calibrated devices, the only other data removed are very erratic data that clearly point to a problem with the device. While some vendors requested that the data from certain test periods be removed, the request could not be honored unless the performance of the device was very erratic, indicating that the device was grossly malfunctioning.

There are many factors to consider when evaluating the performance of the devices. In addition to cost and performance, other factors such as mounting locations, the number of lanes monitored, and ease of setup can be equally important. As a result, this report cannot identify a single device or technology as being the best.

A. Passive Infrared

Passive infrared devices detect the presence of vehicles by measuring the infrared energy radiating from the detection zone. The infrared energy naturally emanating from the road surface is compared to the energy radiating when a vehicle is present. Since the roadway may generate either more or less radiation than a vehicle, the contrast in heat energy is what is detected. The possibility of interference with other devices is minimized because this technology is completely passive.

The two devices tested are designed to monitor one lane of traffic from either a sidefire or overhead location. While the devices provide relay outputs that can only be used to collect count and presence data, vendors indicate that future product upgrades will also offer speed and classification data.

Passive infrared technology is capable of being a good technology for monitoring traffic in urban areas. Good performance was found for both the freeway and intersection locations. No correlation was found with any weather variables. In addition, the two devices tested are each very easy to mount, aim and calibrate. There were, however, significant differences in performance in the devices tested.

1. Passive Infrared -- Eltec 833 and Eltec 842

The Models 833 and 842 by Eltec Instruments are self contained passive infrared detectors. They are designed to mount either overhead or slightly to the side of the roadway facing oncoming or departing traffic. Volume and presence data are available from the relay outputs.

Mounting Location No. 1 -- Freeway Bridge

Description: On July 19, 1995 an Eltec model 842 was provided for the Initial Field Test phase of the project. It was mounted at the freeway at a height of about 24 feet (7.3 m).

Results: The model 842 was observed to undercount vehicles. After conferring with the vendor, it was agreed to remove this device from the test because the model 842 is not intended to detect vehicles traveling faster than 45 mph and was thus not suited for a freeway application.

Mounting Location No. 2 -- Intersection

Description: An Eltec model 833, intended for freeway or intersection mounting applications, was received in exchange for the model 842. This device was first installed on sidefire pole No. 4 at the intersection at a height of 15 feet (4.6 m) on August 14, 1996. On September 30 the device's relay contact closure failed and the device was mailed back to the vendor for repairs. It was remounted on October 10. On October 25 it was moved to a height of 25 feet (7.6 m) to try to correct for overcounting by having the device detect more of a vehicle's roof and less of its tires. On December 13 the device was taken down for mounting at the freeway.

Results: The model 833 was found to predominantly overcount vehicles. When the device was moved to a higher mounting location on October 25, 1996 the performance improved but still tended to overcount. The daily results Continuous Test Number 9 ranged from undercounting 46 percent to overcounting 37 percent. The majority of the days had overcounting of approximately 15 percent.

Manual Observations:

10/10/96	Eltec 833 counted 61 out of 50, double or triple counted some vehicles for no apparent reason -- no correlation observed with speed or class.
10/21/96	Eltec 833 counted 60 out of 50, overcounting with a brief actuation for no apparent reason -- same operation as before.
12/10/96	Eltec 833 counted 57 out of 51, double counted 12, missed 5 vehicles, no correlation between vehicle class and miscounting, freeflow traffic.

Mounting Location No. 3 -- Freeway Bridge

Description: On December 23, 1996 the model 833 was moved to the freeway at a height of about 24 feet (7.3 m), similar to where the model 842 had been mounted.

Results: Manual observations found the device to randomly miss vehicles. The vendor indicated that the unit was not functioning properly. The device could not be returned for inspection or repairs in time for additional testing. No test results are presented for either the 842 or 833 when mounted at the freeway because they never operated successfully. The data collected by the 833 at the intersection should also be considered suspect because the device may have been defective during those tests as well.

Manual Observations:
1/7/97 Eltec 833 counted 35 out of 50, randomly misses vehicles, freeflow.
1/8/97 Eltec 833 counted 23 out of 50, randomly misses vehicles, double counted one semi, freeflow.

Assessment

Summary of results: The only data considered for final analysis for either Eltec device are the model 833 results at the intersection. From this location the device had significant fluctuations in count accuracy. Its best performance came during 24-hour Test Number 4, when the device was observed to count within 1 percent of baseline data. Note that while there was some compensating error during this test period, the device performed as well as the other devices during the 24-hour test.

Other comments: Both Eltec models are easy to mount. They come equipped with an adjustable mounting bracket that easily fit into the device mounting system. Calibration was also very straightforward. With no serial communication or adjustment screws, the only step was to aim the device as described in the manual and check it for basic functioning. With no communication link to the devices, maintainability can be measured only by inspecting the device's outputs. Repeatability was an issue with the Model 833. The first unit received had a bad relay and had to be mailed back for repairs. The replacement unit was functional but the vendor felt the device was somehow defective. There was not time to fix it before the end of the project.

2. Passive Infrared -- ASIM IR 224

The IR 224 is a passive infrared detector made by ASIM AG of Switzerland. It is designed to mount either overhead or slightly to the side of the roadway and must face oncoming traffic. A special alignment tool is provided to aid in aiming. Volume and presence data are available over its relay outputs. The serial communication and supplied software offer monitoring of the detector's real-time performance. The device monitors the infrared energy in three measuring zones; a vehicle must pass through all three zones in order to trigger a detection. This reduces the number of false calls and provides the opportunity for true presence detection.

Mounting Location No. 1 -- Freeway Bridge

Description: The IR 224 device was first installed at the freeway test site on March 5, 1996. It was mounted about 16 feet (5 m) above the roadway facing oncoming traffic. With this mounting location the unit could not be aimed by siting along the body of the detector, as intended, but had to be lowered into position and aimed from a distance. Despite this difficulty, the device was successfully mounted and aimed. On July 25 the aiming was adjusted. On October 4 this IR 224 was removed from the freeway for mounting at the intersection and a second IR 224 put in its place (see mounting location No. 2 below).

Results: Extensive testing from this mounting location at the freeway provided excellent results. The device was usually within 1 percent of loops for a daily count.

Manual Observations:
10/1/96 IR 224 counted 30 out of 30.

Mounting Location No. 2 -- Freeway Bridge

Description: A second IR 224 unit was installed at the same location on the freeway bridge on October 4, 1996 and the original was moved to the intersection.

Results: The IR 224 consistently undercounted daily traffic by about 2 percent, noticeably worse than before, suggesting the second mount was not as optimally aimed as the first. Later in the test this device developed intermittent problems. When examining the data there were clear periods in which the device was not operating correctly. The data would closely follow the loop counts and then abruptly drop to very low counts. This occurred in about one of every three days and could not be correlated to any environmental or other factors. Since there was not time to fully diagnose the problem or to return the device for inspection or repairs, the device was left to operate for the last two months of testing. Whenever an intermittent problem surfaced, the data from those time periods were removed from the published results.

Manual Observations:
10/10/96 IR 224 counted 50 out of 50.
10/21/96 IR 224 counted 50 out of 50, freeflow.
12/4/96 IR 224 counted 49 out of 50, freeflow.
1/8/97 IR 224 counted 49 out of 50, missed one vehicle for no apparent reason, freeflow.

Mounting Location No. 3 -- Intersection

Description: On July 10, 1996 a new IR 224 was mounted on Pole 2 at the intersection.

Results: From Pole 2, the IR 224 undercounted by between 5 and 30 percent. At the vendor's request the device was later moved to Pole 1 at the same approach but at a higher mounting location (see the results from mounting location No. 4).

Manual Observations:
10/1/96 IR 224 counted 10 out of 10, did not miss any vehicles but sometimes vehicle presence was indicated after the vehicle left the detection zone.

Mounting Location No. 4 -- Intersection

Description: On October 4, 1996 the vendor came out to visit the test site and moved one IR 224 from the intersection to the freeway and installed a new IR 224 on Pole 1 at the intersection (see Figure 7).

Results: From Pole 1, the IR 224 performance improved to approximately 5 percent. Since Pole 1 is only about 2 feet (0.6 m) closer to the lane than Pole 2, the higher mount is thought to be the reason for the improved performance. The alignment tool aided greatly in aiming the device at the intersection. The IR 224 had the best overall results of any device at the intersection. The correlation coefficient was very close to 1.000, indicating a high degree of reliability from one time period to the next. On October 21 a manual observation indicated the device counted 27 out of 50 vehicles. This result is not consistent with what was observed at other times and cannot be explained.

Manual Observations:

10/10/96	IR 224 counted 49 out of 50, on one occasion a car sitting at the stop bar was counted twice.
10/21/96	IR 224 counted 27 out of 50, counted two trucks twice, missed others for no apparent reason.
12/4/96	IR 224 counted 12 out of 11, 2 double counts and 1 under count, freeflow.

Assessment

Summary of results: During an optimal 24-hour count period, the IR 224 at the freeway is capable of counting to within 1 percent of baseline data. At the intersection the device is capable of counting to within 2 percent of baseline data. These results are near the accuracy of the baseline data and are among the best results obtained.

Other comments: The IR 224 was easy to mount, coming equipped with an adjustable mounting bracket that fit easily into the project's mounting system. Calibration was also very straightforward. With no adjustment screws the only step was to aim the device as described in the manual and check it for basic functioning. The device can be checked by either observing its relay outputs or monitoring its signal strength with its serial output and supplied software. Maintainability was aided with the serial communication, allowing a check of the unit's performance. Repeatability was good but one device did experience the intermittent problems described above. Also, during one test the device was observed to undercount vehicles during periods of snowfall. One possible explanation for this miscounting is vehicles traveling outside of the device's detection zone. The loops, with a larger detection area, may have detected these vehicles.

B. Active Infrared

Active infrared devices detect the presence of vehicles by emitting laser beam(s) at the road surface and measuring the time for the reflected signal to return to the device. The presence of a vehicle is measured by the corresponding reduction in time for the signal return.

The single active infrared device tested was found to be very accurate at counting traffic at the freeway although some weather conditions did impact its performance. Speed and classification data are also available. The unit is easy to mount and calibrate. At the vendor's request the device was not tested at the intersection.

1. Active Infrared -- Schwartz Autosense I

The Schwartz Autosense I is a self-contained active infrared device. It detects stationary or moving vehicles by detecting presence with its two laser beam detection zones. Vehicle speeds and profile can also be obtained and used for vehicle classification based on height.

The recommended mounting height is about 20 feet (6 m) with an angle of 0 to 40 degrees from vertical. An overhead mounting position is preferred although it can also be mounted in a sidefire position. There are two cables to the device, a power cable and a communication cable. Relay outputs provide loop emulation in one detection zone. The Autosense I offers volume, speed and classification data through RS 232 or RS 422 serial communication. These data are provided in one-hour time intervals for the 24-hours prior to data download.

Mounting Location No. 1 -- Freeway Bridge

Description: The Autosense I was mounted directly over lane one at the freeway at a height of 22 feet (6.7 m) on March 5, 1996. It was originally aimed at about 10 degrees from vertical in the downstream direction. On June 25 it was reaimed from 10 degrees to about 5 degrees from vertical, aimed slightly downstream. In addition, a new software patch was uploaded to the unit, both at the vendor's request. The original Autosense I supplied for the test malfunctioned in August 1996 and was returned for repairs. A new unit was installed in the test and operational on October 4, 1996.

Results: The reaiming described above did not have a noticeable impact on performance, it overcounted by about 1 percent before and after the change. When the Autosense I was returned from repairs, however, it began to undercount by about 2 percent.

Manual Observations:
10/10/96 Autosense I counted 48 out of 50.
10/21/96 Autosense I counted 50 out of 50.
12/4/96 Autosense I counted 48 out of 50, missed two vehicles that were changing lanes, freeflow.

Assessment

Summary of results: The Autosense I performed very consistently in the first 3 months of testing. The daily volume percent difference from loops ranged from undercounting 0.5 percent to overcounting 2.4 percent. In the last 4 months of testing, the range expanded by about twice and weather conditions were observed to have an impact.

Other comments: The Autosense I was observed to both undercount and overcount vehicles during periods of heavy snowfall. Undercounting is thought to be caused by snow accumulating on the road surface and obscuring the lane markings, causing vehicles to travel outside of the device's relatively small detection zone. From a mounting height of 22 feet (6.7 m), the Autosense I has a detection zone that is about 4 feet (1.2 m) wide. The loops, however, have a detection zone that is about 8 feet (2.4 m) wide. On January 5, 1997 when there was 3.1 inches (7.9 cm) of snow, the Autosense I undercounted by 23 percent. On November 24, 1996 when there was 1.1 inches (2.8 cm) of snow, the Autosense I undercounted by 16.6 percent, refer to Figures B-1, B-2 and B-4.

Heavy snowfall is also correlated with overcounting on days such as November 23, 1996 when 6.3 inches (16 cm) of snow fell and the device overcounted 9.1 percent for the day. This overcounting was found primarily in seven 15-minute periods including a count of 2320 vehicles in 30 minutes between the hours 17:15 and 17:45. The results were 1,788 higher than the loops, refer to Figure B-3. The vendor feels this overcounting is probably due to falling snow, which is detected as vehicles by the laser beam.

Rain and freezing rain also caused a combination of undercounting and overcounting on days like December 23, 1996, refer to Figure B-5. On this day, freezing rain occurred at the same time that the Autosense I counts went to zero. When the vendor was contacted, a representative said that wet pavement causes the reflective properties of the road surface to drop, making ranging and counting more difficult. A wet pavement algorithm is employed to compensate, but this algorithm can cause overcounting.

The vendor said that Autosense II and Autosense III have been improved and would not be affected by weather as much as Autosense I.

There were intermittent communication problems with the Autosense I when it was initially installed. At first the cable length of 100 feet (30 m) was thought to be too long, so communication was attempted with an RS 422 line instead of RS 232. This change did not fix the problem; the vendor changed the communication protocol in early July 1996 and was able to establish communication. A new software version was then loaded into the unit. However, intermittent communication problems continued, preventing the download of serial data from most of the 24-hour test periods.

The Autosense I provides volume, speed and classification serial data in 1-hour intervals for the 24 hours prior to download. This fixed format does not fit into the project's data classification scheme which consists of data collected in 15-minute intervals on a continuous basis. In addition, the incoming data are not clearly time stamped.

C. Passive Magnetic

Passive magnetic devices detect the disruption in the earth's natural magnetic field caused by the movement of a vehicle through the detection area. In order to detect this change the device must be relatively close to the vehicles. This limits most applications to installation under the pavement, although some testing has been done with sidefire devices in locations where they can be mounted within a few feet of the roadway.

Inductive loop detectors are classified as active magnetic devices because they supply a small current to the detection area. The presence of a vehicle is determined by the change in current caused by the induced voltage of a passing vehicle, similar in operation to passive magnetic detectors.

Two passive magnetic devices, manufactured by the same vendor, were tested. They were found to perform inconsistently. When working they were capable of counting traffic and calculating speed to within 1 percent of baseline data, but unidentified problems resulted in periods of poor performance. The installation of conduits under the roadway was very difficult.

1. Passive Magnetic -- Safetran IVHS Sensor 232E / 231E Probe

The Safetran 231E Probe is designed to be installed in a conduit located 12 to 16 inches (30 to 40 cm) under the roadway. Two conduits spaced 20 feet (6.1 m) apart were installed at the test site for testing the probes, refer to the Initial Field Test device installation section for a discussion of the conduit installation.

The probes are connected to the IVHS Sensor 232E, a processing card located in the data collection trailer. This card processes the probe's output and generates the relay contact closure that emulates loops and stores data for retrieval via a RS 232 serial connection. The processor can calculate speed based on the shape of the incoming waveform. Volume, speed, and occupancy are then available through the serial outputs. Two probes separated by about 20 feet (6.1 m) can also be used to calculate speed through their relay outputs. Both types of speed data were collected in this test.

Mounting Location No. 1 -- Freeway Conduit

Description: In July 1995 one probe was installed in a 2-inch (5 cm) conduit and the other in a 3-inch (8 cm) conduit located within 20 feet (6.1 m) of one another about 60 feet (18.3 m) downstream of the loop detectors. Refer to Figure 3, Freeway Test Site Schematic. When first installed, the probes were inserted too far into the conduits. On November 16, 1995 the upstream probe had to be pulled back 6 feet (1.8 m) and the downstream probe 2 feet (0.6 m) so they were centered under lane 2. On July 29, 1996 the upstream probe was removed for repairs. When this probe was replaced it was not inserted far enough into the conduit. At the conclusion of testing the probes were removed and their positions measured. The upstream probe was 11.3 feet (3.4 m) from the left edge of lane one and the downstream probe was 8.8 feet (2.7 m) from the left edge of lane one. The vendor indicated these locations should give acceptable results if correctly calibrated. The miscounting from the probes was not always present, indicating the probes may be going in and out of proper sensitivity adjustment.

Results: The Safetran probes have had periods of erratic performance, especially the downstream probe, and periods when the daily percent difference was consistently around 1 percent of loops. The downstream probe has been observed to see adjacent lane traffic. This is likely due to improper sensitivity, not poor probe placement. Refer to the table of summarized continuous test results in Appendix C for more information.

Manual Observations:

10/10/96	IVHS 232E upstream probe counted 42 out of 50. IVHS 232E downstream probe counted 55 out of 50.
10/21/96	IVHS 232E upstream probe counted 35 out of 50 when watching traffic at the loops. IVHS 232E upstream probe counted 38 out of 50 when watching traffic at the conduit, semis double counted, others missed randomly. IVHS 232E downstream probe counted 58 out of 50, half the time it counted vehicles in next lane and half the time it counted a "ghost" image.
10/23/96	IVHS 232E upstream probe counted 50 out of 50, but double counted 2 and missed 2. IVHS 232E downstream probe counted 53 out of 50.
12/4/96	IVHS 232E upstream probe not working, actuation on continuously. IVHS 232E downstream probe not working, actuation on continuously.
1/23/97	IVHS 232E upstream probe counted 17 out of 50, detector card appears to have a grounding problem.

Assessment

Summary of results: When functioning correctly, the probes were generally within 5 percent of loops. On several occasions the probes were within 1 percent of loops. Variation in results may be due to an intermittent grounding problem. This may be accentuated during periods of rainfall when erratic data were observed. As with other devices, erratic data have been removed.

Other comments: There were frequent serial communication problems between the processing card and computer. For this reason, very little serial speed data were obtained from the device. Most of the speed data presented here were calculated by the automatic data recorder from the relay outputs of the two probes. Speed calculated from the relay outputs was generally within 2 mph of the baseline data.

Snow and rain have been observed to affect device performance. On December 8, 1995 snowfall corresponded with overcounting of 22.7 percent. Snow on the road surface most likely caused vehicles to track outside of their normal lanes. The probes may have overcounted by detecting vehicles in both lanes. The correlation with rain is thought to be due to water entering the handhole near the side of the road and shorting out the splice located there. This would explain why the probes' counts suddenly dropped to zero.

The installation of the conduits proved to be a major undertaking. Several days were required to bore under the roadway. The boring was difficult because of the presence of large rocks and chunks of concrete in the roadway's subbase. The conduit installation was by far the most difficult of any of the device installations. Another disadvantage of installation under the pavement is the inaccessibility of the probes during the winter months when the ground is frozen. Also, water was observed in the conduit when the probes were removed. The vendor indicated that the probes are designed to work in this environment but it is possible that they were adversely affected. Poor communication between field personnel and the Project Team resulted in improper probe placement and, because the ground was frozen, there was no way to check or rectify the placement until the spring thaw.

In other applications the 231E Probe has been used to detect traffic from a side mount located within 2 feet (0.6 m) of the roadway. It has also been mounted underneath a bridge to detect vehicles that drive overhead. Neither of these tests were performed as part of this project.

D. Doppler Microwave

Doppler microwave devices transmit low-energy microwave radiation at a target area on the pavement and then analyze the signal reflected back to the detector. According to the Doppler principle, the motion of a vehicle in the detection zone causes a shift in the frequency of the reflected signal. This can be used to detect moving vehicles and to determine their speed.

A total of four different doppler microwave devices from three different vendors were tested. Some of the devices have a simple relay output that registers the presence of a vehicle while others also provide serial communication with real-time speed information. Detailed results from two of the devices are not presented because they are not intended for the single lane, high-volume traffic conditions that were being tested.

Doppler microwave technology was a good technology for detecting traffic at the freeway test site. Poor performance was found at the intersection locations, however, where the devices were observed to undercount or overcount vehicles. No correlation was found with any weather variables. The four devices tested are relatively easy to mount, aim and calibrate. There were, however, some differences in performance in the devices tested.

1. Doppler Microwave -- Peek PODD

The Peek Overhead Doppler Detector (PODD) monitors vehicles in a single lane of traffic. It is mounted either overhead or slightly to the side of the roadway facing oncoming traffic. Volumes are available over the pulse relay loop emulation output. The vendor states that the device can detect vehicles that are traveling at a minimum of 2 to 5 mph. A version of the device is available that can conduct a temporary count with solar or battery supply.

Mounting Location No. 1 -- HOV Lane Freeway Bridge

Description: In the Initial Field Test, the PODD was the only device that had to face oncoming traffic. To accommodate this requirement the device was first mounted at a height of about 24 feet (7.3 m) on the Penn Avenue Bridge over the HOV lane because the traffic in this lane is reversible (see Figure 3). In the morning peak period the traffic travels inbound, away from the device, and in the afternoon peak period it travels outbound, toward the device. The traffic levels in the HOV lane are significantly lower than the mixed flow lanes. Since one of the project objectives is to test devices in an urban environment, including congested traffic, the device was later moved to the eastbound lanes of the freeway with the other devices. No other devices were tested over the HOV lane.

Results: Although the PODD was mounted over the HOV lane to monitor oncoming vehicles, the device was observed to detect departing vehicles more accurately. In the oncoming direction, the PODD overcounted between 11.4 and 29.9 percent for a daily percent difference. In the departing direction, the device ranged from undercounting 29.5 percent to overcounting 14.3 percent. The data that fell at the extreme ends of these ranges occurred on days with snowfall. During optimal performance the PODD detected the departing traffic to within about 5 percent undercounting and the oncoming traffic to within about 20 percent overcounting. The overcounting may be due to a detection zone that was large enough to see the same vehicle twice. A steeper mounting angle may have improved performance. These data were collected before any of the official data collection periods and do not appear in the appendix.

Mounting Location No. 2 -- Freeway Bridge

Description: On December 19, 1995 the PODD was moved to the same location as the other devices, the Penn Avenue Bridge over the eastbound lanes. In order to face oncoming traffic the device was mounted from a pole extending below the mounting truss at a height of about 16 feet (4.9 m) to detect traffic traveling under the Penn Avenue Bridge. This pole is visible as the west facing attachment in Figure 6. The device was aimed 30 degrees from vertical and 3 feet (1 m) north of the center of lane one in order to decrease interference from adjacent lane traffic. The device was taken down for relocation to the intersection on June 25, 1996.

Results: The PODD performed very consistently at the freeway. During six months of testing (Continuous Test Numbers 2 through 4) the results ranged from overcounting 3.6 percent to undercounting 0.7 percent.

Mounting Location No. 3 -- Intersection

Description: On July 10, 1996 the PODD was installed on Pole 4 at the intersection at a height of about 15 feet (4.6 m). On October 25 the device failed and was mailed back to the vendor for repairs. When the device was returned it was mounted at a height of 21.5 feet (6.6 m).

Results: The PODD did not function successfully at the intersection, counting each vehicle two or three times. The vendor said the device was detecting the same vehicle several times because the vehicle was in the detection zone too long. Raising the height from 15 to 21.5 feet (4.6 to 6.6 m) and adjusting the mounting angle did not improve the performance. The device is designed primarily to detect the presence of vehicles at an intersection, not collect count data.

Later the PODD began to miss the majority of the vehicles at the intersection. It was taken down on October 25, 1996 and sent to the vendor for repairs but nothing was found to be wrong with the device. It was eventually moved back to the freeway, where it operated successfully.

Mounting Location No. 4 -- Freeway Bridge

Description: On December 27, 1996 the PODD was mounted back at the freeway in the same location as before, on the end of a vertical pole extending down from the end of the mounting truss.

Results: The second time at the freeway the PODD was observed to overcount vehicles. The aim was probably too shallow, causing the detection zone to be large enough to see adjacent lane traffic or to detect two closely spaced vehicles as one. Aiming adjustments were difficult because of the mounting location.

Manual Observations:

12/30/96	PODD counted 50 out of 50, but double counted 3 and missed 3, missed close following vehicles and detected adjacent lane traffic.
1/8/97	PODD counted 48 out of 50, but double counted 3 and missed 5, missed close following vehicles due to a long actuation and counted 3 adjacent lane vehicles.

Assessment

Summary of results: Under optimal conditions the PODD can count vehicles at the freeway to within 1 percent of baseline data. During Continuous Test Number 2, for example, the results ranged from overcounting 3.6 percent to undercounting 0.7 percent. The second time the device it was observed to detect vehicles in the adjacent lane due to poor aiming. Results from Continuous Test Number 10 ranged from overcounting 17.9 percent to undercounting 2.3 percent. When mounted over the HOV lane the device undercounted oncoming traffic. Traffic count data at the intersection were poor and are not presented here.

Other comments: The PODD is easy to mount and calibrate. The aiming problem encountered the second time the device was at the freeway was in part due to where the device was located. It had to be attached to the vertical pole and then swung down into its final position, making aiming difficult. The overcounting from the HOV lane location is thought to be related to the device aiming as well. Weather conditions did not have an impact on device performance.

2. Doppler Microwave -- Whelen TDN-30

The Traffic Detection Narrow (TDN-30) by Whelen Engineering monitors vehicles in a single lane of traffic. It is mounted directly overhead or slightly to the side of the roadway facing oncoming or departing traffic. Side mounting is recommended only for non-speed applications. Volumes are available over the pulse relay loop emulation output and per vehicle speed data are continuously output over an RS 232 serial line. The device can be configured to observe sudden drops in traffic speeds for use in incident detection.

The TDN-30 is designed primarily to collect speed data. Its algorithms and detection zones are set up for the accurate collection of real time speed data over accurate count data. The device's most common application is incident detection. Due to the nature of the data collection system used in this test, the majority of data collected are vehicle count data.

Mounting Location No. 1 -- Freeway Bridge

Description: The TDN-30 was mounted over the center of lane one at a height of about 24 feet (7 m) on July 19, 1995. It remained there until June 28, 1996 when it was removed for mounting at the intersection.

Results: The TDN-30 tended to undercount vehicles. In Continuous Test Numbers 2 and 3 the daily totals ranged from undercounting 2.6 percent to 13.3 percent. The correlation coefficient and root mean square values indicate the device performs consistently. This consistency is also visible in the volume scatter plots contained in the appendix. Manual observations indicate the device is missing close-following vehicles.

Speed data were obtained by capturing the per vehicle speed serial output from the TDN-30. On June 26, 1996 five minutes of loop and device speed was simultaneously captured. The device count was 111 and the loop count was 127 for this period. The average speeds for the device were 59.6 mph and for the loops 58.6 mph. Figures B-8 and B-9 in Appendix B compares the two sets of vehicle speed data. The correlation between the loops and TDN-30 are apparent.

Mounting Location No. 2 -- Intersection

Description: On July 10, 1996 the TDN-30 was mounted at a height of about 20 feet (6 m) on Pole 2 at the intersection. A few weeks later the device was dropped during a mounting adjustment and had to mailed back to the vendor for repairs. It was remounted in the same position on August 28. On October 25 it was reaimed in a more upstream direction with no noticeable change in performance. On November 19 it was raised to a height of 28.5 feet (8.7 m), again with no noticeable change in performance. The device was taken down on December 13 for mounting at the freeway.

Results: The TDN-30 was not able to collect meaningful count data at the intersection. It was observed to only detect large freeflowing vehicles. The vendor said that the device is not recommended for intersection data collection.

Manual Observations:

10/10/96 TDN-30 counted 2 out of 40, only vehicles detected were a sport utility vehicle and a large tow truck, both were traveling at freeflow speeds.

Mounting Location No. 3 -- Freeway Bridge

Description: On December 27, 1996 the TDN-30 was remounted at the freeway in the same position over lane one.

Results: In Continuous Test Number 10 there was a cable hanging in the TDN-30's field of view, which may have led to some erroneous results. During this period, however, the count results were similar to previous tests. The device was observed to undercount between 2.5 and 13.8 percent. The device was observed to miss close-following vehicles.

Manual Observations:
1/8/97 TDN-30 counted 43 out of 50, missed closely spaced vehicles, freeflow.

Assessment

Summary of results: At the freeway test site the TDN-30 has a tendency to undercount vehicles in the range of 8 percent. On an optimal performance the daily undercounting was about 3 percent. The vendor said this performance is normal, especially when observing departing traffic.

The device's primary function is speed data collection. The speed data collected at the freeway test site agrees very well with baseline loop data. Since the device continuously outputs speed on a per-vehicle basis the data must be captured and manipulated in order to compare to baseline data. Only a few data collection periods were performed.

Other comments: The device is easy to mount and calibrate, requiring no adjustments. Weather conditions did not impact the performance of the TDN-30. The device was observed to miss close-following vehicles.

Every few days the two Whelen devices, the TDN-30 and the TDW-10, were observed to stop working simultaneously. When power to the units was cycled they both started working again. The problem was still present when only one of the devices was operated at a time. The vendor could not explain the phenomena. Slight power fluctuations at the test site are thought to cause the problem.

3. Doppler Microwave -- Whelen TDW-10

The Traffic Detection Wide (TDW-10) by Whelen Engineering was installed at the freeway at the beginning of the project. This device is designed to collect speed data in one wide detection zone, a zone that includes more than one lane. This type of detection does not fit into the single lane tests being done so the data from this device are not presented.

4. Doppler Microwave -- Microwave Sensors TC-26B

The TC-26B by Microwave Systems was installed at the freeway at the beginning of the project. It has a very long hold time, which causes it to miss vehicles when a vehicle enters the detection zone while the device is still placing a call for the previous vehicle. The device was not found to accurately count high volume traffic.

E. Radar

Radar devices use a pulsed, frequency-modulated or phase-modulated signal to determine the time delay of the return signal, thereby calculating the distance to the detected vehicle. Radar devices can also sense the presence of stationary vehicles and sense multiple zones through their range finding ability.

One radar device was tested at the freeway test site. The device offers relay outputs and serial communication for device setup and data retrieval. Volume, occupancy, speed and classification data are available.

The radar technology was a good technology for detecting multiple lanes of traffic at the freeway test site. Rain affected the device's performance, but this is most likely due to water entering the device itself and does not reflect a limitation of the technology. No other weather variables had an impact. The device requires a fair amount of calibration work in order to achieve optimal performance.

1. Radar -- EIS RTMS

The RTMS can be mounted overhead or to the side of the roadway. Unlike other devices which are described as sidefire, the RTMS can be aimed perpendicular to the direction of traffic and can monitor multiple lanes. Volume and presence, including stopped vehicles, is available over the relay loop emulation output. Volume, occupancy, speed and classification data are available over the serial communication line.

The RTMS was not tested at the intersection because the vendor felt the product was not suited to the proposed test setup.

Mounting Location No. 1 -- Freeway Bridge

Description: The RTMS was mounted at a height of 22 feet (6.7 m) over lane two of the freeway on July 19, 1995. On March 5, 1996 it was taken down to repair two blown opto isolators and to remount in a sidefire configuration at the freeway.

Results: The RTMS predominantly counted to within 1 percent of loops at this location. There were periods of undercounting early in Continuous Test Number 2 that occurred during cold temperatures. A correlation with temperature is not likely, however, because this was not observed in other tests.

Mounting Location No. 2 -- Freeway Sidefire Pole No. 1

Description: On April 11, 1996 the RTMS was moved to a sidefire pole near the trailer, approximately 100 feet (30 m) from the roadway (see Pole 2 Figure 3). This location is outside the vendor's recommended range but was the only sidefire pole available at the time. On June 4, 1996 the vendor visited the test site to calibrate the device to monitor traffic in lanes one and two.

Results: From this sidefire location the RTMS undercounted the daily traffic in lane one between 0.9 and 10.1 percent. In lane two the undercounting ranged from 0.2 to 6.6 percent. The vendor felt the distance from the roadway caused the observed performance.

Mounting Location No. 3 -- Freeway Sidefire Pole No. 2

Description: On August 14, 1996 the RTMS was moved to a sidefire pole located 35 feet (10.7 m) from the roadway and was mounted at a height of 19 feet (5.8 m). This sidefire pole was installed specifically for this test (see Pole 3, Figure 3). On August 26 the vendor visited the test site to calibrate the device to monitor traffic in lanes one and two.

Results: The results improved from this new sidefire pole. In lane one the daily counts ranged from overcounting 5.6 percent to undercounting 3.2 percent. In lane two the range was from overcounting 1.4 percent to undercounting 0.4 percent.

Manual Observations:
10/1/96 RTMS counted lane 1 -- 20 out of 21, lane 2 -- 20 out of 20.

Mounting Location No. 4 -- Freeway Bridge

Description: On October 4, 1996 the RTMS was mounted back on the Penn Avenue Bridge over lane one at a height of about 22 feet (6.7 m). On October 31 the vendor visited the test site to calibrate the device.

Results: The RTMS performance improved the second time the device was tested in an overhead location at the freeway. The results ranged from undercounting 3.7 percent to overcounting 1.1 percent. During most of the days the results were within 1 percent of baseline data.

Manual Observations:
10/10/96 RTMS counted 50 out of 50.
10/21/96 RTMS counted 50 out of 50.
12/4/96 RTMS counted 50 out of 50, occasional stop and go traffic, otherwise speed was about 40 mph.
1/8/97 RTMS counted 51 out of 50, double counted one truck, freeflow.
1/9/97 RTMS counted 50 out of 50, freeflow.

Assessment

Summary of results: From an overhead location the RTMS typically undercounted by about 2 percent or less. From a sidefire location the margin increased somewhat but was still within about 5 percent of baseline data, depending on mounting location. The RTMS speed results varied depending on the mounting location. It was most accurate from the overhead position. In 24-hour Test Number 5, for example, the RTMS speed was 7.9 percent higher than the adjusted loop speed.

The RTMS also calculates occupancy and classification data. The occupancy data were not examined because they could not be groundtruthed. The vendor requested that the classification data not be presented because they are intended to provide only an approximate measure of the classification.

Other comments: With a ball and socket type of bracket, the RTMS is easy to mount. Calibration requires a serial connection to the device and the ability to observe the traffic in order to perform manual counts. Experience is helpful in obtaining a successful setup, particularly for a sidefire mounted installation.

The RTMS was observed to perform erratically during periods of rainfall, refer to Figures B-6 and B-7. After consulting with the vendor it is believed that water entered the RTMS unit through a damaged plastic cover over the antennae. This cover has been improved on subsequent devices being manufactured. The rainfall affects the device, not the technology, because on several occasions the device would operate successfully at the beginning of the rain period and then fail later when water penetrated the housing. This is evident in Figure B-6. The data from the rain time periods were clearly erratic and were removed from the data set.

The wiring to the RTMS's opto isolators was initially hooked up in reverse, causing some of them to blow. An upgrade to the RTMS X1 used in the test, the RTMS X2, does not have the same potential for opto isolators to fail.

F. Passive Acoustic

Passive acoustic devices consist of an array of microphones aimed at the traffic stream. The sound of a vehicle passing through the detection zone is detected by the device. The primary source of sound is the noise generated by the contact between the tire and road surface. Devices are thus best used in a sidefire position, pointed at the tire track in a lane of traffic. At slower traffic speeds, such as at an intersection, the sound of a vehicle's engine becomes more important. The devices are passive in that they are listening for the sound energy of passing vehicles.

Two passive acoustic devices from the same vendor were tested. The devices have a simple relay output that registers the presence of vehicles. The devices also offer serial communication for setup, calibration and retrieval of volume, speed, occupancy and classification information.

The passive acoustic technology was marginal for detecting traffic at the freeway and intersection test sites. At the freeway the devices were sidefire mounted on both the bridge and freeway median pole test sites. The performance was better at the median pole site. At the intersection the device had difficulty detecting vehicles that were stopped in the detection zone. Sometimes a stopped vehicle would be missed and sometimes double counted. A correlation was found between low temperature and undercounting. The presence of snow on the roadway was also correlated with undercounting. No other weather correlation was observed. The devices tested are relatively easy to mount, aim and calibrate. There was, however, quite a bit of calibration work done to optimize the performance of the devices.

1. Passive Acoustic -- IRD Smartsonic

Mounting Location No. 1 -- Freeway Bridge

Description: Both Smartsonic units were mounted at a height of about 22 feet (6.7 m) on the Penn Avenue Bridge on July 19, 1995. The Smartsonic over lane one was aimed sidefire at the traffic in lane two. Similarly, the Smartsonic above lane two was aimed at lane one. This sidefire aim is necessary for the device to listen for the sound of a vehicle's tire on the pavement (see close up of bridge mount in Figure 4). Mounting adjustments were made on December 19, 1995 and January 17, 1996. On May 7, 1996 the Smartsonic aimed at lane 1 failed and was taken down for trouble shooting. A bad seal that had allowed water to penetrate and damage the unit was discovered. The device was returned to the vendor in exchange for another.

Results: From the bridge mounting the Smartsonics were observed to undercount daily traffic between 0.7 and 26.0 percent. Notice that the results in the Appendixes indicate in which lane each Smartsonic is located.

Mounting Location No. 2 -- Freeway Median Pole

Description: On August 14, 1996 the Smartsonic aimed at lane 2 was moved from the bridge to the freeway median pole at a height of 15 feet (4.6 m), see Pole 1 in Figure 3. On January 7, 1997 this Smartsonic was hit by a passing vehicle. It incurred a large dent on its housing but continued to intermittently work as well as before.

Results: The results from the median pole were significantly better than at the bridge. The lower mounting height enabled the device to be closer to the traffic. The performance may have also been improved by being mounted away from the echo-filled environment near the bridge. Cold temperature was correlated with undercounting.

Manual Observations:

10/10/96	Smartsonic counted 50 out of 50.
10/21/96	Smartsonic counted 47 out of 50 when watching traffic at the loops. Smartsonic counted 48 out of 50 when watching traffic at the median pole -- missed two vehicles that were changing lanes (50 consecutive vehicles were observed to <u>not</u> change lanes).
12/10/96	Smartsonic counted 49 out of 50, missed one subcompact car, freeflow.
1/7/97	Smartsonic counted 54 out of 50 occasionally counted vehicles in the next lane, recently hit by truck.

Mounting Location No. 3 -- Intersection

Description: On May 30, 1996 the vendor visited the test site and mounted the replacement Smartsonic on Pole 2 at the intersection at a height of about 10 feet (3 m).

Results: Extensive effort went into calibrating the Smartsonic at the intersection. The performance was eventually improved when a new chip was installed on October 17, 1996. After that time the device tended to undercount but was generally within 10 percent of daily loop totals. However, manual observations revealed the device was missing and double counting vehicles and the daily results were mostly compensating errors. See the manual observations below.

Manual Observations:

10/10/96	Smartsonic counted 26 out of 10, very little correlation to actual traffic, actuation indicated too long and counted vehicles that did not exist.
10/21/96	Smartsonic counted 38 out of 50, consistently missed a vehicle on most cycles of the traffic signal but also double counted 5 vehicles.
12/10/96	Smartsonic counted 12 out of 14, often double counted vehicle at stop bar, seeing it when it first pulled up and again when it left, also missed several vehicles for no apparent reason.

Assessment

Summary of results: The Smartsonic devices predominantly undercounted vehicles at both freeway test sites and overcounted vehicles at the intersection test site. From the median pole at the freeway the device was usually within 4 percent of baseline loops. At the other test sites, however, the results ranged into the 20 percent difference.

Other comments: The Smartsonic consistently undercounted in high-volumes of traffic. The scatter plots for this device show a pattern of data points falling below the 45-degree line at high traffic volumes. This pattern is also visible in the count accuracy / speed graph in Figure C-3.

A correlation between snowfall and device performance was observed. On December 23, 1996, for example, there was undercounting of 42.7 percent when 6.2 inches (16 cm) of snow fell, refer to Figure B-12. This undercounting was probably due to vehicles tracking outside of their normal pattern. Undercounting of 10.2 percent also occurred on December 22, 1996 when 2.4 inches (6.1 cm) of snow fell, and during other periods of snowfall.

At the freeway, very cold temperatures were correlated with undercounting. On December 25 and 26, 1996 the low temperature was minus 22 and minus 27 °F (-30 and -33 °C), respectively, and the device undercounted by 13.3 and 15.3 percent. On December 25 the undercounting occurred throughout the day, refer to Figure B-11. On December 26 and other cold days the undercounting occurred primarily at night.

At the intersection, cold temperatures had the opposite effect on performance. Again looking at December 25 and 26, 1996, the device overcounted by 42 and 280 percent. On December 25 the overcounting occurred throughout the day. On December 26 and other cold days the overcounting occurred primarily at night with performance improving at daybreak. Notice that overcounting during cold temperatures at the intersection is opposite the undercounting observed during cold temperatures at the freeway.

In addition to the two days described above, there were five days without snow and with undercounting of 10 percent or more for the Smartsonic at the freeway. The low temperature on these days ranged from minus 11 to minus 27 °F (-24 to -33 °C). During Continuous Test Number 10 there was a clear correlation between both low temperatures and heavy snowfalls and undercounting, refer to Figure B-10.

G. Pulse Ultrasonic

Pulse ultrasonic devices emit pulses of ultrasonic sound energy and measure the time for the signal to return to the device. The return of the sound energy in less time than the normal road surface background indicates the presence of a vehicle. Depending on the mounting configuration, there may be very little background reflection from the road surface, in which case a device may be monitoring the reflection of any signal.

Pulse ultrasonic devices are capable of high count accuracy when optimally mounted. An overhead mounting location provides a perpendicular reflective surface, offering the best signal return. The two devices tested are easy to mount but involve different levels of calibration. Weather variables were not observed to impact their performance.

1. Pulse Ultrasonic -- Microwave Sensors TC-30

The TC-30 by Microwave Sensors monitors vehicles in a single lane of traffic. It is mounted either directly overhead or directly to the side of the roadway. Volume and presence data are available over the relay loop emulation output. Microwave Sensors originally developed the ultrasonic detector to provide automatic pedestrian detection. This was needed for situations in which actuating the push buttons was difficult.

An overhead mount with the detector aimed straight down is preferred for the TC-30 because this offers a perpendicular vehicle surface for reflecting the ultrasonic signal. A sidefire mount is also possible although a perpendicular surface is not always present. The TC-30 also has a built-in adjustment to account for temperature and humidity conditions. These conditions affect the travel of sound through the atmosphere.

The TC-30 is easy to mount and calibrate. Weather conditions did not correlate with device performance.

Mounting Location No. 1 -- Freeway Bridge

Description: The TC-30 was mounted at a height of about 22 feet (6.7 m) over lane one on July 19, 1995. The device was not actually calibrated until December 12, 1995 when the range was lowered so the device would detect more vehicles. Sometime in April 1996 the TC-30 stopped working and was sent back for repairs.

Results: From the freeway overhead location the TC-30 had excellent results. In Continuous Test Number 2, for example, the daily percent difference ranged from overcounting 0.5 percent to undercounting 1.8 percent.

Mounting Location No. 2 -- Intersection

Description: On August 14, 1996, the TC30 was mounted at the intersection on Pole 2 at a height of 10 feet (3 m). This placed the detector 14 feet (4.2 m) from the lane, or about 17 feet (5.2 m) from the vehicle surface. It was aimed at the vehicle's side window, a height of about 4 feet (1.2 m), for an angle of about 20 degrees from horizontal. The TC-30 mounting literature states that for a sidefire mount the TC-30 should be mounted at a height of 3 to 12 feet (0.9 to 3.7 m), aimed directly at the side of vehicles and the range set to extend about halfway into the lane. When contacted regarding the sidefire installation proposed at Pole 2, the vendor requested as low a mount as possible. Ten feet (3 m) was the lowest mounting height possible given the mounting restraints on Pole 2. When the vendor was contacted a second time, they felt this mounting height was too high. They would prefer a height of 6 to 8 feet (1.8 to 2.4 m) in order to make the angle between the detector and car surface as perpendicular as possible. On December 13, 1996 the device was removed for relocation to the freeway.

Results: The TC-30 overcounted at the intersection between 10 and 300 percent. Manual observations indicated the device saw every vehicle but would occasionally count a single vehicle multiple times when it was stopped in front of the detector. This multiple count (or "flickering") is caused when a vehicle is in the threshold area of the detection zone. The vendor said that these results can be expected when the detector is mounted at this height.

Manual Observations:

10/1/96	TC-30 counted 15 out of 15.
10/10/96	TC-30 counted 20 out of 20, but the 21st car was a sedan with very rounded edges that was counted 11 times when it was stopped in front of the detector. Then the device counted 20 out of 20 again for a final result of counting 51 out of 40. Analysis of daily count shows consistent overcounting.
10/21/96	TC-30 counted 56 out 50, double counted once and then counted a large pickup 6 times. Also missed 1 motorcycle.
12/10/96	TC-30 counted 13 out of 13.

Mounting Location No. 3 -- Freeway Bridge

Description: On December 23, 1996 the TC-30 was mounted back at the freeway in the same location as before at a height of 22 feet (6.7 m) over lane one and aimed straight down. It was calibrated on December 27. On January 8, 1997 the relay on the unit was determined to have failed. It could not be returned to the vendor in time for further testing.

Results: For the three days of testing before failure the TC-30 ranged from overcounting 0.7 percent to undercounting 2.0 percent, similar to the performance for the previous freeway location. During these tests, however, the Lane King ultrasonic detector was observed to interfere with the TC-30. The two detectors had to be tested at different times.

Manual Observations:

12/30/96	TC-30 counted 50 out of 50 but double counted 1, missed 1 and counted one adjacent lane truck.
1/8/97	TC-30 relay found to be bad.

Assessment

Summary of results: The TC-30 was an accurate counter both times it was at the freeway. At the intersection, however, the device tended to overcount. Manual observations indicated that the device would count vehicles successfully until a certain vehicle stopped in the detection zone and was counted multiple times.

Other comments: Depending on the mounting height, it is possible for a fast vehicle to be missed by the detector because the TC-30C fires a pulse every 100 ms and the TC-30 every 167 ms. At a mounting height of 20 feet (6.1 m) the detection zone is 4 feet (1.2 m) in diameter. Therefore, a 16-foot (5 m) vehicle traveling 82 mph could be missed by the TC-30. In a similar phenomena it is possible for two closely spaced vehicles to be seen as a single vehicle if the gap between the two is not seen by the detector. At a speed of 60 mph, vehicles following within 35 feet (11 m) of one another could be seen as a single vehicle by the TC-30.

The TC-30 was observed to cause interference with the other pulse ultrasonic detector, the Lane King. The two devices were only tested next to each other for a brief period during Continuous Test Number 10. When the interference was noticed the two devices were tested alternately.

2. Pulse Ultrasonic -- Novax Lane King

The Lane King by Novax Industries monitors vehicles in a single lane of traffic. It is mounted either directly overhead or directly to the side of the roadway. Volume and presence data are available over the relay loop emulation output. A serial communication to the device allows for calibration and trouble shooting. The Lane King has a built-in adjustment to account for temperature and humidity conditions. These conditions affect the travel of sound through the atmosphere.

The Lane King is easy to mount and calibrate although extensive calibration was required to optimize performance. Weather conditions did not correlate with device performance.

Mounting Location No. 1 -- Intersection

Description: The Lane King was first mounted on Pole 4 at the intersection at a height of 19 feet (5.8 m) on August 14, 1996. On October 17 the vendor visited the test site and installed a new device at a height of 14 feet (4.3 m) on Pole 4. This lower mounting height was done to improve the device's performance.

Results: From Pole 4, the Lane King was observed to primarily overcount vehicles. Vehicles in the right turn lane tend to travel in varying places within the lane. The vendor felt this made detection more difficult. Field adjustments to the mounting height and angle corrected for vehicles traveling in various parts of the lane. Overcounting was observed to be caused by the device counting a single vehicle multiple times.

Manual Observations:

10/10/96	Lane King counted 37 out of 50, half of the vehicles missed were tracking away from the pole, adjustments made.
10/21/96	Lane King counted 53 out of 53.
12/10/96	Lane King counted 54 out of 51, 3 overcounts, 0 missed, device did get vehicles that were straddling the two lanes, out of 51 vehicles one was observed to change lanes such that the loop got it but not the device, vice versa occurred once.
1/7/97	Lane King counted 18 out of 20, missed 6 due to too long of an actuation and double counted 4 vehicles when stopped in front of detector, stop and go traffic.
1/8/97	Lane King counted 24 out of 20, double counted 4 vehicles that stopped in front of the device with their bumper in the detection zone, stop and go traffic.

Mounting Location No. 2 -- Intersection

Description: The Lane King was moved to Pole 2 at the intersection on January 10, 1997 at a height of about 12 feet (3.7 m).

Results: From Pole 2 the Lane King was again observed to primarily overcount vehicles. On January 19, 1997 the Lane King was within 1 percent of the loops. This suggests that on good days the device operates very well but was perhaps not optimally calibrated for other test periods.

Manual Observations:

1/13/97	Lane King counted 20 out of 20.

Mounting Location No. 3 -- Freeway Bridge

Description: On December 23, 1996 the first Lane King was removed from the intersection and installed over lane one at the freeway at a height of about 22 feet (6.7 m). It was calibrated on January 10, 1997.

Results: In Continuous Test Number 10, the Lane King undercounted between 1.2 and 0.2 percent of daily baseline totals. During these tests the TC-30 ultrasonic detector was observed to interfere with the Lane King. The two detectors had to be tested at different times.

Manual Observations:

12/30/96	Lane King counted 67 out of 50, device not calibrated -- communication problems.
1/9/97	Lane King counted 50 out of 50, freeflow.
1/9/97	Lane King counted 50 out of 50, freeflow.
1/10/97	Lane King counted 81 out of 50, device not calibrated.
1/10/97	Lane King counted 50 out of 50.

Assessment

Summary of results: The Lane King was an extremely accurate counter when mounted at the freeway. At the intersection the device double counted some vehicles, overcounting in the 20 percent range.

Other comments: On November 15, 1996 freezing rain occurred at the same time the Lane King was observed to overcount. This did not occur often enough to draw any conclusions on the device's performance. As described earlier, the two pulse ultrasonic devices were observed to interfere with one another when mounted next to each other at the freeway and had to be tested alternately.

H. Video

Video devices use a microprocessor to analyze the video image input from a video camera. Two techniques, tripline and tracking, are used to detect traffic. Tripline techniques monitor specific zones on the video image to detect the presence of a vehicle. Video tracking techniques employ algorithms to identify and track vehicles as they pass through the field of view. Tripline and tracking were originally used to differentiate the video technologies being tested. However, since some video devices employ both techniques to detect vehicles, this division was found to be too simplistic and is no longer used.

Video technology can offer a wide variety of traffic information. In addition to conventional data such as volume, presence, occupancy, density, speed and classification, other data such as dwell time, incident detection and even origin destination information can be obtained. Video can also be used to provide surveillance information on a roadway.

Under optimal conditions, highly accurate volume and speed data were obtained from video technology at the freeway test site. At the intersection site the results were much more varied. The results varied greatly from one device to another and from one mounting location another. Multiple factors were observed to affect video's performance. Among these factors were: stationary shadows, moving shadows cast by vehicles, direct sunlight, transition from light to dark or dark to light, wind-induced pole movement, water on the camera lens, icicles hanging in front of the camera lens, salt grime on the camera lens, and cobwebs on the camera lens. Because many of these factors had to be observed first-hand in order to document their effects, it was difficult to correlate the factors with the device performance.

Installation and maintenance of video devices is much more involved than other types of technologies. Camera placement is critical to successful performance. Video systems that require a standard camera also require that the correct lens for the location be selected. The camera must also be aimed while simultaneously viewing the video image. Maintenance work includes verifying that the camera has not shifted over time because even slight movement can misalign zones. The camera lens must also be kept clean. When the cameras were removed in January 1997 considerable grime build up was observed on the lenses. This was caused by the salt and grime spray generated by the traffic. This spray easily reached the cameras, even when mounted at a height of 35 feet (10.7 m). A schedule of monthly cleaning, or more often if warranted, is necessary to maintain proper performance during the winter months.

The video technologies evaluated had varying levels of reliability. Some had to be checked frequently for proper functioning while others could go for months with consistent performance. The most significant weather impacts observed were lighting conditions. The presence of vehicle shadows, stationary shadows, and the transition from day to night and vice versa were the most common conditions that were correlated with miscounting.

Of the four video systems tested, two (the EVA and the Video Trak-900) required that a camera be procured for testing. Two cameras, a low-resolution color camera and a high resolution black and white or monochrome camera, were selected. A video distribution amplifier was used to allow the systems to at times share a camera. Specifications for the two cameras selected are given below:

Color camera: PSA model CCC954 1/3 inch CCD, 330 lines, 1.5 lux with a PSA lens model TG0412AFCS, 1/2 inch, 4.0 mm, F 1.2, autoiris with environmental enclosure.

Monochrome camera: Burle model TC351A 1/2 inch, 580 lines, 0.12 lux with a Burle lens model TC9906A, 1/2 inch, 6 mm and 8mm, autoiris, infrared filter with environmental enclosure including sunshield.

1. Video -- Peek Transyt Video Trak-900

The Video Trak-900 by Peek Transyt can monitor the input from up to four video cameras. Each camera can monitor multiple lanes of traffic with multiple detection zones. The cameras can be mounted either overhead or to the side of the roadway. Many traffic variables including volume, presence, occupancy, density, speed and classification are available.

The cameras must be mounted to a relatively rigid structure to minimize pole movement. In general, the higher the camera can be mounted the better the results will be. A high camera mount minimizes occlusion and reduces exposure to salt spray and other particulates that can dirty the camera lens. The high resolution Burle monochrome camera described above was used for testing the Video Trak-900.

Mounting Location No. 1 -- Freeway Bridge

Description: On March 5, 1996 the Burle Camera was mounted on the Penn Avenue Bridge at a height of about 25 feet (7.6 m). It was aimed at approximately a 45-degree angle directly at the detection zones. On March 14 the vendor visited the project site and calibrated the device. On April 9 the Burle camera was reaimed and an infrared filter was inserted on the camera's lens.

Results: The vendor felt the mount for this camera was lower than desired. The results from lane one varied from overcounting 2.9 percent to undercounting 13.7 percent. In lane two the results varied from overcounting 5.6 percent to undercounting 12.5 percent. Refer to Continuous Test Numbers 3 and 4 and 24-hour Test Number 2.

Mounting Location No. 2 -- Freeway Median Pole

Description: On June 27, 1996 the Burle camera was removed from the Penn Avenue Bridge and mounted on the sidefire pole located in the median of the freeway at a height of about 35 feet (10.7 m). This sidefire pole is located 200 feet (61 m) downstream of the Penn Avenue Bridge and about 170 feet (52 m) downstream of the baseline loops (see Figures 3 and 6). The camera was aimed at the eastbound and HOV lanes.

Results: The results from this location were among the best video system results obtained. In Continuous Test Number 5 and 24-hour Test Number 3, the results in lane one ranged from overcounting 2.5 percent to undercounting 2.9 percent. In lane two the range was overcounting 1.6 percent to 4.8 percent.

Mounting Location No. 3 -- Intersection

Description: On August 14, 1996 the Burle camera was mounted on Pole 3 at the intersection at a height of 37.5 feet (11.4 m). It was aimed to face oncoming traffic in two lanes of the northbound approach. The output from the traffic signal controller that turns the traffic signal green for the northbound approach was wired into the Video Trak-900. This output aided in processing the video image by providing information on when the traffic in each approach is given a green light. On November 12 the vendor visited the test site but was not able to calibrate the Video Trak-900 because of problems with the unit. On November 20 the lens in the Burle camera was swapped from 6 mm to 8 mm in order to zoom in and a sunshield was installed. Extensive calibration work continued with the Video Trak-900 but the device was not calibrated in time for the next phase of testing when the Burle camera was taken down from the intersection on January 2, 1997.

Results: The Video Trak-900 was set up and functioning at the intersection test site but had intermittent problems that caused it to go into a "fail safe" mode. The vendor did not feel the Video Trak-900 was successfully calibrated and asked that no test data be presented

Mounting Location No. 4 -- Freeway Median Pole

Description: On January 2, 1997 the Burle camera with the 8 mm lens was moved back to the freeway median pole at a height of about 35 feet (10.7 m) with the same configuration as before (see Figures 3 and 6). The hardware problems with the Video Trak-900 continued with the new camera location, causing the device to stop working intermittently. When it was working it was observed to overcount vehicles due to shadow problems.

Results: As with the intersection tests, the vendor did not feel the Video Trak-900 was successfully calibrated and asked that no test data be presented.

Assessment

Summary of results: When first tested at the freeway median pole in June 1996, the Video Trak-900 performed well. Counting accuracy was usually within 5 percent of baseline loops. When the camera was moved to the intersection, however, the device developed intermittent failures. Some of these failures were traced to one of the computer boards in the processor but the problem could not be completely eliminated. When the camera was moved back to the freeway the intermittent problems continued. No data are presented after the June testing.

Other comments: As with most of the video systems tested, the Video Trak-900 requires extensive installation and calibration work in order to obtain optimum performance. Throughout the testing the device had to be closely monitored to assure it was operating correctly.

The Video Trak-900 was observed to overcount vehicles during the transition from light to dark. Refer to Figure B-14 for the video results between the hours of 19:00 and 24:00 on June 10, 1996. This graph is typical of the results seen at the evening transition on other days. The evening lighting overcounting explains the cluster of data points that lie above the 45-degree line in the volume scatter plots. This is seen in all of the Video Trak-900 volume scatter plots (Continuous Test Numbers 3, 4, 5, and 24-hour Test Number 2).

The Video Trak-900 was also briefly tested with the low resolution color camera mounted on the Penn Avenue Bridge. The performance with this camera was close but as not as good as the performance with the high resolution monochrome camera. These results are not presented in detail.

On December 26, 1996 the low temperature was minus 27 °F (-33 °C). On this day exhaust plumes from vehicles were observed to cause false detections in the adjacent lane at the intersection test site. Vehicle headlights accentuated the visual impact of the exhaust. In addition, the camera at the intersection apparently moved, causing the Video-Trak detection zones at the intersection to shift to the right. When the camera was taken down from the freeway median pole test site at the conclusion of testing a substantial build up of salt and grime was observed on the camera's housing. This buildup could cause miscounting.

2. Video -- ISS Autoscope

The Autoscope 2004 by Image Sensing Systems can monitor the input from up to four video cameras. Each camera can monitor multiple lanes of traffic with multiple detection zones. The cameras can be mounted either overhead or to the side of the roadway. Many traffic variables including volume, presence, occupancy, density, speed and classification are available. A high resolution monochrome camera used in testing was supplied by the vendor.

The camera must be mounted to a relatively rigid structure to minimize pole movement. In general the higher the camera can be mounted the better the results will be. A high camera mount minimizes occlusion and reduces exposure to salt spray and other particulates that can dirty the camera lens.

Mounting Location No. 1 -- Freeway Bridge

Description: On January 17, 1996 the vendor-supplied camera was mounted on the Penn Avenue Bridge at a height of about 25 feet (7.6 m). It was aimed at about a 45-degree angle directly at the detection zones. On the same day, the vendor visited the project site and began calibrating the Autoscope 2004. On April 9 the camera was reaimed and the device recalibrated.

Results: The vendor felt the mount for this camera was lower than desired. The results from lane one varied from undercounting 2.2 percent to 8.7 percent. In lane two the results varied from undercounting 5.0 percent to 10.6 percent. Refer to Continuous Test Numbers 3 and 4 and 24-hour Test Number 2.

Mounting Location No. 2 -- Freeway Median Pole

Description: On June 27, 1996 the camera was removed from the Penn Avenue Bridge and mounted on the sidefire pole located in the median of the freeway at a height of about 35 feet (10.7 m). This sidefire pole is located 200 feet (61 m) downstream of the Penn Avenue Bridge and about 170 feet (52 m) downstream of the baseline loops (see Figures 3 and 6). A new lens was installed in the camera in order to zoom in on the traffic stream. The camera was aimed at the eastbound and HOV lanes. On July 1 the camera was reaimed.

Results: The Autoscope had very similar results from the higher camera mounting location. The device undercounted by up to 10 percent in both lanes.

Mounting Location No. 3 -- Intersection

Description: On August 14, 1996 the camera was mounted on Pole 3 near the intersection at a height of 35 feet (10.7 m). It was aimed to face oncoming traffic in two lanes of the northbound approach. On August 7 the vendor visited the test site to begin calibrating the Autoscope 2004. On October 3 the lens was swapped from a 4.2 mm to a 6.0 mm in order to zoom in on the roadway. The camera was taken down from the intersection on January 2, 1997.

Results: At the intersection location, the Autoscope 2004 tended to overcount in the right turn lane and undercount in the through lane. In the right turn lane stop-and-go traffic during congested periods was correlated with overcounting. During peak periods a traffic queue from the freeway on-ramp frequently causes traffic to back up into the right turn lane, causing vehicles to stop in the detection zones. During free flow conditions, however, the traffic in the right turn lane usually does not come to a complete stop. Traffic in the through lane, meanwhile, usually does not have to stop and is not affected by peak periods. The undercounting observed in this lane does not correlate with a particular time of day.

The evening lighting transition period may be another possible explanation for the overcounting observed in the right turn lane. However, this phenomena was not observed in the through lane and would be opposite the undercounting observed at the freeway test site.

On November 14, 1996, the Autoscope was observed to continuously count when no vehicles were present. Analysis revealed wind was causing the pole to sway, causing the detection zones to move on and off of a paint stripe on the roadway and register a count about once every second. The zone was adjusted away from the paint stripe and the overcounting did not occur again. The phenomenon was not observed when the Autoscope was first installed and calibrated because it was not a windy day. These errant data from early November were removed from the published data.

Manual Observations:

10/10/96	Autoscope counted lane 1 -- 60 out of 50, double counted slow moving vehicles, seeing the hood and then the roof, no vehicles missed.
	Autoscope counted lane 2 -- 42 out of 40, 2 double counts caused by vehicles in adjacent lane (but they weren't straddling or casting shadow).
	Autoscope counted lane 1 -- 39 out of 40, missed 1 due to occlusion.
	Difference between above counts appears to be the differing sun position due to the time of day.
10/21/96	Autoscope counted lane 1 -- 50 out of 50, overcast, freeflow.
	Autoscope counted lane 2 -- 50 out of 50, overcast, freeflow.
12/4/96	Autoscope counted lane 1 -- 51 out of 50, 1 double count, overcast, freeflow.
	Autoscope counted lane 2 -- 19 out of 21, 1 double count, 3 missed, overcast, freeflow.
	Note: Vehicles in through lane come to a full stop while vehicles in right turn lane do not stop.
12/12/96	Autoscope counted lane 1 -- 27 out of 20, double counted reflection of headlights off pavement and exhaust plume (caused by cold temperature), very heavy traffic.

Mounting Location No. 4 -- Freeway Median Pole

Description: On January 2, 1997 the camera was moved back to the freeway median pole at a height of about 35 feet (10.7 m) in the same configuration as before. The vendor visited the site and calibrated the device on January 8.

Results: The Autoscope 2004 undercounted traffic more the second time it was mounted at the freeway median pole. In lane one the daily undercounting ranged from 8.4 percent to 31.9 percent and lane two from 8.5 to 36.2 percent. A likely explanation for the increased undercounting involves the season. In the summer months the undercounting observed during the day to night transition occurred after 9:00 p.m., well after the peak period. In the winter months, however, the day to night transition occurred much earlier, placing the undercounting within the peak period. Refer to Figures B-13 and B-14 for graphs of the undercounting during June 10, 1996 and Figures B-15 and B-16 for graphs of the undercounting during January 20, 1997. The device also had trouble detecting dark vehicles. A parameter was adjusted to try to compensate for this.

Manual Observations:

1/8/97	Autoscope counted lane 1 -- 50 out of 50.
	Autoscope counted lane 2 -- 78 out of 100, missed dark vehicles, pavement was wet, therefore dark -offering little contrast for dark vehicles, but problems only observed in lane 2, not lane 1, no occlusion observed.
1/23/97	Autoscope counted lane 1 -- 66 out of 70.
	Autoscope counted lane 2 -- 64 out of 70.

Assessment

Summary of results: The Autoscope is capable of performing to within 5 percent of daily traffic volumes at both the freeway and intersection test sites. Extensive testing with the device revealed it to be reliable over a long-term test but susceptible to undercounting during lighting changes such as the transition from day to evening. The lighting impact and other factors such as wind combined to create occasional periods of miscounting.

Other comments: Throughout the testing the Autoscope was observed to undercount vehicles during the evening light transition period. Undercounting is also seen to a lesser extent during the morning transition period. During the summer months this transition occurred later in the evening when there was lower traffic levels, therefore the daily percent difference did not include as much traffic, refer to Figures B-13 and B-14, the results for June 10, 1996. During the winter months, however, the transition occurred earlier in the evening when the traffic volumes were higher. This resulted in a higher daily percent difference, refer to Figures B-15 and B-16, the lighting analysis for January 20, 1997. January 20 is representative of other days when undercounting is observed before sunrise and after sunset in both lanes one and two. The lighting transition undercounting explains the cluster of data points that lie below the 45-degree line, often appearing as a second line, in the volume scatter plots.

On January 22, 1997 light snow began at 09:00, changing to heavier snow at 14:00. Traffic in lane two was very slow from 16:30 to 17:30. During this time Autoscope was observed to miss many dark vehicles in lane two.

During Continuous Test Number 6 there was an apparent correlation between wind and count accuracy. Refer to Figure B-17 for a graph of the daily percent difference and average daily wind speed.

When the camera was taken down from the freeway median pole test site at the conclusion of testing a substantial buildup of salt and grime was observed on the camera's housing. This buildup could cause miscounting.

3. Video -- Eliop Trafico EVA

The EVA 2000 is a video system made by Eliop Trafico of Spain. Multiple lanes of traffic can be monitored with multiple detection zones. The camera can be mounted either overhead or to the side of the roadway. Many traffic variables including volume, presence, occupancy, density, speed and classification are available.

The camera must be mounted to a relatively rigid structure in order to minimize pole movement. In general, the higher the camera can be mounted the better the results will be. A high camera mount minimizes occlusion and reduces exposure to salt spray and other particulate that can dirty the camera lens.

The high resolution monochrome camera manufactured by Burle and the medium resolution color camera manufactured by PSA were used to test the EVA 2000.

Mounting Location No. 1 -- Freeway Bridge

Description: On March 5, 1996 the Burle Camera was mounted on the Penn Avenue Bridge at a height of about 25 feet (7.6 m). It was aimed at about a 45-degree angle directly at the detection zones. On March 12 to 14 the vendor visited the project site and calibrated the device. On April 9 the Burle camera was reaimed.

Results: Only two days of data were obtained from the bridge mounted Burle camera. The EVA 2000 undercounted by about 14 percent in lane one and between 1 and 9 percent in lane two. Later in the testing the EVA 2000 was connected to the color camera at the freeway. More results are available from this location. In Continuous Test Number 10, for example, the daily results in lane one ranged from overcounting by 1.5 percent to undercounting by 17.1 percent and in lane two the range was from overcounting 1.1 percent to undercounting 3.2 percent. These results, especially in lane two, were some of the best video performance obtained.

Mounting Location No. 2 -- Freeway Median Pole

Description: On June 27, 1996 the Burle camera was removed from the Penn Avenue Bridge and mounted on the sidefire pole located in the median of the freeway at a height of about 35 feet (10.7 m). This sidefire pole is located 200 feet (61 m) downstream of the Penn Avenue Bridge and about 170 (52 m) downstream of the baseline loops (see Figures 3 and 6). The camera was aimed at the eastbound and HOV lanes. A communication problem between the EVA processing unit and the PC was solved on July 31. On August 14 the Burle camera was taken down.

Results: No data are presented with the Burle camera mounted on the freeway median pole.

Mounting Location No. 3 -- Intersection

Description: On August 14, 1996 the Burle camera was mounted on Pole 3 at the intersection at a height of 37.5 feet (11.4 m). It was aimed to face oncoming traffic in two lanes of the northbound approach. On November 20 a sunshield was installed and the lens was changed from 6 mm to 8 mm in order to zoom in on the traffic. On October 31 the EVA 2000 was reconfigured to use the color camera at the freeway.

Results: The vendor does not recommend using the EVA 2000 in an intersection application. Another product, the EVA DAI is recommended for such an application. No results from the intersection are published.

Mounting Location No. 4 -- Freeway Bridge

Description: On October 31, 1996 the EVA 2000 was reconfigured to use the color camera mounted on the bridge at the freeway.

Results: The results with the EVA 2000 using the color camera on the bridge were similar to results from the monochrome camera, suggesting the device is not particularly sensitive to the camera's resolution. The results with this camera were among the best observed with a video device. In Continuous Test Number 9, for example, the EVA 2000 counted daily traffic in lane 2 to within 1 percent of baseline data in 13 of 21 days. Greater variation was observed on other days. The EVA 2000 was the only device to not be affected by the morning and evening lighting transition periods, refer to Figures B-13 through B-16.

Assessment

Summary of results: When operating correctly the EVA 2000 is capable of accurate freeway counts, among the best for a video system.

Other comments: Calibration of the EVA 2000 was made difficult by a complicated user interface. Numerous communication problems existed between the video processor and the PC and the calibration steps were not intuitive. It was also difficult to switch from one measuring zone to another. The version tested did not have a relay loop emulation feature so the only way to retrieve data were over the serial communication line. With a 15-minute time interval the device can only store two or three days of data, requiring frequent downloading of data. The data are in a format that requires additional effort to integrate into the project's database. The communication problems experienced with the unit were ultimately traced to a faulty cable. Once this was fixed data could be collected on a more consistent basis.

The EVA 2000 was not observed to be impacted by any weather conditions. Notice that in Figures B-13 through B-16 the EVA 2000 was the only video device that was not affected in the transition from light to dark.

When the camera was taken down from the freeway median pole test site at the conclusion of testing a substantial buildup of salt and grime was observed on the camera's housing. This buildup could cause miscounting.

4. Video -- Rockwell International TraffiCam -- S

The TraffiCam -- S by Rockwell International consists of a camera built into a housing that contains all of the processing hardware. A serial communication to a PC and interface card allows for setup, calibration, data download, and relay loop emulation outputs. Volume and presence data are available over the loop emulation outputs and volume, speed and occupancy data through the serial data. The device can monitor multiple lanes of traffic with multiple detection zones. The device can be mounted either overhead or to the side of the roadway.

The TraffiCam must be mounted to a relatively rigid structure in order to minimize pole movement. In general the higher the device can be mounted the better the results will be. A high mount minimizes occlusion and reduces exposure to salt spray and other particulate that can dirty the camera lens.

Rockwell also makes a TraffiCam -- I that is designed to provide presence detection at an intersection. The TraffiCam -- S is designed to count traffic as well as to calculate vehicle's speed and occupancy and is better suited to a freeway application.

Mounting Location No. 1 -- Freeway Bridge Departing Traffic

Description: The TraffiCam was installed centered over lanes one and two at the freeway test site at a height of about 22 feet (6.7 m) on July 19, 1995.

Results: The vendor was not satisfied with performance from this location and requested the device be relocated to face approaching traffic.

Mounting Location No. 2 -- Freeway Bridge Approaching Traffic

Description: At the vendor's request the TraffiCam was moved to the west end of the Penn Avenue Bridge on December 19, 1995 to face oncoming traffic. As before, it was centered over lanes one and two at a height of about 22 feet (6.7 m), see Figure 3. The vendor made two visits to the test site to calibrate the device. The TraffiCam operated continuously without field adjustments at this location until the end of testing in January 1997.

Results: See summary of results in the assessment section.

Assessment

Summary of results: The TraffiCam performance varied greatly from one test period to another. During an optimal day it is capable of counting to within 5 percent of loops. The speed data were also capable of being within 5 percent of baseline data. The 24-hour Test Number 2 is an example of the device's optimal performance, see Appendix C.

At other times the TraffiCam performance was poor. It was observed to occasionally drastically miscount vehicles but then later recover and operate successfully again. The TraffiCam performance began to deteriorate in the fall of 1996 and by Continuous Test Number 10 was undercounting significantly. The results from this test were removed because the data were not representative of the device capabilities. When the device was taken down a substantial build up of grime was observed on the device's housing. When the device was returned, the vendor said the grime buildup was a factor in the device's performance and increased salt spray in the winter months may explain the deteriorating performance.

Other comments: In the testing performed for this project the only way to collect data from the TraffiCam was to download it over the device's serial connection. Since the device can only store 48 time periods of information, this translated into 12 hours of data in 15-minute intervals. The CammComm processor is designed to provide relay outputs for the TraffiCam but this processor was not operational for most of the test periods. When it was operational the volume data collected did not match the volume supplied from the serial data. The vendor requested that the serial data be selected for publication, not the relay data. As a consequence, there were no full 24-hour periods of data collection and data had to be collected twice a day in order to retrieve as much as possible.

The undercounting may be due to the presence of shadows in the field of view as well as shadows from vehicles in adjacent lanes. The TraffiCam did not appear to perform as well in the daylight hours as it did in the nighttime hours. The performance of overcast days compared to sunny days could not be performed because there was not a source of weather data for this variable.

V. OBSERVATIONS

A. Weather Influences

The influences of rain, freezing rain, snow, wind, temperature, and lighting conditions were examined for each of the devices tested. In general, weather conditions had a minimal impact on the majority of the technologies. Refer to the discussion of the specific device in the previous section for a more detailed description of what weather conditions impacted device performance. Table 5 provides a summary of the environmental factors affecting device performance. The following list highlights some of the weather influences observed:

- The Autosense I active infrared device was impacted by rain, freezing rain and snow. A wet pavement caused errors in the device performance, most often leading to overcounting. Overcounting was also observed during periods of heavy snowfall when snow in the air may have been detected by the device. The relatively small detection zone also caused the device to be sensitive to what portion of the lane vehicles were traveling in. This caused the device to undercount when snow obscured the road surface and vehicles did not travel in the center of the lane, refer to Figures B-1 through B-5.

- The Smartsonic passive acoustic device was impacted by temperature and snow on the road surface. At the intersection low temperatures were correlated with overcounting, while at the freeway, low temperatures were correlated with undercounting. Snow on the road surface also caused vehicles to drive outside the device's detection zone, causing undercounting, refer to Figures B-10 to B-12 and to Figures B-19 and B-20.

- The IVHS 232-E passive magnetic probe was impacted by temperature and possibly by rain. During low temperatures the probes were observed to undercount vehicles. There were also intermittent malfunctions that may have been caused by moisture penetrating the splices in the field.

- The RTMS radar device performed erratically after periods of rainfall. This impact is most likely caused by water entering the housing of the device and causing an error in the operation. This appears to be the case since the performance was not impacted during the first few 15-minute periods of rain but continued after the rain has stopped. This effect is correlated to the particular unit tested, not the RTMS device or the radar technology in general, refer to Figures B-6 to B-7.

- The Autoscope and Video Trak-900 video devices were each impacted by lighting conditions at the freeway test site. Miscounting was observed during the transition periods, especially the transition from day to night. The Autoscope tended to undercount during the evening transition and the Video-Trak overcounted during this period, refer to Figures B-13 to B-16.

- The Autoscope video device was impacted by wind induced pole movement. The video image was observed to move from side to side, causing the detection zones to be actuated as different portions of the image came into the zones, refer to Figure B-17.

- On June 6, 1996 there was a very heavy rainfall with 1.19 inches falling between 3 and 4 p.m., refer to Table B-1 and Figure B-18. This Figure shows the count accuracy in relation to rainfall from one 15-minute interval to the next for the 8-hour period between 12:45 and 8:15 p.m. In this Figure notice the minimal impact rain had on device performance. In the 15-minute period of peak rainfall from 3:15 to 3:30 p.m. the IR 224 passive infrared device undercounted by 7 percent and the Autosense I active infrared, PODD microwave, and the Video Trak-900 video overcounted by about 10 percent. These variations are minimal when combined into a 24-hour count.

- Cold Minnesota winters posed some challenges to the devices tested. Cold temperatures made the underground conduits used by the magnetic probes difficult to access. Cold temperatures also caused some device cables to become brittle and crack open when handled. Finally, extremely cold temperatures created large vehicle exhaust plumes that were detected by some of the video devices. Refer to Figures B-19 and B-20 for a graph of daily device performance compared to the daily low temperature.

B. Traffic Influences

One of this project's primary objectives was to evaluate the performance of non-intrusive technologies in high-volume traffic conditions. At the freeway test site there was recurring congestion in both the morning and evening peak periods. Traffic levels often reached 2,400 vehicles per lane per hour. Performance in heavy traffic conditions was measured by analyzing the results during high-volume periods. The scatter plots display the relationship between traffic volume and device performance. The shape of the scatter plots will either drop or rise for devices that have difficulty counting vehicles during high traffic levels. A scatter plot that drops below a 45-degree line indicates a device that is undercounting vehicles. Similarly, data points falling above a 45-degree line indicate overcounting. Refer to the volume scatter plots prepared for each test period in Appendix C.

The following devices exhibited a tendency to undercount vehicles at the freeway in high-volume traffic conditions:

- The Smartsonic passive acoustic device consistently undercounted in high-volumes of traffic. The scatter plots for this device show a pattern of data points falling below the 45-degree line at high traffic volumes.

- The PODD doppler microwave exhibited a slight tendency to undercount in high-volumes of traffic.

- The IVHS 232-E magnetic device tended to overcount vehicles in high-volumes of traffic during some of the test periods.

Device performance relative to traffic volumes does not provide a complete picture of the wide range of parameters that affect count accuracy. During peak periods, congestion can cause volumes to drop. These low-volume data can not be readily differentiated from low-volume data found in free flowing off-peak periods. A separate analysis of the correlation between the average traffic speed and device performance separates the impact of speed from volume levels. A scatter plot of the relationship between count accuracy on the vertical axis and average speed on the horizontal axis for each 15-minute period provides useful information on the performance of some devices. Devices that miscount at low speeds had difficulty accurately detecting vehicles in congested traffic. Refer to the count accuracy/speed relation scatter plots in Appendix C.

The majority of devices had no trouble accurately detecting vehicles when the average traffic speed dropped. The following device was the only one to exhibit a tendency to miscount vehicles at the freeway during periods of heavy congestion.

- Doppler Microwave PODD shows a slight tendency to periodically undercount vehicles during periods of low traffic speeds.

- The IVHS 232-E magnetic device tended to overcount vehicles during periods of low traffic speeds during some of the test periods.

C. Roadway Influences

The freeway and intersection test sites were selected to offer challenging geometric conditions. In the eastbound direction of the freeway there are three lanes immediately upstream of the test site that merge to two lanes about 200 feet (61 m) downstream of the test site. Refer to Figure 3, Freeway Test Site Schematic. This merge condition causes some vehicles in the right most lane to be in the process of merging left, and therefore not traveling in the center of the lane. Devices mounted in this lane face the challenge of discriminating between vehicles in the center of lane two and vehicles that are partially in lane two. A vehicle is defined to be in lane two if the loop in that lane detects the vehicle. All of the devices were set up to try to detect the same vehicles as the loops. In the final months of testing devices were primarily mounted over lane one in order to eliminate the effect of merging traffic.

The northbound approach of the intersection offers a challenging geometric condition because it is located on a curve. Refer to Figure 7, Intersection Test Site. As with the freeway site, vehicles do not consistently travel in the center of the right turn lane, but tend to crowd the through lane. Vehicles in the through lane are not affected by the curve.

The number of vehicles that traveled significantly far from the center of the right turn lane at the intersection was relatively small. Devices that were monitoring this approach were set up to detect vehicles with a larger zone. This involved widening the size of the detection zones for the video devices or aiming other devices so that their detection zone were larger.

No devices were observed to miscount vehicles as a direct result of these geometric conditions. Some vendors expressed concern that the geometric conditions caused their device to miss vehicles, but manual observations of the freeway and intersection test sites indicated that this effect was very minimal. As noted in the analysis of weather section, some devices have smaller detection zones than others and are more sensitive to where vehicles track within a lane. Miscounting due to geometric conditions, however, was minimized by setting up the devices to operate in the existing site conditions. Occasional changes in vehicle tracking patterns, such as during periods of heavy snowfall, were observed to have a more pronounced effect on device performance.

VI. CONCLUSIONS

There are many points to consider when evaluating the devices tested in this project. The level of expertise required and time spent installing and calibrating a device can become more important than the device's initial cost. A reliable device can reduce the amount of maintenance work that must be done. A device that can do multiple lanes can do the work of several single-lane devices. A device that can be mounted overhead or to the side of a roadway offers more flexibility in its mounting location. A device with serial communication capability can allow for remote adjustment of calibration parameters and trouble shooting. A device that employs wireless communication technology can simplify the data retrieval process. A solar or battery-powered device can be used to obtain temporary counts in a location without an accessible source of power. Some devices offer much more traffic information than just the volume. Some devices are impacted by weather conditions or do not operate as well when the traffic is congested. It is also important to consider a device's intended use. A device used to actuate a signal must meet a different set of performance criteria than a device used to collect historical traffic data. Some devices are designed to offer real time information for ITS type of applications. Simply looking at a summarized presentation of the percent differences is inadequate; all of these factors must be kept in mind when evaluating the performance of the different technologies. As a result, this report cannot identify a single device or technology as being the best.

Most of the devices tested in this project can be used in temporary counting situations, especially devices that have solar or battery-powered operation. Ease of installation and flexibility in mounting locations are important elements in selecting a device to install quickly and move from location to location. The devices that use doppler microwave, active infrared, and passive infrared technologies have a "point-and-shoot" type of setup. Passive magnetic, radar, passive acoustic and pulse ultrasonic devices require some type of adjustment once the device is mounted. In most cases this adjustment must be performed over a serial communication line. Video devices require extensive calibration over serial communication lines and are not well-suited for temporary counting. Additionally, extensive installation work is required to use video and passive magnetic devices, making them less suitable for temporary data collection.

From an overhead mounting location at the freeway test site, the video and passive acoustic devices were found to count between 4 and 10 percent of baseline volume data. Pulse ultrasonic, doppler microwave, radar, passive magnetic, passive infrared, and active infrared were found to count within 3 percent of baseline volume data. These results are based on data collected in 15-minute intervals. It is possible that a device consistently miscounted a particular vehicle, such as a motorcycle, and this would not appear in the data analysis. Since the primary objective was to examine the accuracy of devices in collecting historical traffic data, such errors were not examined.

At the intersection test site the results are more varied. The pulse ultrasonic, passive acoustic, and video devices were generally within 10 percent of baseline volume data while the passive infrared device was within 5 percent.

Speed data were collected from active infrared, passive magnetic, radar, doppler microwave, passive acoustic and video devices at the freeway test site. In general, all of the devices were within 8 percent of the baseline data. Radar, doppler microwave, and video were found to be the most accurate at measuring vehicle speeds. Speed data were not collected at the intersection test site.

Extensive classification analysis was not performed in this test for two primary reasons: First, there was not a reliable baseline to compare data to; secondly, each device measured classification in a different manner, making evaluation difficult. Some classification analysis was performed on the freeway data from the active infrared and video devices. The radar device also provides an approximate two level classification scheme, however the vendor requested that the data not be presented. The classification results are in presented in Table B-2 at the end of Appendix B.

Weather variables were found to have minimal effect on device performance. The greatest impact was snow on the roadway, which caused some vehicles to track outside of their normal driving patterns. Devices with narrow detection zones were most affected. In addition, lighting conditions were observed to affect some of the video devices, particularly in the transition from day to night. The salt spray generated by the traffic stream coated everything in the field with a layer of grime. This impacted the performance of some video devices and possibly other optic-dependent devices, such as the Autosense I active infrared. Extremely cold weather made access to devices difficult, especially for the magnetic probes installed under the pavement. Cold temperatures also caused some cables to become brittle and split open. Overall the effect of weather on device performance was minimal. This is especially true if a device is being used to gather traffic count data for historical use. In this case the data from a day with inclement weather do not represent typical traffic levels and could be discarded. Urban traffic conditions, including heavy congestion, were found to have little affect on the device performance.

In general, the differences in performance from one device to another were found to be more significant than the differences from one technology to another. The detection of traffic can be done with a multitude of technologies. For satisfactory performance from a non-intrusive device it is more important to select a well designed and highly reliable product than to narrow a selection to particular technology.

The technologies with the potential to meet the majority of the test objectives were passive infrared, radar, doppler microwave and pulse ultrasonic. The ASIM IR 224 passive infrared was the only device to excel at both the freeway and intersection test sites. Video and radar devices have the advantage of multiple-lane detection from a single unit. Video has the additional advantage of providing a view of the traffic operations at the test site.

The text of this report and detailed test results are being made available on the World Wide Web. Contact SRF Consulting Group, Inc. or Minnesota Guidestar at the address given in the front of this report for more information.

There are ongoing developments in non-intrusive vehicle detection technologies. Devices are now available that incorporate multiple technologies within a single device. Developments in other technologies, such as passive millimeter microwave and infrared video, will produce additional entries into the market. At the same time, existing technologies are being continually improved upon. Future testing of non-intrusive technologies is needed to provide information on this fast growing field. Proposals are being prepared to continue this project.

Table 4 Device Features and Installation / Maintenance Observations

TECHNOLOGY / Device	Volume	Speed	Presence	Occupancy	Classification	Density	Headway	Dwell Time	Incident Detection	Number of Lanes	Sidefire / Overhead	Oncoming / Departing	Ease of Mounting	Ease of Calibration	Maintainability	Reliability
	Device Features												**Installation / Maintenance**			
Inductive Loop	X		TP							1	N/A	B	-	+	+	+
PASSIVE INFRARED																
Eltec Model 833	X		TP							1	B	B	+	+	+	+/-
Eltec Model 842	X		TP							1	?	B	+	+	+	?
ASIM IR 224	X		TP							1	B	O	+	+	+	+/-
ACTIVE INFRARED																
Autosense I	X	X	TP		X	?				1	B	B	+	+	+	+/-
MAGNETIC																
IVHS Sensor 232E	X	X	TP	X						1	N/A	B	-	+/-	+/-	-
RADAR																
RTMS X1	X	X	TP	X	X		?			8	B	B	+	+/-	+	+/-
DOPPLER MICROWAVE																
TC - 26B	X		P							1*	?	B	+	+	+	?
PODD	X		P							1*	OH	O	+	+	+	+/-
TDW - 10	X	X	P							1*	OH	B	+	+	+	+/-
TDN - 30	X	X	P							1	OH	B	+	+	+	+/-
PULSE ULTRASONIC																
Lane King	X		TP							1	B	B	+	+/-	+	+
TC - 30	X		TP							1	B	B	-	+	+	+/-
PASSIVE ACOUSTIC																
Smartsonic TSS - 1	X	X	TP	X						1	SF	B	+	-	+	+
VIDEO																
EVA 2000s	X	X	?	?	X	?	?		?	4	B	B	-	-	-	-
Autoscope 2004	X	X	TP	X	X	X	X		X	>12	B	B	-	-	-	+
TraffiCam - S	X	X	TP	X						4	B	B	+	-	+/-	+/-
Video Trak-900	X	X	TP	X	X	X	X	X	X	>12	B	B	-	-	-	+/-

* These devices can monitor multiple lanes with one large detection zone but cannot differentiate individual lanes.
X Denotes a device that can perform the stated function.
? Denotes a situation that could not be confirmed.
TP Denotes a device that can measure true presence.
P Denotes a device that can measure presence through a pulse outpost.
\+ Denotes a device that satisfactorily meets the stated condition.
+/- Denotes a device which meets some but not all of the criteria for satisfactory performance.
\- Denotes a device that does not meet the stated condition.
SF Denotes a device that can be mounted in a sidefire position.
OH Denotes a device that can be mounted in an overhead position.
O Denotes a device that can face oncoming traffic.
D Denotes a device that can face departing traffic.
B Denotes a device that can operate in both capacities.

Table 5 Environmental Factors Affecting Device Performance

TECHNOLOGY	Environmental Factors														
	Freeway Test Site						Intersection Test Site				Both Test Sites				
Device	High Speeds	Low Speeds	High Volumes	Low Volumes	Geometrics	Lighting Effects	High Volumes	Low Volumes	Geometrics	Lighting Effects	Rain	Freezing Rain	Snow (1)	High Temperature	Low Temperature
Inductive Loop	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
PASSIVE INFRARED															
Eltec Model 833	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-
ASIM IR 224	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
ACTIVE INFRARED															
Autosense I	+	+	+	+	+	+	?	?	?	?	-	-	-	+	+
MAGNETIC															
IVHS Sensor 232E	+	+	+	+	+	+	?	?	?	?	-	+	+	+	-
RADAR															
RTMS X1	+	+	+	+	+	+	?	?	?	?	-*	-*	+	+	+
DOPPLER MICROWAVE															
PODD	+	+	+/-	+	+	+	-	-	-	-	+	+	+	+	+
TDN - 30	+	+	+	+	+	+	-	-	-	-	+	+	+	+	+
PULSE ULTRASONIC															
Lane King	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
TC - 30	+	+	+	+	+	+	+/-	+/-	+/-	+/-	+	+	+	+	+
PASSIVE ACOUSTIC															
Smartsonic TSS - 1	+/-	+	+/-	+	+	+	+/-	+/-	+/-	+/-	+	+	+	+	-
VIDEO															
EVA 2000s	+	+	+	+	+	+	?	?	?	?	+	+	+	+	+
Autoscope 2004	+	+	+	+	+	-	+/-	+	+	-	+	+	+	+	+
TraffiCam - S	+	+	+	+	+	?	?	?	?	?	+	+	+	+	+
Video Trak-900	+	+	+	+	+	-	?	?	?	?	+	+	+	+	+

(1) Snow is evaluated here as a direct factor in affecting device performance, secondary factors such as vehicle tracking patterns are not included.

* The RTMS unit was observed to miscount following periods of rain and freezing rain due to water entering the housing.

\+ Denotes a device which performs satisfactorily in the stated condition.

+/- Denotes a device which meets some but not all of the criteria for satisfactory performance.

\- Denotes a device which does not perform satisfactorily in the stated condition.

? Denotes a situation that could not be confirmed.

APPENDIX A

DETAILED VENDOR AND PRODUCT LIST

APPENDIX A

DETAILED VENDOR AND PRODUCT LIST

- **INFRARED**

Passive Infrared
ELTEC INSTRUMENTS, INC.
Pam Corrick
P.O. Box 9610
Daytona Beach, Florida 32120-9610
Phone: (800) 874-7780
Fax: (904) 258-3791

♦ **Model 833**
Cost: $820
Additional Equipment Needed: None
Installation: Sidefire or overhead at variable heights.
Capabilities: Long range presence detection (up to 180 feet) including stationary vehicles and speed in one detection zone with relay loop emulation output. Maximum vehicle speed is 100 mph.
Availability: Commercially available.

♦ **Model 842**
Cost: $1,210
Additional Equipment Needed: None.
Installation: Sidefire (15-20 feet high).
Capabilities: Short range presence detection including stationary vehicles in one detection zone with relay loop emulation output. Maximum vehicle speed is 45 mph.
Availability: Commercially available.

Passive Infrared

ASIM ENGINEERING LTD.
Bertrand Steinbach
Walter Kuster
St. Galler - Strasse 70
CH - 8716 Schmerikon
Switzerland
Phone: +41-55-282-41-00
Fax: +41-55-282-31-51

- **IR-222/IR 223**

Cost: $980
Additional Equipment Needed: Installation Tester IT 24 and PC for setup.
Installation: Overhead or sidefire oncoming, 13-26 feet (4-8m) high, up to 52 feet (16m) range.
Capabilities: Single lane discriminating, count, presence with relay for loop emulation or RS 232 serial output.
Availability: Commercially available in Europe.

- **IR-224**

Cost: $1,300
Additional Equipment Needed: Alignment help ZA-V 224B, interface IF232 and PC for setup.
Installation: Overhead or sidefire oncoming, 13-26 feet (4-8m) high, up to 26 feet (8m) range.
Capabilities: Single lane discriminating, count, presence, average speed with 2 x relay or 2 x optocoupler for loop emulation or RS 232 serial output.
Availability: Commercially available in Europe.

- **DT-281 (Doppler Radar and Passive Infrared)**

Cost: $2,400
Additional Equipment Needed: PC for setup and/or data collection.
Installation: Overhead or sidefire oncoming, 13-26 feet (4-8m) high, up to 20 feet (6m) range.
Capabilities: Single lane discriminating, count, presence, speed, length with 2 x relay or 2 x optocoupler for loop emulation or RS 232 or RS 485 for data communication.
Availability: Commercially available in Europe.

Active Infrared
SCHWARTZ ELECTRO-OPTICS, INC.
Brian Domian
3404 North Orange Blossom Trail
Orlando, Florida 32804
Phone: (407) 298-1802
Fax: (407) 297-1794

- **Autosense I**

Cost: $6,500
Additional Equipment Needed: PC for serial data collection.
Installation: Overhead (preferred) or sidefire facing oncoming or departing traffic.
Capabilities: Presence including stationary vehicles, speed, density and classification (vehicle height) in two detection zones with relay loop emulation and RS 232 serial outputs.
Availability: Commercially available.

- **Autosense II**

Cost: $10,000
Additional Equipment Needed: PC for serial data collection.
Installation: Overhead
Capabilities: Presence, classification, and speed with relay loop emulation and RS 232 serial outputs. 3D measurement of vehicles, tow bar detection and separation of closely spaced vehicles
Availability: Commercially available.

- **Autosense III**

Cost: $15,000 (approximately)
Additional Equipment Needed: PC for serial data collection.
Installation: Overhead
Capabilities: Presence, classification, and speed with relay loop emulation and RS 232 serial outputs. 3D measurement of vehicles, tow bar detection and separation of closely spaced vehicles. Covers 2 - 3 lanes depending on mounting height.
Availability: Expected June 1997.

- **<u>MAGNETIC</u>**

Magnetic
SAFETRAN TRAFFIC SYSTEMS, INC.
John Satcher
1485 Garden of the Gods Road
P.O. Box 7009
Colorado Springs, CO 80933-7009
Phone: (719) 599-5600
Fax: (719) 599-3853

♦ **IVHS Sensor 232E / 231E Sensor Probe**
Cost: 232E = $700, 231E = $90 each (each 232E sensor supports two 231E probes)
Additional Equipment Needed: PC for serial data collection.
Installation: Magnetic probe is inserted in a non-ferrous 3 inch conduit placed 14 inches to 24 inches under the roadway.
Capabilities: Probe detects volume, speed and occupancy for one lane, with relay loop emulation and RS 232 serial outputs.
Availability: Commercially available.

- **<u>MICROWAVE / RADAR</u>**

Radar
EIS (ELECTRONIC INTEGRATED SYSTEMS INC.)
Dan Manor
150 Bridgeland Avenue
North York, Ontario Canada M6A 1Z5
Phone: (800) 668-9385
Fax: (416) 785-9332

♦ **RTMS (Remote Traffic Microwave Sensor)**
Cost: $3,300
Additional Equipment Needed: PC for setup and serial data collection.
Installation: Sidefired or overhead facing oncoming or departing traffic.
Capabilities: Presence (including stationary vehicles), volume, speed, classification, headway and occupancy for up to eight separate detection lanes with relay loop emulation and RS 232 serial outputs.
Availability: Commercially available.

Doppler microwave
MICROWAVE SENSORS, INC.
G. Dan Sutton, Sales Manager
Don Johnston, President
7885 Jackson Road
Ann Arbor, Michigan 48103
Phone: (800) 521-0418 or (313) 426-0140
Fax: (800) 847-5762 or (313) 426-5950

♦ **TC-20**
Cost: $629
Additional Equipment Needed: None.
Installation: Overhead mounted, facing approaching traffic or sidefire (12-18 feet average mounting height, maximum pan 45 degrees) facing approaching traffic.
Capabilities: Motion detection in one single or multi-lane detection zone with relay output.
Availability: Commercially available.

♦ **TC-26B**
Cost: $735
Additional Equipment Needed: None.
Installation: Overhead (14-24 feet average) or sidefire mounting, facing approaching or departing traffic.
Capabilities: Long-range or short-range vehicle motion detection (up to 200 feet for cars, 350 feet for trucks) in one single or multi-lane detection zone with relay output.
Availability: Commercially available.

Doppler microwave
PEEK TRAFFIC, INC. - SARASOTA
Bill Ippolito
1500 N. Washington Boulevard
Sarasota, FL 34236
Phone: (301) 733-2125 or 1-800-245-7660
Fax: (301) 945-3558

♦ **PODD (Peek Overhead Doppler Detector)**
Cost: $600
Additional Equipment Needed: None.
Installation: Overhead or sidefire 16-26 feet (5-8 m) high for approaching vehicles only.
Capabilities: Pulse vehicle detection in one single or multi lane detection zone with relay loop emulation output.
Availability: Commercially available.

Doppler Microwave
WHELEN ENGINEERING CO.
Philip Kurze
Route 145 - Winthrop Road
Chester, CT 06412-0684
Phone: (860) 526-9504 or (800) 637-4736
Fax: (860) 526-4784

- **TDW-10 (Wide beam vehicle detector)**

Cost: $995
Additional Equipment Needed: PC for serial data collection.
Installation: Overhead (16-32 feet high) or sidefire (up to 30 feet to the side).
Capabilities: Designed for real time speed studies; the wide beam analyzes several lanes at once and cannot discern individual vehicles. The detector outputs RS 232 serial data and relay loop emulation via pulsed vehicle detection (allows for speed calculation). The detector can also be used for wrong way flow detection and incident detection.
Availability: Commercially available.

- **TDN-30 (Narrow beam vehicle detector)**

Cost: $995
Additional Equipment Needed: PC for serial data collection.
Installation: Overhead or sidefire (note: speed detection is not possible with a sidefire mount).
Capabilities: The narrow beam analyzes one lane for volume and speed. The detector outputs RS 232 serial data and relay loop emulation via pulsed vehicle detection (allows for speed calculation). The detector can also be used for wrong way flow detection and incident detection.
Availability: Commercially available.

- **<u>SONIC / ULTRASONIC</u>**

Pulse Ultrasonic
NOVAX INDUSTRIES CORP.
Doug Grubbe
Western Office
658 Derwent Way
New Westminister
BC V3M 5P8 Canada
Phone: (604) 525-5644
Fax: (604) 525-2739

♦ **Lane King™**
Cost: Contact vendor.
Additional Equipment Needed: PC for setup and serial data collection.
Installation: Directly overhead or sidefire.
Capabilities: Volume, presence via loop emulation and volume with RS 232 serial output.
Availability: Commercially available.

Pulse Ultrasonic
MICROWAVE SENSORS, INC.
G. Dan Sutton, Sales Manager
Don Johnston, President
7885 Jackson Road
Ann Arbor, Michigan 48103
Phone: (800) 521-0418 or (313) 426-0140
Fax: (800) 847-5762 or (313) 426-5950

♦ **TC-30**
Cost: $475
Additional Equipment Needed: None.
Installation: Overhead mounted (12-22 feet, aimed straight down) or sidefire (3-12 feet, perpendicular to traffic).
Capabilities: Presence detection in one relay loop emulation detection zone.
Availability: Commercially available.

♦ **TC-30C**
Cost: $559
Additional Equipment Needed: None.
Installation: Overhead mounted (12 -22 feet, aimed straight down) or sidefire (3 -12 feet, perpendicular to traffic).
Capabilities: Presence detection in one relay loop emulation detection zone.
Availability: Commercially available.

Passive Acoustic

INTERNATIONAL ROAD DYNAMICS INC. (IRD)
Rod Klashinsky
702 43rd Street East
Saskatoon, Saskatchewan
S7K 3T9 Canada
Phone: (306) 653-6600
Fax: (306) 242-5599

- **SmartSonic™ TSS-1**

Cost: Approximately $2,500 - one lane system, $7,000 - four lane system (includes transmission module and controller card).
Additional Equipment Needed: PC for setup and serial data collection.
Installation: Overhead (18-36 feet) or sidefire (up to 25 feet horizontal distance to detection zone).
Capabilities: Presence detection including stationary vehicles in two detection zones with relay loop emulation outputs, volume, speed, occupancy, classification (three classes by length). Detection zone equals 6 to 8 feet in direction of traffic and provides one or two lane selectable zone size in the cross lane direction. Number of lanes = one lane per sensor (4 lanes per controller).
Availability: Commercially available.

- **VIDEO**

Video

ELIOP TRAFICO S.A.
Luis Lopez
Ramon Garcia
Av. Manoteras, 22 (Of. 120)
28050 Madrid
Spain
Phone: +34-1-383 01 80
Fax: +34-1-383 04 02

♦ **EVA 2000s**
Cost: $7,000 to $17,000 (depending on options)
Additional Equipment Needed: Camera and software ($6,000), PC.
Installation: Overhead (30-45 feet) or sidefire (30-54 feet) facing approaching or departing traffic.
Capabilities: Incident detection, volume, speed, density, occupancy and headway in up to four lanes depending on mounting height with relay loop emulation and RS 232 serial outputs.
Availability: Commercially available.

♦ **EVA DAI**
Cost: $8,000 to $18,000 (depending on options)
Additional Equipment Needed: Camera and software ($6,000), PC.
Installation: Overhead (30-45 feet) or sidefire (30-54 feet) facing approaching or departing traffic.
Capabilities: Incident detection, volume, speed, density, occupancy and headway in up to four lanes depending on mounting height with relay loop emulation and RS 232 serial outputs.
Availability: Commercially available.

Video

IMAGE SENSING SYSTEMS
Lisa Dumke
1600 University Ave. W. Suite 500
Saint Paul, MN 55104
Phone: (612) 642-9904
Fax: (612) 603-7795

- **Autoscope 2004**

Cost: Autoscope = $24,000
Additional Equipment Needed: Camera and accessories ($2,350), PC.
Installation: Overhead or sidefire facing approaching or departing traffic.
Capabilities: Volume, occupancy, speed, turning movements, classification (three classes), incident detection, and headway in 48 detection zones with 32 relay loop emulations and RS 232 serial outputs. Up to four camera inputs.
Availability: Commercially available.

- **Autoscope 2004 Lab**

Cost: Autoscope = $9,990 (Universities Only), otherwise contact vendor.
Additional Equipment Needed: Camera and accessories ($2,350), PC.
Installation: Overhead or sidefire facing approaching or departing traffic.
Capabilities: Volume, occupancy, speed, turning movements, classification (three classes), incident detection, and headway in 48 detection zones with 32 relay loop emulations and RS 232 serial outputs. Up to one camera input.
Availability: Commercially available.

Video
ROCKWELL INTERNATIONAL
Greg McKhann
3370 Miraloma
Anaheim, CA 92803-3105
Phone: (714) 762-8804
Fax: (714) 762-1750

- **TraffiCam™ - S**

Cost: $5,000
Additional Equipment Needed: PC for setup and serial data collection.
Installation: Sidefire facing approaching or departing traffic or overhead facing approaching traffic.
Capabilities: Volume, presence, speed, occupancy, visual image with relay loop emulation in 8 detection zone pairs and RS 232, RS 422, or RS 485 serial outputs.
Availability: Commercially available.

- **TraffiCam™ - I**

Cost: $5,000
Additional Equipment Needed: PC for setup.
Installation: Sidefire facing approaching or departing traffic or overhead facing approaching traffic.
Capabilities: Presence and visual image.
Availability: Commercially available.

Video
PEEK TRAFFIC - TRANSYT CORPORATION
Scott Meyerhoff
3000 Commonwealth Blvd.
Tallahassee, FL 32303-3157
Phone: (904) 562-2253
Fax (904) 562-4126

- **Video-Trak® - 900**

Cost: $18,000 (four camera unit - Windows software included)
Additional Equipment Needed: Cameras and mounting hardware - $1,500 each. Camera interface panel - $500 (with six video surge arrestors). PC (minimum of a 486/66 with 16M RAM)
Installation: Overhead or sidefire facing oncoming or department traffic.
Capabilities: Classification (five classes), presence, speed, occupancy, density, headway, delay, length, volume, and incident detection with relay loop emulation and RS 232 outputs in up to 32 zones per camera and 256 zones per unit (eight camera detection unit).
Availability: Commercially available.

ADDITIONAL VENDORS
(NOT TESTED IN PROJECT)

- **INFRARED**

Passive Infrared
SANTA FE TECHNOLOGIES, INC. / TITAN
Jerry Musnitsky
2021 Girard SE Suite 201
Albuquerque, New Mexico 87106-3157
Phone: (505) 243-4100
Fax: (505) 842-1999

♦ **SmartLOOK**
Cost: Contact vendor.
Additional Equipment Needed: None
Installation: Overhead or sidefire facing approaching or departing traffic.
Capabilities: Volume, presence, classification (up to 256 classes), speed, and acceleration.
Availability: Prototype expected Summer 1997.

Active Infrared

SPECTRA SYSTEMS, INC.
(Manufactured by MBB Business Development GmbH, Germany)
Margit Weir
777 Yamato Road Suite 105
Boca Raton, FL 33431
Phone: (561) 998-3160
Fax: (561) 998 - 3166
E-mail: 74111.517@compuserve.com

♦ **TOM (Traffic Observation Module)**

Cost: Contact vendor.
Additional Equipment Needed: Starter kit (including: PC software, interface converter, cable.)
Installation: Overhead
Capabilities: Volume, travel direction, lane position of vehicle (left, middle, right), separation distance (gap), speed, classification, headway, height and length.
Availability: Commercially available.

♦ **SAM (Sensing and Activating Module)**

Cost: Contact Vendor.
Additional Equipment Needed: Starter kit (incl: PC software, interface converter, cable.)
Installation: Sidefire or overhead.
Capabilities: Vehicle / pedestrian presence.
Availability: Commercially available.

- **<u>MAGNETIC</u>**

Magnetic

3M, INTELLIGENT TRANSPORTATION SYSTEMS
Doug Henderson
3M Center
Building 225-4N-14
Saint Paul, MN 55144
Phone: (612) 737-1581
Fax: (612) 737-1055

♦ **Non-Invasive Microloop**

Cost: $125 per probe (approximately)
Additional Equipment Needed: None
Installation: Probe is inserted in a 3-inch conduit placed 24 inches under the roadway.
Capabilities: Used for vehicle detection in highway and arterial applications. Probe detects volume, occupancy and speed (with two sensors)
Availability: Expected June 1997.

Magnetic
NU-METRICS, INC.
John Cavalier
University Drive, Box 518
Uniontown, PA 15401
Phone: (412) 438-8750
Fax: (412) 438-8769

♦ **NC-30x, NC-40, NC-90A, Groundhog G1 & G2**
Cost: NC-30x = $275, NC-40 = $595, NC-90A = $975, G-1 = $1,075, G-2 = $1,895, G-2WX = $1,995.
Additional Equipment Needed: PC, IP10 Interface Card ($450), software ($375 - $950).
Installation: Roadway surface & sub surface.
Capabilities: Volume, presence, speed, classification, headway, and/or occupancy (depending on model) in one detection zone with data available via periodic download.
Availability: Commercially available.

- **SONIC / ULTRASONIC**

Ultrasonic
SUMITOMO ELECTRIC USA, INC.
Takehiko Barada
3235 Kifer Road Suite 150
Santa Clara, CA 95051
Phone: (408) 737-8517
Fax: (408) 737-0134
E-mail: barada@sumitomo.com

♦ **SDU 420**
Cost: $2,200 (May vary) including mounting bracket.
Additional Equipment Needed: Data transmission equipment
Installation: Overhead (15-18 feet high).
Capabilities: Presence in one detection zone, classification (two classes), 8 detector heads for 8 zones per one processing unit.
Availability: Commercially available.

VIDEO

Video
COMPUTER RECOGNITION SYSTEMS, INC.
Salvatore D'Agostino
639 Massachusetts Avenue
Cambridge, MA 02139
Phone: (617) 491-7665
Fax: (617) 491 - 7753
E-Mail Address: salcrsus@ix.netcom.com

- **TAS2 (Traffic Analysis System)**

Cost: $15,000-$25,000
Additional Equipment Needed: Cameras, lenses, mounting hardware, cabling.
Installation: Sidefire or overhead facing oncoming or departing traffic or both (depends on lensing).
Capabilities: Volume, speed, occupancy, density, queue length, dwell time at intersections, classification (four classes), incident detection and loop emulation with RS 232 serial data.
Availability: Commercially available.

Video
SUMITOMO ELECTRIC USA, INC.
Takehiko Barada
3235 Kifer Road Suite 150
Santa Clara, CA 95051
Phone: (408) 737-8517
Fax: (408) 737 - 0134
E-mail: barada@sumitomo.com

- **IDET-100**

Cost: $15,000 (may vary) includes one camera and bracket
Additional Equipment Needed: PC for setup, data transmission equipment.
Installation: Sidefire or overhead facing oncoming or departing traffic, height = 25 - 30 feet.
Capabilities: Presence, volume, classification (two classes), speed, queue length, detection in up to four lanes of two-way traffic.
Availability: Commercially available.

Video
AUTOMATIC SIGNAL / EAGLE SIGNAL
Arnold A. McLaughlin
8004 Cameron Road
Austin, TX 78754
Phone: (512) 837-8425
Fax: (512) 837 - 0196

- **Eagle Vision , P/N EV1000**

Cost: Processor = $15,000, Cameras = $3,000, Software = $500.
Additional Equipment Needed: 12 inch black / white monitor and mouse.
Installation: Overhead facing oncoming or departing traffic with height = 25 - 40 feet.
Capabilities: Presence, dwell time, incident detection with 32 detection zones per processor, 8 detector zones per camera. Range of detection is 500 feet in 5 lanes.
Availability: Commercially available.

Video
CONDITION MONITORING SYSTEMS, INC.
Kay Dermer
2412 East First Street
Long Beach, CA 90803
Phone, Fax: (310) 438-4875

- **Mobilizer**

Cost: $3,000 - $5,000 (estimate) - includes dedicated processor and software.
Additional Equipment Needed: Camera(s)
Installation: Overhead or sidefire facing approaching or departing traffic or remote video tape analysis service.
Capabilities: Volume, presence, occupancy, turning movements, speed, acceleration, delay, classification, lane changes and headway with RS 232 serial output
Availability: Contact vendor.

Video

NESTOR, INC., INTELLIGENT SENSOR DIVISION
Laurent Meilleur
One Richmond Square
Providence, RI 02906
Phone: (401) 331-9640
Fax: (401) 331-7319
Email: Traffic@Nestor-pc.ccmail.compuserve.com

- **Traffic Vision**

Cost: Contact vendor.
Additional Equipment Needed: None
Installation: Left, center, or side mounted camera placement with oncoming, receding, or bi-directional traffic. Detection range = 50 to 400 feet (typical). Up to six lanes per camera, up to four cameras per system.
Capabilities: Vehicle presence, counts, occupancy, speed, queue length, headway, lane changes, vehicle classification (13-level FHWA), link travel time between camera sights, pedestrian and bicycle detection.
Availability: Commercially available.

APPENDIX B

SPECIAL DATA ANALYSES

APPENDIX C

DETAILED TEST RESULTS

APPENDIX D

DETAILED BASELINE CALIBRATION RESULTS

TABLE OF CONTENTS

Appendix D -- List of Figures

Appendix D -- List of Tables

APPENDIX D

DETAILED BASELINE CALIBRATION RESULTS

The following manual observations were made regarding inductive loop performance.

11/22/96	Loop D2-2 (intersection) counted 50 out of 50, 5 vehicles stopped on the loop, the rest went through without stopping. Stop and go traffic in the right turn lane caused 4 vehicles to move into through lane, effectively straddling the two lanes, 3 of these were detected by D2-2 and one was not.
11/22/96	Loop D2-3 (intersection) counted 50 out of 50, no vehicles came to a full stop, one vehicle straddled the two lanes but was detected. Snow on pavement observed to cause vehicles in the right turn lane to travel closer to the through lane, but both the Eltec 833 and Lane King on Pole 4 still saw them.
11/22/96	Loop D4-1 (intersection) counted 20 out of 20, freeflow.
12/10/96	Loop 1 (freeway) counted 50 out of 50. Loop 2 (freeway) counted 50 out of 50. Loop D2-2 (intersection) counted 5 out of 5. Loop D2-3 (intersection) counted 50 out of 50. Loop D4-1 (intersection) counted 10 out of 10.
1/8/97	Loop 1 (freeway) counted 50 out of 50, freeflow, 45 mph. Loop 2 (freeway) counted 50 out of 50, freeflow, 45 mph.

TABLE D-1 FREEWAY LOOP CALIBRATION

TEST 9 - 11/06/96 AM Peak Freeway Loop Calibration

Time	Freeway Lane 1 Adjusted Manual (7)	Loop 1A/1B	Diff	Freeway Lane 2 Adjusted Manual (7)	Loop 2A/2B	Diff	Comments
715	457.5	456	-1.5	354	352	-2	slow
730	477.5	479	1.5	328	327	-1	stop/go
745	472	473	1	378	375	-3	stop/go
800	500	501	1	439	441	2	slow
Total	1907	1909	2	1499	1495	-4	
%			0.10%			-0.27%	
Std. Dev.			1.17			1.87	

TEST 8 - 9/27/96 AM Peak Freeway Loop Calibration

Time	Freeway Lane 1 Adjusted Manual (7)	Loop 1A/1B	Diff	Freeway Lane 2 Adjusted Manual (7)	Loop 2A/2B	Diff	Comments
715	594	600	6	623	624	1	
730	574	576	2	591	593	2	
745	564	564	0	528	530	2	
Total	1732	1740	8	1742	1747	5	
%			0.46%			0.29%	
Std. Dev.			2.49			0.47	

TEST 7 - 1/19/96 AM Peak Freeway Loop Calibration

Time	Freeway Lane 1 Adjusted Manual (7)	Loop 1A/1B	Diff	Freeway Lane 2 Adjusted Manual (7)	Loop 2A/2B	Diff	Comments
800	115.5	118	2.5	120.5	121	0.5	slow traffic
805	120	119	-1	118	122	4	slow traffic
810	110	110	0	123	121	-2	slow traffic
815	106.5	108	1.5	106.5	105	-1.5	slow traffic
820	113.5	111	-2.5	115.5	115	-0.5	slow traffic
825	108.5	110	1.5	117.5	120	2.5	slow traffic
830	100	100	0	109	108	-1	slow traffic
835	109.5	109	-0.5	115.5	116	0.5	slow traffic
840	111.5	111	-0.5	113.5	115	1.5	slow traffic
845	106	106	0	120	115	-5	slow traffic
850	114.5	117	2.5	119.5	121	1.5	slow traffic
855	105	107	2	113	115	2	slow traffic
Total	1320.5	1326	5.5	1391.5	1394	2.5	
%			0.42%			0.18%	
Std. Dev.			1.48			2.30	

Notes:

1. Loop 1A is the upstream loop in lane 1 at the freeway.
2. Loop 1B is the downstream loop in lane 1 at the freeway.
3. Loop 2A is the upstream loop in lane 2 at the freeway.
4. Loop 2B is the downstream loop in lane 2 at the freeway.
5. Loop HOV A is the upstream loop in the HOV lane at the freeway.
6. Loop HOV B is the downstream loop in the HOV lane at the freeway.
7. Adjusted manual counts are calculated by splitting the "mid-lane traffic" between the corresponding lanes.

TABLE D-1 (Continued) FREEWAY LOOP CALIBRATION

TEST 6 - 11/02/95 AM Peak Freeway Loop Calibration

	Freeway Lane 1						Freeway Lane 2						HOV Lane						
Time	Adjusted Manual (7)	Loop 1A	Diff	Loop 1B	Diff	Avg Diff	Adjusted Manual (7)	Loop 2A	Diff	Loop 2B	Diff	(8) Avg Diff	Adjusted Manual (7)	Loop HOV A	Diff	Loop HOV B	Diff	Avg Diff	Comments
630	202	202	0	202	0	0	206.5	207	0.5	209	2.5	1.5	23	23	0	23	0	0	freeflow
635	210	209	-1	210	0	-0.5	218	215	-3	217	-1	-2	33.5	32	-1.5	32	-1.5	-1.5	freeflow
640	218	218	0	217	-1	-0.5	216.5	217	0.5	223	6.5	3.5	39	40	1	40	1	1	freeflow
645	188	187	-1	188	0	-0.5	171	172	1	172	1	1	46	46	0	46	0	0	stop/go
650	192	191	-1	192	0	-0.5	181.5	182	0.5	181	-0.5	0	51	52	1	52	1	1	slow
655	198	197	-1	198	0	-0.5	197.5	195	-2.5	201	3.5	0.5	61	61	0	61	0	0	slow
700	191.5	192	0.5	192	0.5	0.5	160.5	162	1.5	162	1.5	1.5	63	63	0	62	-1	-0.5	stop/gp
705	192	192	0	193	1	0.5	195	192	-3	196	1	-1	76	74	-2	74	-2	-2	stop/go
710	189.5	190	0.5	191	1.5	1	205.5	205	-0.5	205	-0.5	-0.5	95	96	1	96	1	1	slow
715	191.5	191	-0.5	192	0.5	0	187	188	1	189	2	1.5	101.5	101	-0.5	100	-1.5	-1	stop/go
720	195	195	0	195	0	0	181	181	0	184	3	1.5	102	102	0	102	0	0	slow
725	186	184	-2	185	-1	-1.5	186.5	184	-2.5	183	-3.5	-3	117	117	0	117	0	0	freeflow
Total	2353.5	2348	-5.5	2355	1.5	-2	2306.5	2300	-6.5	2322	15.5	4.5	808	807	-1	805	-3	-2	
%			-0.23%		0.06%	-0.08%			-0.28%		0.67%	0.20%			-0.12%		-0.37%	-0.25%	
Std. Dev.			0.72		0.68	0.62			1.64		2.44	1.71			0.89		0.99	0.92	

TEST 5 - 11/02/95 AM Peak Freeway Loop Calibration

	Freeway Lane 1						Freeway Lane 2						
Time	Adjusted Manual (7)	Loop 1A	Diff	Loop 1B	Diff	Avg Diff	Adjusted Manual (7)	Loop 2A	Diff	Loop 2B	Diff	(8) Avg Diff	Comments
630	200.5	202	1.5	202	1.5	1.5	205.5	207	1.5	209	3.5	2.5	freeflow
635	210	209	-1	210	0	-0.5	218	215	-3	217	-1	-2	freeflow
640	217	218	1	217	0	0.5	218	217	-1	223	5	2	freeflow
645	188	187	-1	188	0	-0.5	172	172	0	172	0	0	stop/go
650	192	191	-1	192	0	-0.5	181.5	182	0.5	181	-0.5	0	slow
655	198	197	-1	198	0	-0.5	197.5	195	-2.5	201	3.5	0.5	slow
700	190	192	2	192	2	2	160	162	2	162	2	2	stop/gp
705	194	192	-2	193	-1	-1.5	194	192	-2	196	2	0	stop/go
710	190.5	190	-0.5	191	0.5	0	204.5	205	0.5	205	0.5	0.5	slow
715	190.5	191	0.5	192	1.5	1	187.5	188	0.5	189	1.5	1	stop/go
720	195	195	0	195	0	0	180.5	181	0.5	184	3.5	2	slow
725	184	184	0	185	1	0.5	187.5	184	-3.5	183	-4.5	-4	freeflow
Total	2349.5	2348	-1.5	2355	5.5	2	2306.5	2300	-6.5	2322	15.5	4.5	
%			-0.06%		0.23%	0.09%			-0.28%		0.67%	0.20%	
Std. Dev.			1.14		0.83	0.94			1.74		2.48	1.78	

TEST 4 - 10/16/95 PM Peak Freeway Loop Calibration

	Freeway Lane 1						Freeway Lane 2						HOV Lane						
Time	Adjusted Manual (7)	Loop 1A	Diff	Loop 1B	Diff	Avg Diff	Adjusted Manual (7)	Loop 2A	Diff	Loop 2B	Diff	(8) Avg Diff	Adjusted Manual (7)	Loop HOV A	Diff	Loop HOV B	Diff	Avg Diff	Comments
1610	187.5	187	-0.5	189	1.5	-0.5	216.5	216	-0.5	217	0.5	0	59	58	-1	58	-1	1	freeflow
1615	200.5	200	-0.5	201	0.5	0	205.5	205	-0.5	207	1.5	-0.5	67	67	0	67	0	0	freeflow
1620	196.5	198	1.5	198	1.5	-1.5	205	203	-2	203	-2	2	57	58	1	58	1	-1	freeflow
1625	166.5	166	-0.5	166	-0.5	0.5	213	213	0	221	8	-4	60	60	0	61	1	-0.5	freeflow
1630	170	170	0	171	1	-0.5	224.5	222	-2.5	226	1.5	0.5	65	66	1	66	1	-1	freeflow
1635	193.5	193	-0.5	193	-0.5	0.5	218.5	218	-0.5	219	0.5	0	70	69	-1	70	0	0.5	freeflow
1640	193	196	3	196	3	-3	216.5	213	-3.5	215	-1.5	2.5	73	70	-3	71	-2	2.5	freeflow
1645	194	190	-4	190	-4	4	222	221	-1	225	3	-1	73	71	-2	72	-1	1.5	freeflow
1650	208	210	2	210	2	-2	177.5	178	0.5	184	6.5	-3.5	79.5	79	-0.5	79	-0.5	0.5	slow
1655	177	177	0	177	0	0	186	187	1	191	5	-3	79.5	79	-0.5	79	-0.5	0.5	slow
1700	177.5	175	-2.5	176	-1.5	2	126.5	126	-0.5	129	2.5	-1	65	66	1	66	1	-1	stop/go
1705	172	173	1	173	1	-1	132.5	124	-8.5	129	-3.5	6	73.5	71	-2.5	72	-1.5	2	stop/go
Total	2236	2235	-1	2240	4	-1.5	2344	2326	-18	2366	22	-2	821.5	814	-7.5	819	-2.5	5	
%			-0.04%		0.18%	0.07%			-0.77%		0.94%	0.09%			-0.91%		-0.30%	-0.61%	
Std. Dev.			1.81		1.76	1.76			2.43		3.29	2.67			1.29		1.01	1.13	

Notes:

1. Loop 1A is the upstream loop in lane 1 at the freeway.
2. Loop 1B is the downstream loop in lane 1 at the freeway.
3. Loop 2A is the upstream loop in lane 2 at the freeway.
4. Loop 2B is the downstream loop in lane 2 at the freeway.
5. Loop HOV A is the upstream loop in the HOV lane at the freeway.
6. Loop HOV B is the downstream loop in the HOV lane at the freeway.
7. Adjusted manual counts are calculated by splitting the "mid-lane traffic" between the corresponding lanes.

TABLE D-1 (Continued) FREEWAY LOOP CALIBRATION

TEST 3 - 10/16/95 Mid-day Freeway Loop Calibration

Time	Freeway Lane 1 Adjusted Manual (7)	Loop 1A	Diff	Loop 1B	Diff	Avg Diff	Freeway Lane 2 Adjusted Manual (7)	Loop 2A	Diff	Loop 2B	Diff	(8) Avg Diff	HOV Lane Adjusted Manual (7)	Loop HOV A	Diff	Loop HOV B	Diff	Avg Diff	Comments
1440	182.5	184	1.5	184	1.5	-1.5	212.5	217	4.5	224	-11.5	-8	26	26	0	26	0	0	Freeflow
1445	160	157	-3	158	-2	2.5	190	190	0	191	-1	-0.5	27	28	1	28	1	-1	Freeflow
1450	160	159	-1	159	-1	1	188	189	1	197	-9	-5	32	31	-1	32	0	0.5	Freeflow
1455	108	110	2	110	2	-2	175.5	177	1.5	174	1.5	0	29	29	0	29	0	0	Freeflow
1500	111	112	1	111	0	-0.5	177	176	-1	178	-1	0	28.5	28	-0.5	28	-0.5	0.5	Freeflow
1505	163	165	2	166	3	-2.5	208.5	206	-2.5	210	-1.5	0.5	39.5	40	0.5	38	-1.5	0.5	Freeflow
Total	884.5	887	2.5	888	3.5	-3	1151.5	1155	3.5	1174	-22.5	-13	182	182	0	181	-1	0.5	
%			0.28%		0.40%	0.34%			0.30%		1.95%	1.13%			0.00%		-0.55%	-0.27%	
Std. Dev.			1.84		1.74	1.76			2.19		4.75	3.20			0.65		0.75	0.53	

TEST 2 - 10/12/95 Mid-day Freeway Loop Calibration

Time	Freeway Lane 1 Adjusted Manual (7)	Loop 1A	Diff	Loop 1B	Diff	Avg Diff	Freeway Lane 2 Adjusted Manual (7)	Loop 2A	Diff	Loop 2B	Diff	(8) Avg Diff	HOV Lane Adjusted Manual (7)	Loop HOV A	Diff	Loop HOV B	Diff	Avg Diff	Comments
1145	164	159	-5	159	-5	5	199.5	201	1.5	196	3.5	1	-	-	-	-	-	-	freeflow
1150	137.5	139	1.5	139	1.5	-1.5	216.5	212	-4.5	206	10.5	7.5	-	-	-	-	-	-	freeflow
1155	125	124	-1	125	0	0.5	187	185	-2	177	10	6	-	-	-	-	-	-	freeflow
1200	146.5	142	-4.5	142	-4.5	4.5	185.5	186	0.5	177	8.5	4	-	-	-	-	-	-	freeflow
1205							186	183	-3	176	10	6.5	-	-	-	-	-	-	freeflow
1210							181	183	2	178	3	0.5	-	-	-	-	-	-	freeflow
1215							184.5	184	-0.5	182	2.5	1.5	-	-	-	-	-	-	freeflow
1220							193.5	190	-3.5	186	7.5	5.5	-	-	-	-	-	-	freeflow
1225							203	199	-4	190	13	8.5	-	-	-	-	-	-	freeflow
1230							176	171	-5	163	13	9	-	-	-	-	-	-	freeflow
1235							199	197	-2	186	13	7.5	-	-	-	-	-	-	freeflow
1240							197	196	-1	192	5	3	-	-	-	-	-	-	freeflow
Total	573	564	-9	565	-8	8.5	2308.5	2287	-21.5	2209	99.5	60.5	-	-	-	-	-	-	
%			-1.57%		-1.40%	-1.48%			-0.93%		-4.31%	-2.62%			-		-	-	
Std. Dev.			2.66		2.81	2.72			2.23		3.80	2.85			-		-	-	

TEST 1 - 9/28/95 PM Peak Freeway Loop Calibration

Time	Freeway Lane 1 Adjusted Manual (7)	Loop 1A	Diff	Loop 1B	Diff	Avg Diff	Freeway Lane 2 Adjusted Manual (7)	Loop 2A	Diff	Loop 2B	Diff	(8) Avg Diff	HOV Lane Adjusted Manual (7)	Loop HOV A	Diff	Loop HOV B	Diff	Avg Diff	Comments
1845	173	172	-1	173	0	0.5	195	194	-1	189	6	3.5	32	32	0	32	0	0	freeflow
1850	167	166	-1	166	-1	1	200	199	-1	197	3	2	27	26	-1	26	-1	1	freeflow
1855	166.5	168	1.5	168	1.5	-1.5	218.5	217	-1.5	214	4.5	3	18.5	16	-2.5	16	-2.5	2.5	freeflow
1900	181	180	-1	180	-1	1	184	177	-7	174	10	8.5	38	33	-5	33	-5	5	freeflow
1905	165	165	0	165	0	0	188.5	187	-1.5	186	2.5	2	25.5	26	0.5	26	0.5	-0.5	freeflow
1910	180.5	179	-1.5	179	-1.5	1.5	202.5	203	0.5	199	3.5	1.5	17	15	-2	15	-2	2	freeflow
Total	1033	1030	-3	1031	-2	2.5	1188.5	1177	-11.5	1159	29.5	20.5	158	148	-10	148	-10	10	
%			-0.29%		-0.19%	-0.24%			-0.97%		-2.48%	-1.72%			-6.33%		-6.33%	-6.33%	
Std. Dev.			1.00		0.99	0.98			2.37		2.54	2.37			1.82		1.82	1.82	

Notes:

1. Loop 1A is the upstream loop in lane 1 at the freeway.
2. Loop 1B is the downstream loop in lane 1 at the freeway.
3. Loop 2A is the upstream loop in lane 2 at the freeway.
4. Loop 2B is the downstream loop in lane 2 at the freeway.
5. Loop HOV A is the upstream loop in the HOV lane at the freeway.
6. Loop HOV B is the downstream loop in the HOV lane at the freeway.
7. Adjusted manual counts are calculated by splitting the "mid-lane traffic" between the corresponding lanes.
8. In lane 2 the average of loops 2A and 2B was selected for all but 9/28/95 and 10/12/95 because loop 2B was recalibrated after 10/12/95.

TABLE D-2 INTERSECTION LOOP CALIBRATION

Intersection Manual Counts
06-03-96,7:30 to 8:30

Time	Manual Count 1	Loop D2-3	Manual Count	Loop D2-2	Manual Count	Loop D4-1
745	177	175	38	39	19	18
800	152	152	28	28	22	22
815	142	144	27	28	27	29
830	144	142	16	17	27	25
Total	615	613	109	112	95	94
Percent Difference		-0.3%		2.8%		-1.1%

Intersection Manual Counts
09-23-96,8:30 to 9:30

Time	Manual Count	Loop D2-3	Manual Count	Loop D2-2	Manual Count	Loop D4-1
845	93	94	16	16	39	40
900	48	47	16	16	31	31
915	59	60	17	18	20	21
930	48	48	11	11	39	39
Total	248	249	60	61	129	131
Percent Difference		0.4%		1.7%		1.6%

Intersection Manual Counts
09-23-96,16:30 to 17:30

Time	Manual Count	Loop D2-3	Manual Count	Loop D2-2	Manual Count	Loop D4-1
1645	151	152	47	48	39	39
1700	126	123	56	58	44	44
1715	112	108	90	93	36	36
1730	118	120	63	64	23	23
Total	507	503	256	263	142	142
Percent Difference		-0.8%		2.7%		0.0%

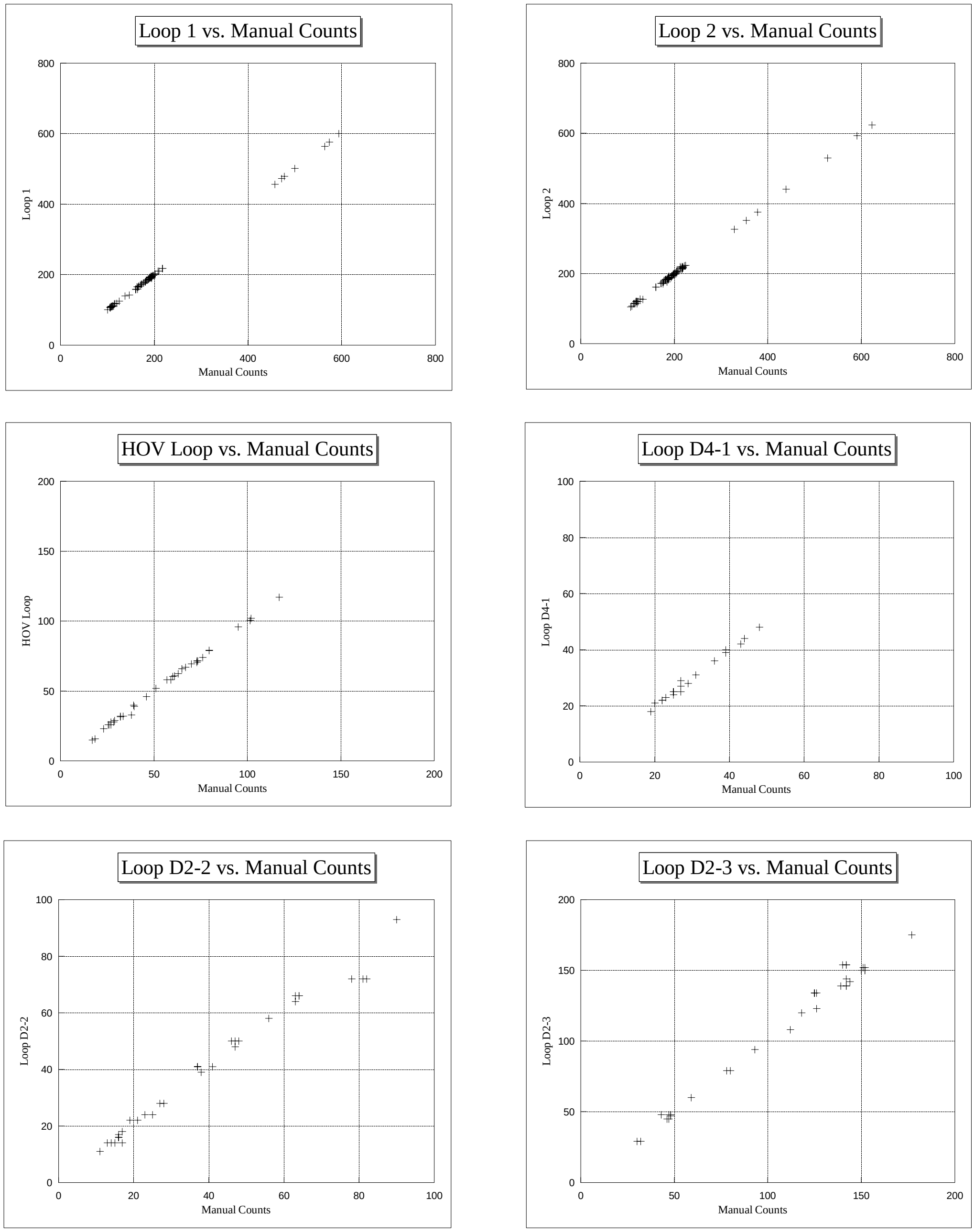
Intersection Manual Counts
12-04-96,9:30 to 10:30

Time	Manual Count 1	Loop D2-3	Manual Count 2	Loop D2-3	Manual Count 1	Loop D2-2	Manual Count 2	Loop D2-2	Manual Count	Loop D4-1
945	43	48	47	48	25	24	23	24	43	42
1000	78	79	80	79	15	14	13	14	48	48
1015	47	45	46	45	19	22	21	22	25	25
1030	30	29	32	29	17	14	14	14	22	22
Total	198	201	205	201	76	74	71	74	138	137
Percent Difference		1.5%		-2.0%		-2.6%		4.2%		-0.7%

Intersection Manual Counts
12-05-96,7:45 to 8:45

Time	Manual Count 1	Loop D2-3	Manual Count 2	Loop D2-3	Manual Count 3	Loop D2-3	Manual Count 1	Loop D2-2	Manual Count 2	Loop D2-2	Manual Count 3	Loop D2-2	Manual Count	Loop D4-1
800	142	154	140	154	142	154	64	66	63	66	64	66	29	28
815	125	134	125	134	126	134	82	72	81	72	78	72	27	27
830	139	139	142	139	142	139	48	50	47	50	46	50	25	24
845	150	150	152	150	152	150	41	41	37	41	37	41	25	25
Total	556	577	559	577	562	577	235	229	228	229	225	229	106	104
Percent Difference		3.8%		3.2%		2.7%		-2.6%		0.4%		1.8%		-1.9%

Figure D-1   Loop Calibration - Traffic Volume Scatter Plots



Note: Freeway loop calibration counts were done in both 5 and 15 - minute intervals (including: Loops 1, 2, and HOV). Intersection loop calibration counts were done only in 15 - minute intervals (including: Loops D4-1, D2-2, and D2-3).

APPENDIX E

WEATHER SUMMARY

APPENDIX F

INDUCTIVE LOOP DETECTOR SPECIFICATIONS

APPENDIX F

INDUCTIVE LOOP DETECTOR SPECIFICATIONS

I. FREEWAY TEST SITE

A total of six loops were used at the freeway test site. Two are located in each of the following lanes: lane one, lane two and the HOV lane. The upstream loop in each lane is denoted with an A and the downstream loop with a B. In the HOV lane, which is reversible, the upstream loop is defined for traffic traveling in the eastbound direction, refer to Figure 3.

The six loops were originally installed for the Hughes' *Detection Technology for IVHS* project in 1992. The following information regarding the wire loop information and details regarding their installation was obtained from Appendix G of the Hughes project's Final Report:

Manufacturer: Triangle Cable Company

Shape and size: 6 by 6 feet (1.8 by 1.8 m) rectangular

Date installed: 11/17/92

Loop construction: sawcut into concrete road surface, 1.5 inches (4 cm) deep, 12-gauge wire with 3 turns, RHW insulation, PVC conduit to handhole near edge of roadway and PVC conduit homerun to trailer, approximately 65 feet (20 m).

Mn/DOT supplied the inductive loop detectors manufactured by Sarasota which were installed in the data collection trailer. Initial calibration tests were conducted and the sensitivity settings for each loop were optimized. The final setup was as follows:

Loop Detector	Lane	Sensitivity	Home Run Distance
Sarasota 224N GP5 (4 channel)	1A	6	120 feet (37 m)
	1B	4	120 feet (37 m)
	2A	4	130 feet (40 m)
	2B	4	130 feet (40 m)
Sarasota 222N GP5 (2 channel)	HOV A	4	170 feet (52 m)
	HOV B	4	170 feet (52 m)

II. INTERSECTION TEST SITE

Of the 15 loops in place at the Penn Avenue and I-394 south ramps intersection test site, three were selected for data collection. They are located in the right turn lane of the northbound approach (D2-3), the through lane of the northbound approach (D2-2) and the through/left turn lane of the eastbound approach (D4-1) (refer to Figure 7).

The loops were installed in accordance with Mn/DOT specifications in about 1990.

The City of Minneapolis has jurisdiction over the operation of the traffic signals at the intersection and with their permission the loop detector outputs were split in the traffic signal control cabinet and brought back to the data collection trailer. After checking the loops against manual counts the sensitivities were not adjusted. They were set up as follows:

Loop Detector	Lane	Sensitivity	Home Run Distance
Sarasota 224 GP3 (4 channel)	D2-2	3	90 feet (27 m)
Sarasota 222T GP3 (2 channel)	D2-3	2	80 feet (24 m)
Sarasota 222 GP3 (2 channel)	D4-1	3	260 feet (79 m)