NIT PHASE II

EVALUATION OF NON-INTRUSIVE TECHNOLOGIES
FOR TRAFFIC DETECTION

FINAL REPORT

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EXECUTIVE SUMMARY

Introduction

The availability of reliable traffic data plays an important role in managing today’s transportation infrastructure. In urban areas, conventional methods for collecting historical and real-time traffic data are often inadequate because these methods require disrupting traffic flow to install and maintain them. These “intrusive” methods, such as inductive loop detectors and pneumatic road tubes, have become more and more problematic as traffic volumes on the nation’s roadways continue to increase. Non-intrusive technologies have emerged to challenge these conventional traffic data collection methods. As these new technologies become more mainstream, there is a need to conduct objective field tests in order to better understand their benefits and limitations.

A comprehensive project to evaluate emerging technologies is being conducted by the Minnesota Department of Transportation (Mn/DOT), with funding assistance and technical guidance from the Federal Highway Administration (FHWA). The “Evaluation of Non-Intrusive Technologies for Traffic Detection” (NIT) project is now in its second phase of testing. For Phase II, extensive field tests were conducted at the newly constructed test facility at I-394 and Penn Avenue in Minneapolis, Minnesota. The facility features an overhead catwalk and adjustable sidefire tower for evaluating sensors in a variety of mounting locations. An environmentally controlled equipment shelter houses data collection equipment.

The goals of Phase II are to develop standardized test guidelines, conduct extensive field tests of non-intrusive technologies for use in a variety of applications, and examine the deployment issues and costs associated with the technologies. This project examines the traffic data collection capabilities of each sensor, including the application to historic and Intelligent Transportation Systems (ITS) data collection purposes.

The nine sensors evaluated in this phase represent a wide variety of approaches to traffic detection. The sensors tested utilize magnetic, passive acoustic, ultrasonic, microwave, passive infrared, active infrared and video technologies. Two of the sensors combine multiple technologies into one unit. Volume, speed and presence were the primary traffic parameters evaluated. Testing was conducted in 24-hour test periods. After each test period sensors were moved to a new mounting location.

Results

There are many factors to consider when evaluating the performance of non-intrusive technologies. 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 product or technology as being the best. Rather, the reader should interpret these results against their specific detection needs. The following text highlights key features and findings for each sensor.
1. **SEO Autosense II** is an active infrared sensor that is installed above a single lane of traffic. The sensor is easy to calibrate and was very reliable during the test periods. Care must be taken during installation to ensure the sensor is aimed 5 degrees from vertical. The sensor provided accurate speed and volume results at the freeway test site.

2. **ASIM IR 254** is a passive infrared sensor that can be mounted above or to the side of the roadway to detect a single lane of traffic. The sensor is easy to install and was very reliable during test periods. Calibration is simple in an overhead installation, but was difficult to aim in a sidefire deployment. The sensor provided accurate speed and volume results at the freeway test site during off peak conditions. Volume performance was not as accurate during congested periods.

3. **ASIM DT 272** sensor utilizes two technologies – ultrasonic and passive infrared – to detect vehicles in a single lane of traffic from above or to the side of the freeway. The sensor is easy to install and calibrate. It provided accurate volume results at the sidefire freeway test site. The sensor did not perform as accurately at the overhead location. Volume performance was not as accurate during congested periods. The study’s data acquisition system had difficulties capturing data from the sensor, limiting the amount of data that was collected.

4. **ASIM TT 262** sensor utilizes three technologies – ultrasonic, passive infrared and Doppler radar – to detect vehicles in a single lane of traffic from above the roadway. The sensor is easy to install and calibrate, and was reliable during the test periods. The sensor provided accurate speed and volume results at the freeway test site.

5. **ECM Loren** is a Doppler microwave sensor that is designed to monitor multiple lanes of traffic from a sidefire location. Despite repeated efforts to calibrate and repair the sensor’s interface unit, it did not function properly in this project. The technology employed shows promise but needs refinement.

6. **3M Microloop magnetic sensors** utilize electromagnetic energy disturbances to detect the presence of traffic from beneath the pavement. The probes can be installed in conduit or under a bridge deck to detect traffic. Conduit installation can be costly, depending on the local conditions. The probes themselves are easy to install and calibrate, and were very reliable during the test periods. The sensor provided accurate speed and volume results at the freeway test site.

7. **SmarTek SAS-1** is a passive acoustic sensor that is designed to monitor multiple lanes of traffic from a sidefire location. The sensor is easy to install and calibrate, and was reliable during the test periods. Sensor aiming and mounting locations are flexible, but best performance is obtained when the sensor is aimed approximately 45 degrees from vertical. The sensor provided accurate speed and volume results at the freeway test site. Volume performance was not as accurate during congested periods.
8. Traficon Video Image Processor (VIP) is a video sensor that monitors multiple lanes of traffic from overhead or sidefire mounting locations. The sensor is easy to install and was reliable during the test periods. Calibration is an iterative process that takes time to learn how to perform effectively. The sensor provided accurate speed and volume results at the freeway and intersection test sites.

9. ISS Autoscope Solo is a video sensor that monitors multiple lanes of traffic from overhead or sidefire mounting locations. The sensor is easy to install and was reliable during the test periods. Calibration is an iterative process that takes time to learn how to perform effectively. The sensor provided accurate speed and volume results at the freeway and intersection test sites.

Conclusions

Phase II of the NIT project has furthered the understanding of non-intrusive technologies used for traffic detection. One of the unique features of this phase of testing has been the assessment of sensor performance in a wide variety of mounting configurations. Following are some of the conclusions reached in the test:

- Mounting locations were found to have varying impacts on sensor performance. Some results are readily intuitive, such as the optimal performance of video sensors occurring when the cameras are located closest to the freeway and as high as feasible. Such a location places the camera on top of the traffic as much as possible, thereby minimizing the effects of occlusion caused by vehicles blocking the view of other vehicles in adjacent lanes. Other results are not as intuitive, such as the impact mounting location had on the SmarTek passive acoustic sensor. In this case, the sensor performed best when installed at a 45-degree angle to the roadway (equal distance for both vertical height and horizontal offset between the sensor and centerline of the roadway). This location allows the sensor to receive the strongest acoustic signal when listening for the sound emanating from the tire and pavement interface.

- Volume performance at the freeway test site revealed that most sensors had an absolute error of between 2 percent and 10 percent when mounted within vendor-recommended ranges. The most accurate sensor was the SEO Autosense II with a deviation of 0.7 percent from baseline data. The ASIM TT 262, 3M Microloop, Traficon and Autoscope Solo follow closely with errors ranging from 1 percent to 5 percent.

- Speed data was collected from eight out of the nine sensors tested in the project. In general, all of the sensors were within 8 percent of the baseline data. The ASIM TT 262 and 3M Microloop were found to be the most accurate at measuring vehicle speeds.

- The SmarTek sensor was observed to undercount vehicles during periods of heavy congestion. The 24-hour count accuracy ranged from 6 percent to 12 percent at the vendor-recommended location.
• Five out of nine sensors are capable of sidefire detection. Four out of nine sensors are capable of detecting multiple lanes from a single unit.

• Video has the additional advantage of providing a view of the traffic operations at the test site. This feature is useful in system calibration and trouble-shooting as well as providing traffic operations staff with surveillance of the roadway.

• The 3M Microloop is capable of detecting traffic through a bridge deck.

• The ECM Loren sensor was not operational for most test periods and at this time is not recommended for deployment.

• In general, the variation in performance from one sensor to another is more significant than the differences from one technology to another. For satisfactory performance from a non-intrusive sensor, it is more important to select a well-designed and highly reliable product than to narrow a selection to particular technology.

Further tests of non-intrusive technologies are needed to provide ongoing information on this fast-growing field. Continued research can provide an independent evaluation of new sensors as they are brought to market. Additional testing in varied environments will provide more results on the impact that weather conditions have on sensor performance. Weather impacts were more fully examined in Phase I. Future phases of the NIT project are currently in the planning stages. A brief field test is poised to begin on non-intrusive applications to bicycle and pedestrian detection. A future project phase seeks to design, build and test a portable non-intrusive detection system. Refer to the project’s website for updated information: http://projects.dot.state.mn.us/nit/.
1. PROJECT OVERVIEW

1.1 INTRODUCTION

Historical traffic data and real-time data collection are critical components in managing today’s transportation infrastructure. New technologies have emerged to challenge conventional traffic data collection methods, such as inductive loop detectors and road tubes. Non-intrusive technologies have gained popularity because of the advantages in installation, detection and maintenance compared to conventional methods. As these new technologies continue to emerge, there is a need to conduct objective standardized field tests in order to better understand these new traffic detectors.

In response to this need, the Minnesota Department of Transportation (Mn/DOT), with funding assistance and technical guidance from the Federal Highway Administration (FHWA), implemented the “Field Test of Monitoring of Urban Vehicle Operations Using Non-Intrusive Technologies” (NIT) Project in 1994. With constant development of new traffic detection technologies and improvement in existing technologies, there is a need to conduct a comprehensive evaluation of all non-intrusive sensors available on the market today. Building on the success of Phase I study, Phase II was initiated in 2001 and has completed an extensive evaluation activity by examining new sensors and the use of non-intrusive technologies for real-time/Intelligent Transportation System (ITS) applications.

The goals of Phase II are to develop standardized test guidelines, conduct extensive field tests of non-intrusive technologies for use in a variety of applications, and examine the deployment issues and costs associated with the technologies. This project examined the traffic data collection capabilities of each sensor, including the application to historic and ITS data collection purposes.

Beginning in September 2001, non-intrusive sensors were evaluated in a variety of environmental and traffic conditions at both intersection and freeway test sites. Emphasis was placed on urban traffic conditions, such as heavy congestion, and on performance in a wide variety of mounting configurations. Volume, speed and presence were the primary traffic parameters evaluated. In addition to motorized traffic detection, detection of bicycles and pedestrians is being conducted as a follow-up phase of this project. Standardized testing criteria have been developed so that the results from this project will be directly and easily comparable to results obtained by other transportation agencies. Standard Test Guidelines were developed for the project’s Evaluation Test Plan, completed in October 2001. Refer to Chapter 2 in the Evaluation Test Plan for more information. This report is available on the project’s website at http://projects.dot.state.mn.us/nit/.

The Twin Cities metropolitan area provides an excellent opportunity to evaluate the sensors in many types of weather extremes, including very cold and hot temperatures, rain, snow and high winds. The test location is Penn Avenue and I-394 near downtown Minneapolis.
Minneapolis, Minnesota. This location offers both freeway and urban intersection test facilities.

Traffic detection sensors representing the following eight non-intrusive technology groups were evaluated:

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

1.2 BACKGROUND

Monitoring traffic volumes has been a basic element of highway program administration for over seven decades. Historical traffic volume data is used for a variety of purposes, such as traffic forecasting, traffic operations analysis and operations management. Traffic volume measurements are also valuable indicators of congestion, potential air pollutant concentrations, expected fuel tax collections and as a general indicator of economic conditions. In addition, collection of other historical traffic parameters, such as speed and vehicle classification, is also required. Finally, in conjunction with traffic monitoring, there is a need to monitor other transportation facility users, such as bicyclists and pedestrians.

Beyond the collection of traffic data for historical purposes, ITS applications require a variety of additional traffic parameters that are used in real-time applications. These parameters include lane occupancy, travel time, presence and speed data. Non-Intrusive technologies can provide these real-time performance measures for use in ITS applications such as traffic management, incident detection and signal operations.

From the early 1960s to the early 2000s, the portion of the nation’s travel that occurred on urban highways increased from 46 percent to 60 percent. Although the collection of traffic data within urbanized areas poses several challenges, the urbanization of the nation’s highway travel, as well as concerns with congestion, air pollution and intermodal coordination, makes it imperative that additional resources be directed to improving traffic monitoring programs within urbanized areas. Major impediments to urban area traffic monitoring are cost, safety and traffic disruption associated with the installation of detectors in active roadways.
This project continues the work began in Phase I, the two-year field test of non-intrusive traffic detection technologies, completed in May 1997. Phase I was initiated by the FHWA and conducted by Mn/DOT and SRF Consulting Group, Inc. (SRF). It compared alternatives to conventional roadway-based sensor technologies by the use of non-intrusive technologies. Seventeen sensors representing seven different technologies were evaluated in varying environmental and traffic conditions. Testing was done on both urban freeway and intersection locations. The evaluation involved primarily volume and speed data with some vehicle classification data. The evaluation also focused on ease of system setup and use, general system reliability and system flexibility. Information regarding the utility and cost-effectiveness of these sensors was published in the Final Report dated May 1997. For more information, refer to the Phase I Final Report at Mn/DOT’s Minnesota Guidestar website at www.dot.state.mn.us/guidestar or at the project’s website at http://projects.dot.state.mn.us/nit/.

In June 1997, Mn/DOT circulated a questionnaire to over 400 individuals who expressed interest in the results of the NIT research. Over 95 percent of those responding expressed a need for continuing the NIT testing and evaluation and the need to initiate objective testing and evaluation of sensing technologies. Nearly one-half of the responders expressed an interest in serving on either a Technical Working Group (TWG) or a Technical Analysis Group (TAG). The responders represented state agencies, cities, other countries, technology manufacturers, university research entities and consultants engaged in designing and installing traffic detection technologies.

In late 1997, a TWG comprised of practitioners from state and international DOTs, metropolitan planning organizations and academic institutions convened to determine the direction of the follow-up project. In addition to the Phase I focus on historic data collection for planning, the TWG recommended that Phase II investigate ITS data collection applications. The TWG continues to provide guidance and develop policy for this project.

In order to improve upon the facilities available in Phase I, Mn/DOT built a permanent test shelter at the test site. Refer to the section titled Project Test Site Description for more information. After completing construction of the shelter in April 2001, the data acquisition system was installed and the sensors were procured, installed and pre-tested through the summer of 2001. The official freeway data collection lasted from October 2001 to early March 2002. The intersection test was then conducted in late March 2002.

1.3 PROJECT GOALS AND OBJECTIVES

The primary goal of the NIT project is to compare non-intrusive vehicle detection technologies with conventional roadway-based vehicle detection technologies. Sensors were evaluated for use in ITS and other applications. Specific goals and their supporting objectives are listed below:

Goal 1: Develop Standardized Evaluation and Reporting Procedures

Objective 1-1: Develop Standardized Test Procedures
Objective 1-2: Develop Standardized Statistical Analysis Procedures
Objective 1-3: Develop Standardized Report Guidelines
Goal 2: Assess the Performance of Non-Intrusive Technologies in Historical Data Collection Applications

Objective 2-1: Assess Performance in Various Mounting Configurations
Objective 2-2: Assess Performance in Various Traffic Conditions
Objective 2-3: Assess Performance in Various Roadway Environments
Objective 2-4: Assess Performance in Various Weather Conditions
Objective 2-5: Assess Performance in Detection of Motorized Traffic
Objective 2-6: Assess Performance in Detection of Non-Motorized Traffic
Objective 2-7: Assess Performance in Detection of Trains

Goal 3: Assess the Performance of Non-Intrusive Technologies in ITS Applications

Objective 3-1: Assess Performance in Various Mounting Configurations
Objective 3-2: Assess Performance in Various Traffic Conditions
Objective 3-3: Assess Performance in Various Roadway Environments
Objective 3-4: Assess Performance in Various Weather Conditions
Objective 3-5: Assess Performance in Detection of Motorized Traffic
Objective 3-6: Assess Performance in Detection of Non-Motorized Traffic
Objective 3-7: Assess Performance in Detection of Trains

Goal 4: Document Non-Intrusive Technology Deployment Issues

Objective 4-1: Document Installation Issues
Objective 4-2: Document Maintenance Issues
Objective 4-3: Document Operational Issues

Goal 5: Document Non-Intrusive Technology Costs

Objective 5-1: Document Sensor Cost
Objective 5-2: Document Installation Cost
Objective 5-3: Document Maintenance Cost
Objective 5-4: Document Operational Cost

1.4 Definition of Non-Intrusive Technologies

Non-intrusive technologies, as defined for the purposes of this test, are traffic detection sensors that cause minimal disruption to normal traffic operations during installation, operation and maintenance as compared to conventional detection methods, and can be deployed more safely than conventional detection methods. Based on this definition, non-intrusive sensors refer to those sensors that do not need to be installed in or on the pavement, but can be mounted overhead or to the side of the roadway. In addition, sensors that are installed beneath the pavement by “pushing” a conduit under the roadway are considered non-intrusive for the purposes of this evaluation.
1.5 **ROLE OF NON-INTRUSIVE TECHNOLOGIES**

Comprehensive traffic information on the use of transportation facilities in urban areas provides the basis for many of the decisions made regarding the transportation infrastructure. The traditional methods of urban traffic data collection are used at both fixed locations and temporary locations. Inductive loops cut into the pavement are typically used for long-term data collection at fixed locations. They serve many of the detection requirements of transportation planning, traffic operations and ITS applications. Road tube counters and manual counts are typically used at temporary locations where only a short period of data collection is needed. They are normally used to collect peak hour traffic for traffic operation analysis and to develop Average Daily Traffic.

Non-intrusive technologies play an important role in meeting the detection requirements for both historic and real-time applications. The feasibility of conventional versus non-intrusive detection methods depends on the application under consideration. A traffic operations system in an urban area may require frequent detection stations, making it very difficult to implement conventional roadway-based detection.

The difficulties and limitations of traditional data collection methods in urban areas include the following:

- All intrusive technologies have safety problems. For example, on very congested freeways and arterials, volumes may be high 24 hours per day, not providing a window for safe installation. Staff safety is also a concern when road tubes must be set where traffic volumes are high during daylight hours and relatively high during nighttime hours. Field personnel conducting manual counts are 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 their personal safety.

- Depending on when they are installed, loop detectors are cut into the pavement, often resulting in premature pavement failure. Even when the installation is under the final overlay, replacement loops must be saw cut when the original loops fail.

- Installing intrusive technologies on moderate- or high-volume roadways will result in traffic disruption. Temporary closure of traffic lanes is needed to provide safety for personnel installing road tubes or inductive loop detectors. Any necessary maintenance or inspection will inevitably cause traffic disruption or lane closure.

- Cost limits the number of locations where fixed counting stations can be located. There are not sufficient resources available for enough fixed counting stations to provide for all of the traffic detection needs in an urban area. Also, there are counts, such as turning movement counts, complex weaving section movements, vehicle occupancy counts, etc., where the fixed loop detectors typically cannot provide the data needed. Emerging NIT sensors can collect this data.

- Roadway geometrics can make it difficult to obtain accurate counts using intrusive technologies. These include geometrics where there is significant lane changing or
where vehicles do not follow a set path in making turns. They also include situations where turning movement counts are needed over long periods of time, making manual counts and use of road tubes not feasible.

- Arterial geometrics with multiple-lane roads are difficult to count with road tubes because they must be laid across more than one lane. Road tubes are also difficult to use on roads with curb and gutter. Road tubes may double-count if vehicles strike them at an angle.

- Inductive loop detectors can be a problem if vehicles do not track in the center of the lane; drivers traveling to the right or left of the center may be double-counted because the influence area of a loop extends beyond the physical dimensions of the loop. Weaving sections are also a problem; vehicles may be double-counted or missed altogether. This is particularly problematic in urban areas. In general, straight, level and basic freeway sections must be selected for traditional data collection. Emerging NIT sensors may be able to monitor traffic in these conditions.

- Environmental conditions, such as rain or snow, cause wet pavement that inhibits the use of road tubes. Also, any sensor that is placed on the pavement, such as magnetometers, piezos or road tubes, is susceptible to being damaged by snow removal equipment or street sweepers. In very high or low temperatures, the ability to use manual counts is limited. The traditional intrusive road tube methods are also a problem in these extreme conditions. Low temperatures also hamper tube and weigh-in-motion accuracy, and shorten battery life. Solar panels are less effective in winter months.

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

- Collecting data through direct observations by field personnel has a number of drawbacks, cost being the most significant. In addition, lighting conditions and staffing limitations can cause difficulties for manual counts. Limited vantage points can cause difficulties for manual counts. Some valuable traffic data is not collected, because it is impractical using traditional methods.

Despite these drawbacks, traditional methods do have some advantages over new technologies. For example, inductive loop detectors are very accurate when operating correctly. This is largely due to the fact that the technology has matured from over several decades of use. Also, transportation professionals are very familiar with the operational and maintenance issues of loops and other conventional data collection methods. Ultimately, all of these factors should be considered when selecting a method of traffic detection.
1.6 DESCRIPTION OF NON-INTRUSIVE TECHNOLOGIES

The non-intrusive technologies identified for evaluation include passive infrared, active infrared, magnetic, radar, Doppler microwave, pulse ultrasonic, passive acoustic and video sensors. Each of these technologies has been used in traffic-related applications. However, none of these technologies has been used extensively to replace the traditional methods of traffic data collection in urban areas.

All but ultrasonic and acoustic applications utilize some form of electromagnetic energy to detect the presence of a vehicle. Video image processors using visible spectrum imagery exploit the shortest electromagnetic energy wavelengths; followed by active infrared, passive infrared, microwave and magnetic detectors, which use comparatively long electromagnetic energy wavelengths.¹

Passive sensors do not transmit energy, but rather detect energy that is emitted by the vehicles and roadway or is reflected from them. The magnetometer, another type of passive detector, detects perturbations in the Earth’s magnetic field caused by metallic components in vehicles. Active sensors transmit energy, a portion of which is reflected or scattered from the vehicle and roadway back toward the sensor. The inductive loop detector is, in principle, an active sensor as it detects changes in the electromagnetic field created near the sawcut. Ultrasonic and acoustic sensors detect pressure waves in the form of sound energy.²

Rather than evaluating the performance of each technology group (i.e., ultrasonic detectors versus passive infrared detectors), all of the sensors in this test were evaluated against the baseline data. Any general observations of a technology’s performance are noted, but this is not a formal objective of this evaluation.

A brief overview of the principles, stated capabilities and limitations of each type of technology are described below. Other sources provide a more thorough description of each technology. Interested readers are encouraged to consult the Traffic Detector Handbook by the FHWA and JHK & Associates, the Detection Technology for IVHS by the FHWA and Hughes Aircraft Company, or the soon-to-be-published Sensor Technologies and Data Requirements for ITS by Dr. L. A. Klein.

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¹ Klein, L. A., Sensor Technologies and Data Requirements for ITS
² Ibid
1.6.1 Magnetic

Basic Principles of Operation

Magnetometers are passive sensors that detect perturbations in the Earth’s magnetic field caused by the metallic components of vehicles. There are two major types of magnetometers: induction magnetometers and dual-axis magnetometers. Induction magnetometers sometimes referred to simply as magnetic detectors, measure changes in the magnetic flux lines when metal components in a vehicle, especially the engine, travel past the detection zone. Other components of a vehicle, such as the alternator, also create changes in the magnetic field. The magnetic flux change can be observed by measuring the corresponding changes in the electric current induced in the sensor. These current fluctuations give an imprint of the vehicle’s presence, but cannot detect stopped vehicles. Dual-axis fluxgate magnetometers detect changes in the horizontal and vertical components of the Earth’s magnetic field caused by the passage or presence of a vehicle. This type of sensor can detect both moving and stationary vehicles.

Stated Capabilities

Magnetic sensors can detect volume, classification, headway, presence and speed with algorithms or two sensors in a speed trap configuration.

Limitations

Magnetic sensors that attach to the surface of the roadway are subject to damage and/or dislocation caused by normal road traffic or equipment, such as street sweepers and snow plows. Sensors that mount underneath the pavement require boring to install conduit. Some induction magnetometers cannot detect stopped vehicles.

1.6.2 Infrared – Passive and Active

Basic Principles of Operation

Infrared sensors detect infrared radiation (electromagnetic radiation with a frequency range of $10^{11}$ to $10^{14}$ Hertz) that reaches the detector. There are two basic types of infrared sensors. The first type, passive infrared sensors, detect the changes in infrared energy emitted or reflected from a target area. They detect the difference between the baseline amount of infrared energy emitted and reflected from the pavement and the vehicle’s emitted and reflected infrared energy as it passes through the target area.

The second type, active infrared sensors, transmit low-energy laser beam(s) to a target area on the pavement and measure the time for the reflected signal to return to the sensor. The presence of a vehicle is measured by the corresponding reduction in time for the signal return.

Infrared detectors work well in both day and night conditions. They are not affected by sun glint, elongated shadows or headlight glare. Long wavelength passive infrared sensors can potentially see through rain, snow and fog better than visible light.
Stated Capabilities
Passive infrared sensors can detect volume, presence, occupancy and speed in sensors with multiple detection zones.

Active infrared sensors can detect volume, presence, density, classification and speed.

Limitations
Active near-infrared laser sensors are generally limited to the same range in inclement weather as can be seen with the human eye.

Current Applications
Passive infrared sensors can be used in solar powered large-scale traffic data acquisition systems, intersection applications (request an extension of green phase) and in many military and security applications.

Active infrared or laser range finder technology is used in a wide range of applications, including measuring vehicle emissions, military targeting, aircraft obstacle avoidance and spacecraft docking. (Olson, et. al. 1994)

1.6.3 Microwave Radars and Passive Millimeter-wave Radiometers

Basic Principles of Operation
Continuous-wave Doppler microwave radar sensors 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. However, Doppler sensors cannot detect the presence of motionless objects, such as stopped vehicles.

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

A related type of sensor, the passive millimeter-wave radiometer, operates at a shorter wavelength than microwave sensors. Similar to the passive infrared sensor, it detects the difference between the baseline amount of energy emitted and reflected from the pavement in the millimeter-wave band of the sensor and a vehicle's emitted and reflected energy in the millimeter-wave band of the sensor as the vehicle passes through the detection area of the sensor.

Stated Capabilities
Doppler microwave sensors can detect volume and speed.

Radar microwave sensors can detect volume, presence and speed.
Limitations

Doppler microwave sensors can only detect vehicles moving faster than a certain minimum speed. Minimum speeds vary from sensor to sensor.

The Texas Department of Transportation has developed a Microwave Vehicle Presence Detection Specification. The purpose of this document is to establish minimum performance criteria for microwave traffic detectors. This specification provides detailed requirements that should be considered when selecting microwave traffic sensors. It is included in Appendix F for a reference.

1.6.4 Passive Acoustic and Ultrasonic

Basic Principles of Operation

Sonic or passive acoustic sensors use a receiver to detect the sound energy created by passing vehicles to determine their presence. The technology also has the potential to classify vehicles by comparing the sonic signature created by the passing vehicle with a set of preprogrammed sonic signatures of various classes of vehicles. Passive acoustic sensors have the advantage of working equally well in all environmental conditions. They are also completely passive, only receiving sound.

Ultrasonic sensors transmit ultrasonic waves (sound pressure pulses with a frequency above 20,000 Hertz) at a target area on the pavement, which is then reflected back to the ultrasonic receiver. There are two basic types of ultrasonic sensors. The first type, pulse ultrasonic sensors, measure the time it takes for a portion of the sound energy to be reflected from the target area to a receiver. The time taken for the ultrasonic pulse to be reflected to the receiver is analyzed and compared to the time taken for the reflected pulse to return from the baseline roadway in the target area to determine the presence, length and height of a vehicle. The result is a determination of vehicle volume, presence, classification and occupancy.

The second type, continuous wave ultrasonic sensors, output a continuous ultrasonic signal at the target area and uses the Doppler principle to analyze the reflected signal. The Doppler principle refers to the phenomena that the frequency of the reflected signal changes due to the speed of the object reflecting the ultrasonic energy. This change in frequency from the baseline reflected frequency is used to identify the presence of a moving object in the target zone and to calculate the speed of the object.

Stated Capabilities

Passive acoustic sensors can detect volume, speed and occupancy.

Doppler ultrasonic sensors can detect volume, presence and speed.

Pulsed ultrasonic sensors can detect volume, presence, classification and occupancy.
Limitations

Sonic or passive acoustic sensors are limited by environmental conditions that inhibit the propagation of sound waves. Such conditions include strong winds and heavy snowfall or precipitation. Loud vehicles, such as trucks traveling in adjacent lanes, can give false readings. The nature of sound propagation limits the detector to short-range uses. Finally, some pulse ultrasonic sensors have difficulty measuring the lane occupancy of fast-moving vehicles.

1.6.5 Video

Basic Principles of Operation

Video-based detectors use a microprocessor to analyze the video image input. Video detection sensors use different approaches. Some analyze the video image of a target area on the pavement. The change in the image of the target area as a vehicle passes through the target area is processed. Another approach identifies when a target vehicle enters the video field of view and tracks the target vehicle through this field of view. Still other video sensors use a combination of these two approaches.

Stated Capabilities

Videos sensors can be used to collect volume, speed, presence, occupancy, density, queue length, dwell time, headway, turning movements, lane changes and classification.

Limitations

Environmental conditions that affect the video image quality can reduce system performance. Such conditions include fog, rain, dust or snow in the air; frost, condensation or dirt on the camera lens; and adverse lighting conditions, such as headlight glare on wet pavement, low-angle sunlight, poor vehicle-road contrast and headlight reflection on curved roadways. Proper setup and calibration is critical to achieving satisfactory performance in poor lighting conditions.

1.7 Vendor Participation and Sensors

1.7.1 Vendor and Sensor Identification

An extensive database of vendors that manufacture non-intrusive technologies has been developed. This database includes vendors from the United States and around the world. These vendors were first contacted in April 2000 to identify candidate sensors and determine interest in participating in phase II of the NIT project. This list was compiled from a variety of sources: sensors tested in other related test projects, information obtained from the TAG and TWG, a review of professional journals, an extensive internet search, and information provided by the FHWA and project team members. Table 1 lists the vendors that participated in the evaluation. Refer to Appendix A for a list of sensors for which detailed information has been compiled and Appendix B for an extensive list of vendors. Figures 1 through 10 show all the sensors tested in the project.
### TABLE 1
SUMMARY OF PARTICIPATING VENDORS AND SENSORS

<table>
<thead>
<tr>
<th>Vendor / Sensor</th>
<th>Technology</th>
<th>Sensor Features&lt;sup&gt;(1)&lt;/sup&gt;</th>
<th>Volume</th>
<th>Speed</th>
<th>Presence</th>
<th>Occupancy</th>
<th>Classification</th>
<th>Headway</th>
<th>Incident Detection</th>
<th>Lane</th>
<th>Mounting OH/SF</th>
<th>Power Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEO Autosense II</td>
<td>Active Infrared</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>OH</td>
<td>115 VAC</td>
</tr>
<tr>
<td>3M Microloop</td>
<td>Magnetic</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>1&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>Under Pavement</td>
<td>12-24 DC</td>
<td></td>
</tr>
<tr>
<td>ECM Loren</td>
<td>Microwave</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>3</td>
<td>SF</td>
<td>12 VDC</td>
</tr>
<tr>
<td>SmarTek SAS-1</td>
<td>Passive Acoustic</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>SF</td>
<td>12-24 VDC</td>
</tr>
<tr>
<td>ASIM IR 254</td>
<td>Passive Infrared (PIR)</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>1</td>
<td>OH/SF</td>
<td>12 VDC</td>
</tr>
<tr>
<td>ASIM DT 272</td>
<td>PIR/Ultrasonic</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>OH/SF</td>
<td>10-15 VDC</td>
</tr>
<tr>
<td>ASIM TT 262</td>
<td>PIR/Ultrasonic /Radar</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>1</td>
<td>OH</td>
<td>12 VDC</td>
</tr>
<tr>
<td>ISS/TCC Autoscope Solo</td>
<td>Video</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>&gt;12</td>
<td>OH/SF</td>
<td>24 VAC</td>
</tr>
<tr>
<td>Traficon VIP</td>
<td>Video</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>&gt;12</td>
<td>OH/SF</td>
<td>5 VDC</td>
</tr>
</tbody>
</table>

Notes:
- OH: Indicates a sensor can detect traffic from an overhead mounting location
- SF: Indicates a sensor can detect traffic from a sidefire mounting location
- X: Denotes a sensor that has the capability of collecting the stated data
- <sup>(1)</sup>: Not all features were evaluated as a part of this project
- <sup>(2)</sup>: 3M Microloop can monitor multiple lanes of traffic by inserting additional probes under each lane
Figure 1: ASIM - IR 254

Figure 2: ASIM - TT 262
Figure 3: ASIM - DT 272

Figure 4: SEO - Autosense II
Figure 5: Autoscope Solo

Figure 6: Traficon
Figure 7: ECM - Loren

Figure 8: SmarTek
Figure 9: 3M - Microloop

Figure 10: Spectra - NTMS
1.7.2 Selection Criteria

The following criteria were used to determine which sensors were considered for the NIT project:

1. The sensor must cause either no disruption or very minimal disruption to normal traffic operations and must be capable of deployment with improved safety (compared to conventional detection methods). The sensor must be purely non-intrusive by being mounted overhead, to the side or beneath the pavement and not requiring cutting into the pavement.

2. The sensor must be currently available in either 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.

3. The manufacturer/vendor must be willing to provide technical support for the sensor during installation as well as during the initial test period. The initial test does not include sensor “development” time, so installation and setup must be reasonably simple.

4. The sensor must have outputs that are “reasonably” compatible with existing data collection programs and sensors. Outputs should be capable of being loaded into a database without significant manual manipulation or manual data input. Where possible, wireless data transmission capabilities should be tested.

5. The sensor must have a production and total deployment cost that is reasonably cost-effective. This cost-effectiveness is based on the sensor’s capabilities for its intended application (temporary or permanent) in comparison to traditional counting methods.

The vendors having the potential to meet these criteria were invited to participate in the evaluation. Through this contact, each vendor provided technical details of each product, status of each product (commercially available, fully developed and tested prototype or in initial development stage), and interest in participating in the test.

1.7.3 Benefits of Participation

There is a tendency for some of the vendors to be skeptical of “yet another test program” because they feel there have been enough tests of these sensors. The vendors of commercially available sensors generally indicated that they would like to see a more rapid incorporation of these sensors into use, rather than continued testing programs. For this reason, it is important to emphasize the distinction between this test and the other evaluations.
The distinctions between this test and other detection sensor tests are as follows:

- This test focuses on using the sensors for a variety of applications. These include detection of historic traffic data, traffic operations and ITS applications.

- This project tests a wide variety of sensors simultaneously. Many other field tests have tested only a few sensors at a time.

- This test uses several techniques to gather extensive baseline data against which the performance of the sensors will be compared, providing a permanent record of the sensor and baseline data to the vendors.

- The test results are available on a monthly basis. Each vendor was provided with the output from their sensor(s) and output from the baseline data. In addition, a video record was available, which combined the view of the roadway target area and the response of the detectors. The detector responses were coded and each vendor is told only the code for their sensor(s).

- The test provides a long-term test bed for vendors to evaluate their products in a wide variety of environmental conditions, traffic conditions and mounting configurations. The test serves as an additional means to assist in the development of their products. It was made clear to all vendors that every effort will be made to provide them with valuable data on a timely basis in return for their participation in the test.

- The test focuses on evaluating the capabilities of the various sensors and evaluates the relative cost effectiveness of the sensors for the appropriate types of traffic data collection efforts.

Vendors participating in the NIT project realize two primary benefits:

- Participating in the evaluation yields valuable information on sensor performance in a variety of real-world weather, mounting and traffic conditions. Vendors participating in the first phase found this information useful in product development efforts.

- Evaluation results are widely distributed to transportation practitioners via the project’s website and by quarterly evaluation reports.

1.8 Project Test Site Description

The NIT test site is located at I-394 and Penn Avenue in Minneapolis, Minnesota, the same location used in Phase I. This site includes freeway and intersection roadway traffic, and bicycle and pedestrian trails. A nearby railroad corridor allows for expansion to include train detection. Figure 11 illustrates the NIT test site location.
Figure 11: NIT Project Test Site Location
The freeway test site features both overhead and side mounting locations. A catwalk was installed on the Penn Avenue Bridge for Phase II of this project to provide access for installing sensors above the three eastbound lanes of Interstate 394. Sensors were installed on three mounting poles attached to the catwalk, one over each lane of traffic, facing departing traffic. The poles are adjustable to allow testing at heights ranging from 20 to 30 feet (6 to 9 meters) above the pavement. In addition, an aluminum adjustable tower was deployed for testing sidefire-installed sensors. The crank-up tower can be extended to accommodate mounting heights ranging from 5 to 45 feet (2 to 14 meters) and be moved among three bases with offsets of 15, 25, or 35 feet (5, 8, or 11 meters) from the edge of the nearest lane of I-394. In-place inductive loops on I-394 provide baseline data. Figure 12 illustrates the catwalk on the bridge and Figure 13 shows the aluminum tower on sidefire.

The intersection test site is located at the nearby signalized intersection of Penn Avenue and the I-394 south ramps. Sensors were installed in two locations: the northeast light pole observing traffic data on northbound approach and the northwest light pole observing traffic data on the eastbound exit ramp. Both approaches have in-place loops that provide baseline data for evaluation. Figure 14 demonstrates the intersection test site layout.

Two test sites have been identified for future bicycle and pedestrian detection. The first is the intersection of Penn Avenue and the I-394 south ramps. This location provides sensor evaluation in typical pedestrian and bicycle detection applications at signalized intersections. The second test site is the Cedar Lake Trail. This is a bicycle and pedestrian commuter facility located within one-half mile of the NIT test site. The trail includes a pedestrian lane and two bicycle lanes. The lanes are physically separated on parts of the trail and delineated with paint on others. The proposed test site is on the western end of the I-394 underpass. An in-place trail counting station is located to provide loop detectors for baseline data. Evaluation activities are currently underway at the Cedar Lake Trail facility.
Figure 12: Catwalk for Overhead Mounting

Figure 13: Aluminum Tower for Sidefire Mounting
Figure 14: Intersection Test Site
Infamous Minnesota weather conditions provide a host of weather extremes, including high winds, rain, fog, sleet, snow and a wide variety of temperature conditions. In addition, the NIT site offers a significant range of traffic conditions: 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 offers a variety of lighting conditions, depending on the time of year. Low-angle sunlight creates long shadows in the winter and bridge shadows year-round. All of these conditions create a challenging test environment. A photograph of the test site is provided in Figure 15.

Figure 15: NIT Test Site
1.9 **PROJECT TEAM DESCRIPTION**

The project team is comprised of individuals from the following agencies/organizations: FHWA, Mn/DOT (Office of Traffic Engineering/ITS, Office of Management Data Services, Electrical Services Section and the Traffic Management Center), the City of Minneapolis, the University of Minnesota’s Center for Transportation Studies and SRF Consulting Group, Inc. Project Team members include the following:

- Ralph Gillman, FHWA – Federal FHWA Representative
- Jeff Patten, FHWA – Federal FHWA Representative
- James McCarthy, FHWA – Local FHWA Representative
- Farideh Amiri, Mn/DOT Office of Traffic Engineering/ITS Section – Mn/DOT Project Manager
- James Kranig, Mn/DOT Office of Traffic Engineering/ITS Section – Project Team Member
- Tom Peters, Mn/DOT Office of Traffic Engineering/ITS Section – Project Team Member
- Curt Dahlin, 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
- Jim Aswegan, Mn/DOT Metro Division Freeway Operations Section – Project Team Member
- Beverly Farraher, Mn/DOT Metro Division Traffic Section – Project Team Member
- Sarah Kline-Stensvold, Mn/DOT Network Operations – Project Team Member
- Curtis Gobeli, Mn/DOT Electrical Services Section – Project Team Member
- Marlin Reinardy, Mn/DOT Electrical Services Section – Project Team Member
- Dave Long, Mn/DOT Electrical Services Section – Project Team Member
- Steve Mosing, City of Minneapolis – Project Team Member
- Ted Morris, University of Minnesota, CTS – Project Team Member
- Brian Scott, SRF Consulting Group, Inc. – Project Team Member
- Erik Minge, SRF Consulting Group, Inc. – SRF Project Manager
- Bingwen Hao, SRF Consulting Group, Inc. – Project Team Member
- Bruce Shriver, SRF Consulting Group, Inc. – Project Team Member
One of the project goals is to make the NIT evaluation results a valuable source of information to a variety of transportation professionals. Emphasis is placed on those individuals responsible for routine traffic data collection. To this end, the test results will be presented in a readily accessible format and will include discussion of the installation and maintenance requirements of each detector. In addition, ITS practitioners require more detailed information on the real-time performance and descriptions of data flow. Finally, other project audiences will require more detailed information regarding performance under a variety of operating conditions. The following project audiences have been identified:

- Data collection practitioners
- Traffic operations practitioners
- ITS practitioners
- Professional organizations
- Transportation agencies
- Academia
2. FIELD TEST METHODOLOGY

2.1 INTRODUCTION

This chapter presents an overview of the test procedures that were used to evaluate the non-intrusive technologies tested in this project. The major components in this chapter include the data acquisition system, baseline data ground-truth description, sensor data collection, test conditions and data analysis. Also included in the following section is a discussion national standards. The basic approach for this evaluation is to utilize a comparative test between baseline data and sensor data for various traffic parameters. The approach used here is derived from the Standard Test Guidelines that were prepared earlier in the project. The objective driving the standardized testing criteria is to ensure that the results obtained in this evaluation can be directly and easily compared to results obtained by other transportation agencies. Standard testing will create an environment of continuity and ultimately reduce the amount of testing that must be conducted. Refer to chapter 2 of the previously published Evaluation Test Plan. This document is available on the project website at http://projects.dot.state.mn.us/nit/.

2.2 NATIONAL STANDARDS

Within the last several years, emphasis has been placed on producing traffic and transportation hardware that is transferable among competing vendors. Such standards are intended to result in hardware components that are not dependant on a manufacturer’s proprietary protocol. Several standards are documented as follow. These are included as a reference.

NTCIP: The National Transportation Communications for ITS Protocols (NTCIP) standardization will help establish system interoperability and integration. NTCIP standards aim to provide common protocol for different types of equipment to communicate. This will allow equipment to mix and communicate between systems operated by adjacent agencies. NTCIP Traffic Sensing System (TSS) is defined as any system capable of detecting and communicating certain traffic parameters using NTCIP. A TSS includes a range of sensors, from simple presence detectors to more sophisticated sensors that provide a variety of traffic parameters. For more information on the NTCIP TSS standards refer to www.ntcip.org. The NTCIP TSS working group has developed the NTCIP Object Definitions for Transportation Sensor Systems, which is available for review at this site.

ASTM: The American Society of Testing Materials (ASTM) is in the process of developing standard test methodologies for evaluating traffic sensors. The ASTM subcommittee E17.52 is preparing this methodology. While this effort only addresses conventional vehicle data collection methods (road tubes, piezo-electric devices, inductive loop detectors, and tape switches), the results will also be applicable to non-intrusive technologies. The ASTM initiative includes procedures for field and bench testing, desired sensor performance standards, and methods for documenting test results. The E17.52 subcommittee is preparing the Draft Standard Test Method for Validating
Vehicle Data Collection Devices for Vehicle Counts and Classifications and also a Standard Specification and Test Method for Highway Traffic and Monitoring Devices. Among other things, the latter document defines standard terminologies that are used to characterize vehicles and traffic flow. The document also specifies test methods for validating operation and performance of traffic monitoring devices. For more information refer to www.astm.org.

FCC: Traffic sensors must also meet Federal Communication Commission (FCC) regulations. In particular, FCC Rules and Regulations Part 15 covers the radiated signals of electronic devices and class B digital devices. The purpose of Part 15 is to limit the maximum electric field strength from such devices to prevent unintentional interference to other services. The regulations require that all intentional radiators, such as inductive loop detectors, be tested for compliance and certified and registered with the FCC before being offered for sale or manufactured. The FCC has stated that vehicle traffic counters that employ inductive loop technology are considered intentional radiators under 47 CFR 2 and 15. In addition, microprocessors contain high frequency clocks, which, if not properly filtered, can emit high frequency signals that can cause interference on connecting cables. Sensor manufacturers should certify that their equipment meets Part 15 requirements. Such equipment must be compliant with all pertinent or applicable FCC Rules and Regulations. The Part 15 Rules and Regulations are located at www.fcc.gov/oet/info/rules. See sections 15.107 and 15.109.

2.3 DATA ACQUISITION SYSTEM

The data acquisition system developed for the second phase of the NIT project consists of both hardware and software components. The hardware components include five personal computers, a television, three videocassette recorders (VCR), a standard hardware equipment rack, a PEEK Automatic Data Recorder (ADR), and a terminal panel providing power and communications interfaces between sensors and shelter. The software includes detector interfaces, ADR data process interface and real-time data acquisition software custom-built by SRF Consulting Group for this project.

2.3.1 Data Acquisition Hardware

- Personal computers: used for sensor calibration, data downloading, data storage and data processing through each sensor’s interface software.

- Television: used for traffic monitoring and video detector calibration.

- VCRs: used for recording traffic images during official 24-hour data collection periods. Three VCRs enabled recording over a 24-hour period by using eight-hour tapes.

- Equipment rack: used to hold data acquisition components such as TV, VCRs, AC power supplies, loop detector cards, vendor detector cards/processors and the Automatic Data Recorder.
- PEEK ADR 3000: used to collect all of the loop emulation relay outputs into a single database. It allowed for the collection of all data outputs simultaneously. The ADR was programmed to collect the data from detectors and baseline loops in 15-minute intervals for each 24-hour data collection period.

- Terminal panels: used for power supply and communication interface between the shelter and sensors installed in the field. Terminal panels were installed both in the shelter and in junction boxes on the catwalk and sidefire tower. Terminal ends were numbered in both the shelter and in the junction boxes on the catwalk and sidefire tower.

Figure 16 illustrates the shelter layout.

![Figure 16: Shelter Schematic Layout](image)

### 2.3.2 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 detections of this traffic from each sensor. A data acquisition software interface for this purpose was developed by SRF. 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 17 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 sensor. These tapes were made available to vendors for their use.
In addition to displaying the real-time contact closures on the user interface, the data was also written to a database for off-line analysis. The state change of each relay input was time stamped and coded. This allowed the database to be searched to select all sensor inputs for a given lane over a given time period. Each detection zone’s occupancy values were obtained by measuring the amount of time that a relay was "on". For a given space between two zones, speed was calculated by measuring the time between a vehicle arrival at the upstream zone and arrival at the downstream zone. Volume data was also be collected by counting the number of events in a given time period.

During the course of developing the data acquisition system an inherent timing accuracy of 0.01 seconds was identified in the system. This means that contact closure events are time-stamped to the nearest 0.01 second, resulting in a measurement precision that impacts some data analysis efforts. For example, a 0.01 second precision generates error in speed calculation of approximately 10 percent for vehicles traveling at 60 mph.

Figure 17: Data Acquisition Software
2.4 Baseline Data Collection

2.4.1 Ground-truth Source

Baseline data sources were carefully ground-truthed using manual observations in order to precisely state the benchmark against which the non-intrusive technologies were tested. For volume, traffic flows were videotaped so that the tape could be counted multiple times in order to obtain the desired 95 percent confidence interval. For speed, a calibrated probe vehicle was driven through the loop detection area.

2.4.2 Inductive Loop Detectors as Baseline Source

The freeway loop detectors provide baseline data for volume, speed and occupancy. Since the intersection loops are not arranged in a “speed trap” configuration, they only provide volume data. The loop detectors were carefully ground-truthed at the beginning of the evaluation. Additional observations were made every two months in order to identify any change in performance over the course of the evaluation.

**Volume** – Loop detector and video image data were collected in 15-minute increments with a synchronized starting time during four one-hour periods of the day and on several different days. The first observation was made during the morning peak period, second from mid-day traffic conditions, third from the afternoon peak period and the fourth extracted from evening traffic conditions. Two observers counted the tapes as many times as necessary to obtain the desired 95 percent confidence level. The tape was stopped as often as needed to accurately record vehicle-by-vehicle data and allow one lane to be observed at a time. The videotapes reduced counting fatigue and ensured the confidence level of the manual observation. Multiple counts identified the amount of human error present in the observation. In general, the difference from one observer to another was within only a few vehicles per 15-minute period. The average manual value was used for comparison with loop values.

Two project personnel manually counted a total of 46 hours of videotapes over the course of several ground-truth periods. At the freeway, comparison to loop values revealed a difference that ranged from 0.1 percent to a worst case of 3 percent during one one-hour observation period. Most of the hourly percent differences were less than 2.0 percent. At the intersection, the loop was found to vary from 2.8 percent to 8.6 percent in the northbound through lane. The loop in the northbound right-turn lane was not accurate enough for this study and was not used as a baseline data source. Refer to Appendix C for the full calibration results.

**Speed** – Speed outputs obtained from the freeway loop detectors provide an excellent measure of vehicle speeds. Once calibrated, the accuracy obtained from the loops equaled the accuracy possible with radar. Manual sampling was used to ground-truth the speed data. The speed observations were conducted with a probe vehicle driven through the detection zone at a predetermined speed. The speedometer of the probe vehicle was verified by comparing the speed displayed on the speedometer with the speed calculated by driving a predetermined distance. The qualified probe vehicle was then used to
the speed. The probe vehicle was identified by using a cellular phone and driving during off-peak hours. Its speed, lane and time were recorded for each run and compared against the per-vehicle loop speed output. The sample size necessary to accurately ground-truth the speed baseline data was determined based on the need to satisfy a 95 percent confidence interval.

A total of 21 runs were made with the probe vehicle. The average percent difference between the loop speed and probe vehicle speed were 1.2 percent for the right and left lane and 3.3 percent for the center lane of the freeway. Detailed results are included in Appendix C.

The loop detectors also provide the baseline data source for occupancy. As described in Section 2.2.2 (Data Acquisition Software), the timing system has a timing precision of 0.01 seconds. This impacted the ability to reliably collect occupancy data. Occupancy data collection issues are further discussed in Section 3.

2.4.3 Manual Observation as Baseline Source

Manual observations were used as the baseline source for presence data collection at the intersection. Loop detectors were considered, but manual observations proved more efficient given the relatively small amount of presence data that was collected. To conduct manual observations of vehicle presence, an observer simply monitored each sensor’s output while vehicles passed in front of the sensor. The number of vehicles missed (false negatives) and the number of errant detections (false positives) was recorded.

2.5 Sensor Data Collection

Various activities were completed before testing began. These activities include, but are not limited to:

- Determining the location of any test site utilities that may conflict with test activities
- Identifying the baseline data source to be used on site
- Preparing the sensor mounting structure(s)
- Preparing the on-site data acquisition equipment
- Identifying and installing the weather information system

2.5.1 Freeway Sensor Installation

Sensors were mounted at both overhead and sidefire mounting positions at the I-394 test site. The overhead mounting used vertical poles attached to a catwalk structure installed specifically for this project. Access to the catwalk structure was available on the southeast quadrant of the Penn Avenue Bridge to I-394. Project staff accessed the catwalk using a preinstalled foot ladder attached to the bridge parapet. Sensor installation proceeded from this point as specified in the vendor specifications and according to testing criteria.
Sidefire mounting was accomplished using an extendable tower offset from the roadway at a selectable distance of 15, 25, or 35 feet (5, 8, or 11 meters) from the edge of the nearest lane. The tower was placed on preinstalled concrete pads and then moved from pad to pad as required. Pivots at the tower base allowed the tower to be carefully tipped from its lowest vertical position to a horizontal position, allowing access to the tower top for sensor installation. Project staff installed the sidefire sensors as specified in the vendor specifications and in accordance with standardized testing criteria.

Two existing poles at the intersection were used to mount sensors for intersection tests. One pole monitored a single-lane off-ramp and the other monitored a two-lane approach. Three conduits were directionally bored under the roadway for the testing of magnetic probes. Refer to the test site description for more information.

Sensor cabling was installed concurrently with the sensor installation in the field. Conduit for the cabling is provided between the field test sites and equipment shelter. Conduit sizes vary from two to four inches. Junction boxes were used to terminate sensor pigtail cabling and make a connection to home run cabling back to the shelter.

### 2.5.2 Sensor Bench Tests

Bench tests were used to verify each sensor’s power supply voltages, communication requirements, software functionalities and ability to perform general operating functions as stated in vendor specifications before it was installed in the field. Each sensor was powered and wired inside the shelter based on the specifications contained in the vendor’s operation and installation manual. For some sensors, such as microwave, infrared and acoustic, bench tests were performed using simulated inputs from real-world detection objects. This consisted of either a simple hand swipe within the Field of View (FOV) or moving some other type of inanimate object within the detection zone of the sensor. The operation and communication was verified through real-time signals displayed on the interface software whenever the sensor detected a moving object.

Video sensor bench tests examined the quality of video and data communications. Video communication was verified by observing real-time camera outputs on a television monitor. Data communication was confirmed by sending commands to the processor or adding detection zones on the screen using the interface software. Communication was confirmed in the shelter before the video sensors were installed in the field.

During the bench tests, communication wires were numbered and labeled to help the installation in the field. After successful bench tests, sensors were installed in the field using the confirmed wiring and power supply.

### 2.5.3 Sensor Adjustments and Calibration

All non-intrusive sensors were carefully calibrated before any formal data collection activities began. The calibration of each sensor consists of a variety of activities. Some sensors had a simple point-and-shoot installation that required only proper aiming. Other sensors had one or more parameters that were calibrated based on the specific test
environment. Sensor calibration was typically an iterative process. Vendor guidelines were followed and sensor performance was monitored during the calibration process. In general, the vendor-supplied documentation was not adequate to complete calibration. In most cases, the vendors were contacted for assistance or clarification in the course of calibrating each sensor. Before the official data collection was started, a reasonable effort was made to optimally calibrate the sensor. In addition, the sensor performance was inspected to verify that it was within the vendors’ expected performance range.

Experience shows that a wide variety of ability levels is often necessary to complete the calibration of each sensor. Some sensors are simple to install and calibrate, allowing a typical electrical contractor or public agency technician to install with little past experience. Other sensors are more complex and may require prior experience or oversight by a manufacturer’s representative to successfully deploy. The level of expertise needed to calibrate each sensor were gauged and documented.

After this initial setup was completed, data was collected and supplied to vendors for their comments. Any additional calibration needed after this point was conducted on the sensors as required. Every effort was made to accommodate vendors’ requests for mounting changes and calibration.

In most cases, the on-site project staff conducted the calibration procedures. Some vendors also visited the test site to set up sensors. In these cases, the calibration process was done by the vendors and observed by project personnel. Every effort made to calibrate the sensors was to ensure that the optimal performance was obtained.

### 2.5.4 Sensor Official Tests

During the evaluation, all available data outputs were collected from the sensors. Some sensors provide a standard relay contact closure output with the relay normally open and then closing when a vehicle was detected. Other data was supplied through a serial communication link to a data collector. All available data outputs were collected and included in the evaluation. The following sections describe the test periods.

#### 24-Hour Data Collection Test Periods

All official data collection periods were 24 hours in length. Data was collected from each sensor and baseline loops in 15-minute intervals. Twenty-four-hour volume and speed data were collected for each sensor starting at either midnight or noon of the day in accordance with the test schedule. The local weather data, including temperature, precipitation, humidity and wind speed, was recorded from the national weather website [www.weather.com](http://www.weather.com). In addition, weather data from the National Climatic Data Center was collected.

The data acquisition software interface used during Phase I of the NIT project 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. A similar interface was used in this installment of the NIT project. This allowed for a detailed manual analysis of the
performance of each sensor to identify if there were any systematic problems with
detection under specific conditions, such as heavy congestion, low light levels, shadows,
rain, snow, etc. This display was recorded onto videotapes during 24-hour test periods.
The videotapes provided an opportunity for vendors and other interested parties to
analyze sensor performance on a vehicle-by-vehicle basis.

2.6 Test Conditions

A variety of test conditions were included in each sensor’s evaluation. This section
presents the roadway, traffic and mounting test conditions.

2.6.1 Mounting Configurations

Sensor mounting parameters vary from vendor to vendor and from sensor to sensor. Each sensor has its optimal mounting configurations as well as mounting limits. At a
minimum, each sensor was evaluated at 5-foot increments in mounting height and 10-foot
increments in horizontal offsets within the vendor-recommended mounting
specifications. The mounting increments provide a good picture of sensor sensitivity to
mounting variations without making the test process too cumbersome. In addition, the
test mounting configurations extended the recommended ranges to at least 20 percent
beyond the maximum and minimum specified. The goal during testing is to document
the level of degradation, if any, which results from deviating from the vendor’s
recommended ranges. Refer to the test site description for more information on the
mounting locations. Table 2 indicates the vendor-recommended mounting heights and
offsets for each sensor. Table 3 shows the mounting heights and offsets that were tested
for each sensor.

### TABLE 2

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Height Range from Ground</th>
<th>Side Range from Shoulder</th>
<th>Mounting Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>ASIM IR 254</td>
<td>16 ft</td>
<td>32 ft</td>
<td>0 ft</td>
</tr>
<tr>
<td>ASIM DT 272</td>
<td>1.64 ft</td>
<td>39 ft</td>
<td>1.64 ft</td>
</tr>
<tr>
<td>ASIM TT 262</td>
<td>16 ft</td>
<td>32 ft</td>
<td>N/A</td>
</tr>
<tr>
<td>Autosense II</td>
<td>20 ft</td>
<td>25 ft</td>
<td>N/A</td>
</tr>
<tr>
<td>ECM Loren</td>
<td>20 ft</td>
<td>40 ft</td>
<td>26 ft</td>
</tr>
<tr>
<td>SmarTek</td>
<td>25 ft</td>
<td>40 ft</td>
<td>10 ft</td>
</tr>
<tr>
<td>Autoscope</td>
<td>25 ft</td>
<td>45 ft</td>
<td>0 ft</td>
</tr>
<tr>
<td>Traficon</td>
<td>25 ft</td>
<td>45 ft</td>
<td>0 ft</td>
</tr>
</tbody>
</table>

Notes:

(1) The 3M Microloop magnetic probes were installed under the pavement at a depth of approximately
18 to 34 inches.

(2) SF denotes sensors mounted Sidefire, OH denotes sensors mounted Overhead.
<table>
<thead>
<tr>
<th>Test Site</th>
<th>Mounting Location</th>
<th>Height</th>
<th>Vendor Recommended Mounting Height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>3M</td>
</tr>
<tr>
<td>Freeway</td>
<td>Base Location #1</td>
<td>5 ft</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>(Sidefire)</td>
<td>15 ft</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 ft</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 ft</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 ft</td>
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<td>40 ft</td>
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<td></td>
<td></td>
<td>45 ft</td>
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<td></td>
<td>Base Location #2</td>
<td>5 ft</td>
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</tr>
<tr>
<td></td>
<td>(Sidefire)</td>
<td>15 ft</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 ft</td>
<td></td>
</tr>
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<td></td>
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<td></td>
<td>45 ft</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Base Location #3</td>
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</tr>
<tr>
<td></td>
<td>(Sidefire)</td>
<td>15 ft</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>20 ft</td>
<td></td>
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<td></td>
<td></td>
<td>40 ft</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>45 ft</td>
<td></td>
</tr>
<tr>
<td>Catwalk</td>
<td>(Overhead)</td>
<td>21 ft</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>17 ft</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 ft</td>
<td></td>
</tr>
<tr>
<td>Under Pavement</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Under Bridge</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Intersection</td>
<td>NE Luminaire Extension</td>
<td>37 ft</td>
<td></td>
</tr>
<tr>
<td>NW TMC Pole</td>
<td>Optimal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3
MOUNTING HEIGHT AND OFFSET TEST SCHEDULE
2.6.2 Road Geometric Test Conditions

Test sites with multiple lane configurations are ideal due to the dynamic traffic conditions that they provide. Multiple lane geometrics create lane change situations, varying shadow conditions and other challenging test conditions that are typical of a real-world application. The I-394/Penn Avenue location provides these challenging test conditions.

2.6.3 Traffic Level Test Conditions

The freeway test site provides both high-speed free-flow conditions and congested conditions on a recurring basis (i.e., during peak periods). Sensors were evaluated during 24-hour test periods in order to observe performance in varying traffic levels.

2.7 Data Analysis

Volume and speed data was compared to the baseline data collected from the loop detectors. The interaction among several different variables was examined to identify correlation with sensor performance. Matrixes were developed to identify the relationship, for example, between congestion and sensor performance. The challenge was to analyze as many of these effects within the time and budget available.

The results from the statistical analysis are presented in a clear and concise manner in the hope that they will be readily accessible to a diverse audience. Summarized test results, including extensive graphs and tables, are assembled for each test period. Several data analysis approaches, such as scatter plots, correlation coefficient and general statistical analysis were applied.

2.7.1 Scatter Plots

Scatter plots show the relationship between two sets of numbers as one series of x-y coordinates. Each point on a scatter plot represents traffic data for a given sampling interval (i.e., 15 minutes) as measured by the baseline on the horizontal axis and the sensor under test on the vertical axis. Data points falling on a linear 45-degree line represent perfect agreement between the two compared data sets. This approach provides a powerful, straightforward visual representation of variation between each sensor and the baseline data. Observations, such as the influence volume or speed have on sensor performance, can be made by examining the patterns in the scatter plots. Scatter plots were made for a subset of the volume and speed data collected during the evaluation. One typical 24-hour test period in which the sensors were installed at a vendor-recommended height was selected for each sensor. Figure 18 provides examples of volume scatter plots. Notice that the sensor and loop data are in closer agreement in the first graph. This graph represents results from a sensor mounted directly above one lane of traffic. The second graph is from one of several lanes being monitored from a sidefire location.
2.7.2 Correlation Coefficient Calculation

The correlation coefficient is a dimensionless index that ranges from -1.0 to 1.0. It quantifies the linear nature of the data points seen on a scatter plot, providing a measure of each sensor’s variation from the baseline data from one time interval to the next. The closer the correlation coefficient is to 1.0, the more closely the data sets match. The

Figure 18: Examples of Volume Scatter Plots
correlation coefficient was calculated for each of the evaluation tests. The Pearson’s product-moment correlation coefficient was used for this calculation.

2.7.3 Percent Difference

The total percent difference determined from the summation (volume) or means (speed) of two data sets provides an easily understood measure of sensor performance. The total percent difference between baseline data and sensor data was calculated for each evaluation 24-hour test period. This information indicates how close the data collected from the sensors are to the baseline data. Notice that the total percent difference may be more pronounced in low-volume studies. Whenever possible, data was aggregated into sample sizes of at least 100 observations.

Daily total percent differences present long-term patterns in sensor performance. However, the aggregation of data into daily totals can obscure the performance of a sensor that both under and over counts, having compensating errors. For this reason, the absolute percent difference was used as the major comparison measurement. For volume, the absolute percent difference is the ratio of the accumulated absolute errors over the total volume for a complete test period. For speed, the absolute percent difference is the mean of the absolute average speed of each interval. Since absolute errors do not compensate one another, the value is either bigger than or equal to the total percent difference. The daily absolute percent difference should be used in conjunction with other statistical measures, such as correlation coefficient.

2.7.4 Standard Deviation

Standard deviation is a useful statistic for evaluating the deviation between measured data and baseline data. The smaller the standard deviation, the less a sensor varies from the baseline. It is important to examine the percent difference, correlation coefficient and standard deviation when interpreting the results.

2.7.5 Count Accuracy/Speed Relationship Graphs

Sensor 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 sensor performance can distinguish 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 sensors. Figure 19 provides an example of a count accuracy/speed relationship graph. Notice that this figure reveals a tendency for the sensor to undercount when traffic speeds are low.
Figure 19: Example of Count Accuracy/Speed Relationship
3. TEST RESULTS

The evaluation goals and objectives identified in the Evaluation Test Plan were followed throughout the test. The results for each of the five evaluation goals are summarized below. The next portion of this section presents detailed test results for each of the nine non-intrusive sensors evaluated. Finally, Section 3.8 documents sensor costs.

Goal 1: Develop Standardized Evaluation and Reporting Procedures

Standard Test Guidelines were developed for the project’s Evaluation Test Plan. The guidelines identify recommended practices for conducting field tests of non-intrusive traffic sensors. The goal was to develop a standardized approach that will enable results from this evaluation to be easily compared to results obtained in other evaluations. This is hoped to decrease the amount of redundant testing that is required. The guidelines propose installation, operation, maintenance, cost, standards compliance and several specific test scenarios for consideration in further evaluations. The Evaluation Test Plan is available on the project’s website at http://projects.dot.state.mn.us/nit/.

Goal 2: Assess the Performance of Non-Intrusive Technologies in Historical Data Collection Applications

The majority of field tests assessed sensor performance in historical data collection. Substantial volume and speed data was collected in various mounting configurations, traffic conditions and roadway environments. The results were presented in different formats to reveal the accuracy of each sensor under the above study conditions. The assessment of sensor performance in weather conditions was not a focus of this project phase because of the time and budget available. Phase I examined weather impacts in more detail. The evaluation of non-motorized traffic detection, such as pedestrian and bicycle detection, is currently underway. An assessment of train detection will be conducted in a future study.

Goal 3: Assess the Performance of Non-Intrusive Technologies in ITS Applications

The primary ITS parameter studied in this phase of the evaluation is sensor ability to detect vehicle presence. This was assessed on a vehicle-by-vehicle basis for each of the sensors installed at the intersection test site. Real-time data on vehicle speed and occupancy was also collected. Questions about the timing accuracy obtainable with the data acquisition system limited the extent to which these parameters were studied.

In order to better understand the impact timing precision had on the data, a subset of data was analyzed for reasonableness by comparing the upstream loop activation to the downstream loop activation for a given vehicle. In theory, the time period each loop is “on” should be the same for a vehicle at constant speed.
A sample of approximately 500 vehicles was selected from a low-volume time period when lane-changing behavior was minimal and speeds were constant. The occupied time values from the upstream loop ranged between +/- 0.05 seconds of the downstream loop. The average upstream and downstream occupied times were 0.26 and 0.25 seconds, respectively. The standard deviation of the differences was 0.021 seconds. The data was normally distributed around a difference of zero. These values identify a certain level of uncertainty in capturing the real-time data, but also suggest that the timing accuracy of 0.01 seconds is not the sole culprit because the standard deviation is even higher (0.021 seconds).

The NIT local evaluation team proposed several hypotheses for explaining the inconsistent data that the data acquisition system has captured. One hypothesis is that the loop detector card sensitivities may not be identical to one another. Another hypothesis is that multiplexed loop detector cards may introduce timing errors. In general it was felt that further analysis was needed to explore these issues. Unfortunately time and budget did not allow this issue to be fully resolved during the current phase of testing.

**Goal 4: Document Non-Intrusive Technology Deployment Issues**

Deployment issues were documented in this report based on project personnel’s first-hand experiences with the sensors. The ease of installation, calibration and operation are detailed for each sensor in the remaining portion of this section. See also Table 6 in the Conclusions section for a summary of these evaluation measures.

**Goal 5: Document Non-Intrusive Technology Costs**

Vendor-recommended retail costs were obtained for each of the sensors evaluated in this phase of the project. See Section 3.8 for more information.

The five evaluation goals listed above include several test objectives, as detailed in Section 1.3. These objectives were selected based on practical issues that would be of interest to the traffic monitoring community. The evaluation of sensor performance focused mainly on the accuracy of volume and speed detection. In addition, installation, calibration and the sensor cost are also the primary concerns. Specifically, the ease of installation was assessed as average installation time, degree of difficulty of wiring and the level of expertise needed. The calibration evaluation focused on the ease of using vendor software and difficulties in the calibration process. Presence and lane occupancy data was also collected for some sensors. While every attempt was made to test the full capability of each sensor, some forms of data, such as classification could not be ground-truthed and are not presented here. Finally, costs are tabulated for each sensor.

Another emphasis in this project is to test sensors in a real-world environment rather than in a controlled laboratory setting. The detailed analysis of each sensor includes information on where sensors were mounted and how they performed under various mounting locations and environmental conditions. Refer to Table 4 for a summarized description of sensor mounting.
locations for each test period. Whenever possible, the most challenging conditions were selected, including heavy traffic and a variety of mounting locations. Specific test objectives, such as determining the mean time between failures or testing under all weather conditions, were outside the scope of this project.

In testing and presenting the results for these sensors, emphasis has been placed on making the data easy to interpret for a diverse audience. An attempt has been made to make the statistical analyses performed as straightforward and intuitive as possible. Most of the data was collected in 15-minute intervals and assembled into daily totals and daily percent differences as compared to baseline data. The correlation coefficient, standard deviation and absolute percent difference are used to express the variation between detector data and baseline data.

This Final Report contains more data than was posted on the project website during the project. In general, all data from calibrated sensors is presented here, except as noted in this section. A sensor 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 sensors, the only other data removed are very erratic data that clearly point to a problem with the sensor. While some vendors requested that the data from certain test periods be removed, the request could not be honored unless the performance of the sensor was very erratic, indicating that the sensor was grossly malfunctioning.

There are many factors to consider when evaluating the performance of the sensors. 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 sensor or technology as being the best. Rather, the reader should interpret these results against their specific detection needs.

3.1 Passive Infrared

Passive infrared sensors react to positive or negative changes in the thermal radiation produced by movement of a vehicle into or through their field of view. The infrared energy naturally emanating from the road surface is compared to the energy radiating when a vehicle is within the detection zone. Since the roadway may generate either more or less radiation than a vehicle, the contrast in heat energy is what is measured. There is no possibility of interference with other sensors because this technology is completely passive.

ASIM IR 254 is the only passive infrared sensor tested in this project.
3.1.1 Passive Infrared -- ASIM IR 254

Sensor Description

The IR 254 is a passive infrared sensor made by ASIM Technology Ltd of Switzerland. The sensor monitors the infrared energy in three measuring zones; a vehicle must pass through all three zones in order to trigger detection. The sensor is a single lane detector and designed to mount either overhead or slightly to the side of the roadway and must face oncoming traffic. It requires a 5.5 to 15 V DC power supply and RS 485 interface module to provide two-way communication. The serial communication and supplied software offer sensor calibration and monitor the detector’s real-time performance. The model tested in this project does not have relay outputs, so all data was collected through the serial interface. Detection capabilities include count, speed, presence and length classification data.

Wiring: Wiring consists of a power cable and a two-way data communication cable that connects the sensor to the IF 485 data interface module located in the equipment rack. The interface module then connects to a computer.

Calibration: The calibration is quite straightforward. The calibration software “Inst254.exe” is available as an installation and alignment tool. The program was DOS-based during the test, but a Windows-based software is now available. The user manual has a clear description of the calibration parameters. The interface is user-friendly and fairly simple. Most calibration parameters have default values and do not need to be adjusted. The only exception is to fine-tune the parameter “measure distance” in order to obtain optimal speed results.

Data Collection: The IR 254 data collection procedure is simple. The real-time data is automatically time stamped and then collected and downloaded to the hard drive of a desktop computer using the data collection software “multstat.exe.” The program generates a text format data file in the background and closes it when the program is terminated. Extra effort was necessary to aggregate the real-time data into 15-minute intervals in order to compare with the baseline data. The sensor tested does not provide relay outputs but this output is available if specified.

Test Description

The IR 254 sensor was first installed at the freeway test site on May 30, 2001. It was mounted at 21 feet above the roadway facing oncoming traffic. After bench testing and calibration, the first official data collection began at the overhead freeway location on October 3, 2001 in accordance with the overall test plan. On October 15, 2001, the sensor was moved to the sidefire tower and data was collected on November 1, 2001.
The sensor was installed back at the overhead bridge test location and tested in March 2002 at a height of 17 feet. On March 15, 2002, the sensor was installed on the sidefire pole at the intersection and a presence test was conducted.

**Test Results at Mounting Location No. 1 -- Freeway Overhead Bridge**

**Installation:** Overhead installation was quite simple. It took approximately 15 minutes to attach the sensor to the frame of the catwalk using a U bracket and other hardware accessories provided by the vendor. The sensor is required to be mounted facing approaching traffic parallel to the traffic flow with a downward angle of approximate 45 degrees. It is absolutely essential that the detector be firmly mounted and aimed correctly for proper operation.

**Detection Accuracy:**

*Volume:* IR 254 valuation at the freeway mounting location provided mixed results. The volume accuracy was good except for periods of heavy traffic during the peak hour. The absolute percent differences varied from 0 percent to 10 percent during off peak periods and more than 10 percent under counting during the peak hour.

*Speed:* The test data reveal the sensor was underestimating speed by 10 percent on average. The results may be improved by adjusting the “measure distance” to an optimal level.

**Test Results at Mounting Location No. 2 – Freeway Sidefire Tower**

**Installation:** IR 254 sidefire installation required additional mounting accessories and more effort to aim than overhead mounting. The calibration required not only a firm mount on the sidefire tower but also an accurate alignment. The calibration can only be completed after the alignment is confirmed. The aiming difficulty comes from the three-dimensional alignment geometry, which requires mounting at a certain height, facing approaching traffic with a downward angle of approximate 45 degrees and keeping the three detection zones parallel to the traffic flow. The detector can only function correctly if these alignment requirements are met. However, there is not an efficient tool to aid the alignment. In this project, two laser pointers were used to perform the alignment during the early morning or late evening when the laser beam was visible on the pavement. The angle was ensured to be 45-degrees and the laser pointers were attached to the sensor to help verify that three-detection zones were parallel to the centerline of the detection lane. This method was just a temporary solution and did not provide optimal alignment.

Our test site could not accommodate the vendor-recommended angle of 45 degrees and 15-foot height because the shortest distance between the sensor and the centerline of lane is 22 feet. Therefore, no results are presented.
Test Results at Mounting Location No. 3 – Intersection Sidefire Pole

Installation: Evaluation at the intersection encountered the same alignment difficulty. The sensor was installed on a sidefire light pole on the northwest corner of the intersection to monitor the traffic on the eastbound exit ramp. The sensor was aimed by test personnel using laser pointers to assist in the aiming.

Detection Accuracy:

Result: Because of the difficulty in sensor alignment, the IR 254 was not successfully calibrated, even though several attempts were made. Therefore, results are not available at this location.

3.1.2 Assessment Summary

The ASIM IR 254 passive infrared detector is simple and straightforward to use. The sensor is small and easy to mount. The detection accuracy was good during free flow traffic conditions but undercount by more than 10 percent during heavy traffic.

At the overhead freeway location, the IR 254 was capable of counting traffic with less than 5 percent difference from the baseline during the light traffic off peak periods. The difference was over 10 percent from the baseline under heavy traffic during the peak period. The alignment requirements for the sidefire installation make it difficult for the sensor to obtain optimal performance. Therefore, overhead mounting locations are recommended.

The IR 254 was easy to mount 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 sensor as described in the manual and check it for basic functioning. The sensor can be checked by monitoring its signal strength with its serial output using supplied software.

3.2 Active Infrared

Active infrared sensors 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 sensor. The presence of a vehicle is measured by the corresponding reduction in time for the return signal.

There was one active infrared sensor formally tested in this project: Autosense II. In Phase I of the NIT Project, the Autosense I was evaluated. Also included is a brief description Spectra Research’s NTMS laser sensor that was demonstrated at the test site during spring 2002.
3.2.1 Active Infrared -- Schwartz Autosense II

Sensor Description

The Autosense II is a self-contained active infrared sensor made by Schwartz Electro-Optics Incorporated. Both stationary and moving vehicles are detected in two laser beam detection zones. Autosense II is a single lane detector and designed for overhead installation only. The recommended mounting height is between 19.5 feet and 23 feet facing down towards the pavement with a five-degree tilt toward the approaching traffic. Power (120 VAC) and communication cables connect to the sensor. Relay outputs provide loop emulation in one detection zone. The Autosense II offers volume, speed and classification data through the RS 232 or RS 422 communication module. In addition, the sensor employs a scanning laser rangefinder to measure three-dimensional vehicle profiles and provide vehicle classification data.

Wiring: The communication wiring is straightforward. There are two cables to the sensor, one for power and one for communication. The communication cable connection is well documented in the installation and operation manual.

Calibration: The Autosense II calibration procedure is intuitive and documented in the user manual. The interface program “AS2TEST” is used to calibrate the sensor. The program runs under standard disk operating system (DOS). It has self-testing function to verify satisfactory operation. The interface is user-friendly. Most calibration parameters have default values and do not need to be adjusted in most cases. The vendor provided very good technical support during the test.

Data Collection: Relay outputs provide loop emulation in one detection zone. In addition, the interface software “AS2TEST” is used to display and collect real-time message data. Both types of outputs were collected for this test. The standard operating mode outputs a series of five messages for each vehicle in real-time to the data collection system via RS-232 or RS-422 serial interface. The data file is generated in real-time when requested through the software interface. The file terminates when stopped through the software interface. The Autosense II provides volume, speed, vehicle profiles and classification data in real-time serial data for each vehicle. This format did not readily fit into the project’s data classification scheme, which consists of data collected in 15-minute intervals. Therefore, the data was stored and downloaded in text file format. Extra effort was made to process the real-time data into 15 minutes interval aggregated data in order to compare with the baseline. The vendor indicated that the aggregation function would be automated in future software upgrades.
Test Description
The Autosense II was mounted directly over the left lane of the freeway at a height of 21 feet (6.7 m) on October 3, 2001. It remained at this location throughout the test.

Test Results Mounting Location – Freeway Overhead Bridge

Installation: The installation is straightforward, but required extra effort when attached to the catwalk because of its weight (29 pounds) and dimensions (16.5 inch x 13 inch x 5 inch). Extra care was made to secure the sensor to the catwalk to reduce the risk of falling onto approaching traffic. A custom-built mounting plate was developed to firmly mount the sensor with five-degree tilt toward approaching traffic on the catwalk.

Detection Accuracy:

*Volume:* The Autosense II provided excellent results. The absolute percent difference between sensor data and loop data averaged 0.7 percent. This is within the accuracy level achievable with the baseline loop detectors.

*Speed:* The 24-hour test data indicate that the absolute percent difference of average speed between the sensor and baseline was 5.8 percent. The sensor was overestimating the speed. Vendor claimed that the new software would improve the accuracy of speed estimation.

3.2.2 Assessment Summary

The sensor was found to be very accurate for volume at the freeway location. The Autosense II performed consistently throughout all six months of continuous testing. The daily volume absolute percent difference between sensor and loop ranged from 0.7 percent to 2.4 percent. The sensor unit is easy to calibrate. At the vendor’s request, the detector was not tested at the intersection. A software upgrade to automate the data aggregation will improve the data collection process. The sensor also provides classification data, but this was not formally evaluated.

3.2.3 Active Infrared -- NTMS

Spectra Research did not formally participate in this project. However, they have developed a unique portable non-intrusive traffic sensor, the Non-Intrusive Traffic Monitoring System (NTMS), to monitor freeway traffic from the side of freeway by installing directly on the ground. Because of this unique application, they were allowed to demonstrate their sensor at the NIT test site. Two informal tests were conducted and general information is provided in this section. No detailed results are included in this report.
Sensor Description

The NTMS sensor is a highly portable, non-intrusive sensor. The system consists of two infrared laser transmitters and receivers contained within an enclosure that serves as an optical platform and protection box. Two parallel laser beams emulate two tape switches or a pair of road tubes to monitor multiple-lanes (up to four lanes) from the side of the roadway. Lane identification is determined by measuring the time required to reflect off of a vehicle wheel. The axle detection messages are passed to a host processor (the Diamond unit), which calculates the traffic parameter’s speed, axle length, number of axles and classes. A variety of commercially available host processors can be used to collect data from the Spectra unit. A Diamond unit was used in this test.

The NTMS unit is powered by a 12 VDC, 33 Ah internal battery. A 750mA solar panel with reverse diode protection is mounted on the top cover of the NTMS to augment the battery and extend operating time. An external connector is provided for battery charging or adding an additional external battery.

Wiring: Wiring consists of a single cable that connects the NTMS to auxiliary inputs of the host processor. A laptop can link to the host unit to download the data and monitor real-time data collection.

Calibration: Proper calibration requires careful sensor placement and leveling. The calibration is verified by comparing sample volume to manual observations. Extra effort may be needed to achieve optimal leveling at some locations.

Data Collection: The data collection procedure is simple and straightforward. The NTMS is a sensor only and all data is stored and processed in the host processor. The type of data collected (raw, binned, sensor, etc.) is determined by the configuration of the host. For the Diamond unit, the data can be downloaded to a laptop in any desired format.

Test Description

The vendor visited the freeway test site on May 6, 2002, and a bench test was conducted. The sensor was tested on June 18, 2002.

Test Results at Mounting Location No. 1 -- Freeway Overhead Bridge

Installation: The NTMS sensor is placed directly on the ground, not requiring a pole or other mounting structure to install. Careful placement and leveling are critical to proper sensor performance. The NTMS unit weighs 79 pounds with dimensions of 21 x 21 x 12 inches. Nominal setup times range from 15 to 30 minutes. Extra time may be needed for leveling, depending on the site conditions.
Detection Accuracy:

*Volume:* From this single test, evaluation at the freeway mounting location provided mixed results. The absolute percent difference of 15-minute interval ranged from 0.2 percent to 13 percent undercounting at lane one, 0 percent to 6.5 percent undercounting at lane 2 and 0.3 percent to 8.9 percent undercounting at lane three. This is attributed to intermittent slow moving traffic, tailgating, and the maximum axle spacing configuration in the host device as one would encounter with road tubes.

*Speed:* Test personnel did not collect speed data from the NTMS. The vendor indicated that speed accuracies of approximately +/- 2 MPH have been obtained in other field tests.

### 3.2.4 Assessment Summary

The NTMS sensor is convenient for safe, quick, temporary data collection on the side of roadways because of its portable feature. It can detect multiple lanes with straightforward setup and calibration. The 15-minute interval volume percent difference between sensor and baseline data ranged from 0 percent to 13 percent among three lanes. However, the test was short and quick and not enough data was collected at this point. The full evaluation could be performed in the future.

### 3.3 Magnetic

Passive magnetic sensors 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 sensor must be relatively close to the vehicles. The sensing zone is roughly equal to half the height of the vehicle and can be increased by wiring additional sensors in series. This limits most applications to install under the pavement, including underneath bridge decks as evaluated here. Some testing has been done with sidefire sensors in locations where they can be mounted within a few feet of the roadway.

Inductive loop sensors are classified as active magnetic sensors 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.

One passive magnetic sensor, the Micro-loop manufactured by 3M, was tested in this project.
3.3.1 Passive Magnetic – #702 Micro-loop Probe & Canoga™ C800 Detector Card

Sensor Description

The Canoga Non-invasive Microloop vehicle detection system was developed by the 3M Intelligent Transportation Systems. It consists of three components: Canoga Model 702 Non-invasive Microloop probe(s), Canoga C800 series vehicle detectors, and 3M ITS Link Suite application software. The Microloop probe is designed to be installed in a three-inch non-metallic conduit and placed 18 to 34 inches under the roadway. Multiple probes can be used to detect multiple lanes.

The probes are connected to the Canoga C800 series vehicle detector, a processing card installed in a standard vehicle detector rack located inside the shelter. This detector processes the probe’s outputs and generates both contact closures and serial communication outputs. The detector can also store volume and occupancy data, which can be retrieved via an RS 232 serial connection. The detector and interface software can calculate speed based on the shape of the incoming waveform. Volume, speed, length 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.

Wiring: The Microloop probes were connected to the Canoga C800 vehicle detector by the same homerun cable used in standard inductive loop installations.

Calibration: Sensor calibration and setup is done through the 3M ITS Link Suite or board mounted switches. Special training was offered by 3M ITS.

Data Collection: The interface software support data collection well. It can provide real-time and aggregated archived data for any specified interval. In addition, relay outputs are provided to the Canoga card. During the test, the relay outputs were collected by the ADR.

Test Description

Three 3-inch non-metallic conduits were installed under the roadway in June 2001. Two probes were installed for each lane, resulting in six probes installed in lead and lag conduits.

In April 2002, one of the probes was mounted under I-394 immediately east of Penn Avenue. A section of two-inch conduit was wedged between two beams using a pair of tennis shoes to obtain a secure fitting. A single probe was then taped to the conduit and wiring brought back to the shelter. Refer to Figure 20 for a picture of this unique mounting location.
Test Results at Mounting Location No. 1 -- Freeway Conduit

Installation: Under-pavement installation requires three-inch conduits located under the road surface. Special care was made to verify that the conduits are installed at a depth of 18 to 34 inches. It took eight hours to directionally bore the three conduits, 1.5 hours to insert the carriages and probes, approximately three hours to pull homerun cables and three hours to splice wires and connect interface panels.

Detection Accuracy:

*Volume:* Microloops installed at the freeway test location provided excellent results. The absolute percent difference between sensor and baseline was under 2.5 percent. This is within the accuracy of the baseline loop detectors.

*Speed:* The 24-hour test data reveal that the absolute percent difference of average speed between the sensor and baseline data varied from 1.4 percent to 4.8 percent for lane 1 to lane 3.

Test Results at Mounting Location No. 2 -- Freeway Under Bridge
Installation: This temporary installation used a unique approach to attach a probe to the underside of a bridge. As described earlier, a spare section of two-inch non-metallic conduit was wedged between two beams under the I-394 structure and a single probe was taped to the conduit. A magnetic monitor was used to select a section of bridge that had minimal interference due to re-enforcing bars.

Detection Accuracy:

**Volume:** The Microloop test results, when detecting traffic through the I-394 bridge structure, were essentially the same as a conventional under pavement installation. The absolute percent difference was 1.8% for the 24-hour test.

**Speed:** Speed was not available because only one probe was installed.

### 3.3.2 Assessment Summary

Microloops were found to be very accurate for volume detection at the freeway location and performed consistently throughout the test period. The sensor demonstrated high reliability during the test. The software interface is user-friendly and can provide aggregated archived data for any specified interval. Technical support from the vendor is recommended, especially for the initial calibration, but the sensor needs almost no further adjustment once it is calibrated.

Significant expense is required to install three-inch conduits for the probes, especially when the conduit must be directionally bored. The under-bridge installation offers a unique alternative for quickly installing a sensor non-intrusively.

### 3.4 Microwave

Microwave sensors 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. Microwave sensors can also detect the presence of stationary vehicles and sense multiple zones through their range finding ability. The only microwave sensor tested in this project was ECM’s Loren.

#### 3.4.1 Microwave-ECM Loren

**Sensor Description**

The Loren microwave sensor was developed in France and is distributed by ECM Inc. The sensor unit consists of a microwave sensor (Loren) and cabinet-mounted IRIS unit. The Loren is a multiple lane traffic detector, which is designed for sidefire installation only. Traffic data can be collected and stored temporarily inside Loren. The IRIS unit is an interface unit between the sensor and the host computer. Operational commands and data downloading can only be conducted through the IRIS unit. The interface software
“WELCOME” is provided by the vendor for calibration and data collection. The sensor can collect vehicle count, speed, length and occupancy data. A 12 VDC power supply is required for both the sensor and the IRIS unit.

**Wiring:** A null modem cable is necessary to connect the Loren sensor and the IRIS unit. An RS 232 link is used between the IRIS unit and the host computer. Special care is needed to confirm the connections on the IRIS board.

**Calibration:** The calibration procedure is not user-friendly. It requires at least a half-day to learn the calibration procedure. Extra effort was needed to follow the setup and calibration procedure as described in the user manual and “Quick Setup List.” All operational commands need to be typed in and the key calibration parameters such as lane position and width need to be determined manually. A script was developed by the vendor but could not be used because of continuous communication problems in the IRIS unit.

**Data Collection:** The Loren sensor can provide both real-time and aggregated archived data for certain specified intervals. The real-time data file is generated by initializing the “open file” function and finished by selecting “close file” function in the interface. The data file is a text format file with per vehicle records, which need to be processed to acquire aggregated data. The software interface does not have such a capability.

**Test Description**

The Loren sensor was installed and bench tested during the vendor visit on June 18, 2001. Communication problems occurred throughout the seven months of testing. The vendor visited the site for the second time on September 19, 2001 to trouble-shoot the problem. On October 10, the IRIS unit was sent to Texas for inspection and repair and an inspection report was requested. The unit was sent back to the test site on December 19, 2001. Substantial effort and time were expended in trouble-shooting and vendor consultation to try to make it work. However, communication problems with the IRIS unit continued to occur. Because of the test schedule and budget, the sensor was not tested in this project and no data was collected.

**3.4.2. Assessment Summary**

ECM’s Loren microwave sensor is early in its development cycle and did not function properly during this test. Previous tests of microwave sensors in Phase I of the NIT project indicate that the technology is very effective at collecting volume and speed data. Accurate and reliable speed data is obtained using the Doppler principle.
3.5 PASSIVE ACOUSTIC

Passive acoustic sensors utilize an array of microphones aimed at the traffic stream. The sensors detect vehicle presence by receiving the sound of a vehicle passing through the detection zone. The primary source of sound is the noise generated by the contact between the tire and road surface. Sensors 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 sensor is passive in that it is listening for the sound energy of passing vehicles. One passive acoustic sensor was tested in this phase.

3.5.1 Passive Acoustic – SmarTek

Sensor Description

SmarTek System Incorporated manufactures the SAS-1 passive acoustic sensor. It is a non-contact, passive sensor, which provides multi-lane traffic monitoring and traffic detection. The sensor receives different acoustic signals (engine, fans, belts, tire noise, etc.) and converts them to digital signals. The processing software can then display and detect the traffic using advanced signal processing, spatial processing and a vehicle detection algorithm. The system unit consists of an SAS-1 sensor, a pluggable terminal block connector and interface software. The system is powered by 12 VDC. The Sensor is designed for sidefire mounting only. A homerun cable connects the sensor to the processor; an RS-232 cable is required to link the processor and computer. The sensor provides both real-time data and aggregated data for a defined time interval. In addition, relay outputs provide loop emulation in each detection zone.

Wiring: The wiring specifications and diagram are provided in the Installation and Setup Guide. A significant effort was needed to become familiar with the wiring as described in the System Architecture and Quick Checkout sections of the manual.

Calibration: The SmarTek sensor is calibrated with the interface software “SAS Monitor and Setup.” The interface is very user-friendly. Calibration should be performed under free flow conditions. The software allows the user to define the lane position and lane width based on the acoustic signal received from the traffic. Each vehicle passing though the sensor is displayed with the green acoustic power “blobs” within the defined detection zone on screen. Thus, traffic can be visualized on the screen and the counts can be verified with manual observations. The calibration is straightforward by conducting the iterations between fine-tuning the parameters and verifying the sample data with baseline data. However, there is no step-by-step calibration procedure in the manual, calibration practice and consultation with the vendor was necessary after reviewing the manual. The effort and time needed to master the calibration varies depending on the individual, it took one day for test personnel to learn the calibration.
The vendor provided several software updates during the course of this evaluation. The interface software “SAS Monitor and Setup” V3.00.24 was used in the test on October 2001. The first upgraded version V4.00.08 added new features and was installed on Nov 26, 2001. It was upgraded again to V.4.00.17 with a new speed calibration feature.

Data Collection: The SmarTek interface software provides both real-time data and historical data for a user-specified time interval selected from a predefined list of intervals. Both types of data can be stored in the sensor and downloaded to the base computer periodically. The sensor also generates relay outputs, which were collected by ADR and used for the evaluation in this project.

Test Description

The SmarTek sensor was initially bench-tested in the lab at SRF in March 2001. It was officially mounted on the sidefire tower at the test location in May 2001. The vendor visited the site and helped test personnel obtain a better understanding of the setup and calibration procedures. The first official test was conducted on October 16, 2001. Because the sensor can support a wide range of heights and offsets, it was mounted at five heights and three offsets during the test between October 1, 2002 and January 18, 2002. It was one of the sensors that was fully tested for all the mounting locations. It should be noted that the offsets of base two (25 feet from roadway) and base three (35 feet from roadway) exceed the vendor-specified detection range (20 feet from roadway). The sensor was tested on these two bases only for research purposes; other deployments should consider the vendor’s recommendation. The sensor was moved to intersection in March 2002 for additional testing.

Test Results at Mounting Location No. 1 -- Freeway Sidefire Tower

Installation: SmarTek installation is very simple and straightforward with the mounting tube and flange provided by the vendor. Precise alignment is not critical because the sensor can cover a wide detection area. The user defines the detection zone within this area. The vendor-recommended heights range from 25 feet to 40 feet, and the recommended offset range from 10 feet to 20 feet. Higher mounting positions can reduce possible occlusions for multiple lane applications.

Detection Accuracy:

Volume: The SmarTek sensor monitored three lanes of traffic and was tested at five different heights on each of three bases. Only the first base was within the vendor-recommended offset range. At the first base (15 feet from the first lane), the sensor provided better results for lane two and three than lane one. The 24-hour data show that the absolute percent differences for lane two and three were under 8 percent at all heights, and between 12 percent and 16 percent for lane one with heights less than 30 feet. The sensor provided good results under free
flow traffic but undercounted during congested periods when average vehicle speeds dropped. Test data show that the absolute percent differences for 15-minute intervals were between 0 percent and 5 percent during off peak, and varied from 10 percent to 50 percent depending on site geometry during the congested periods. The results for base two and three are just for research purposes. Twenty-four-hour test data from these bases reveal that most results were under 10 percent absolute difference, which is similar to the results obtained at base one. Refer to the figures in Appendix E for more information.

**Speed:** At base one, the SmarTek performed well in speed detection. The absolute average percent differences were under 8 percent for most mounting locations and between 12 percent and 16 percent for lane one with heights less than 30 feet. The results at base two and three show that the best results occurred when the sensor was aimed at a 45-degree angle from vertical.

**Test Results at Mounting Location No. 2 -- Intersection Sidefire Pole**

**Installation:** The SmarTek sensor was mounted at a height of 15 feet and a presence test was conducted.

**Data Collection:** Vehicle presence was evaluated by manually comparing the sensor output (LED on interface panel) to vehicles observed approaching the intersection.

**Detection Accuracy:**

**Results:** The sensor was 100 percent accuracy for the vehicle presence test.

### 3.5.2 Assessment Summary

Passive acoustic technology can detect multiple lanes of traffic with a sidefire installation. The SmarTek sensor is easy to install and calibrate. The interface is user-friendly and both real-time and historical data are available. Test results show that the optimal installation position is to have equal distance for both vertical height and horizontal offset between the sensor and centerline of multiple lanes (so that the sensor is mounted at 45-degrees). This allows the sensor to receive the maximum acoustic signal and provide optimal detection results. The performance of the sensor was reliable and consistent throughout the test. The sensor demonstrated good results in detecting traffic during free flow conditions but occasionally experienced undercounting during heavy traffic conditions. Figure 21 illustrates an example of undercounting during heavy traffic conditions when average traffic speeds are reduced. Notice that the left graph is for lane 1, which experiences a clear pattern of undercounting by 30 percent to 50 percent when average traffic speeds drop to between 20 and 40 mph. In the graph on the right (lane 3), however, the accuracy does not correlate with varying traffic speeds. This is most likely due to the detection angle between the sensor and roadway being closer to 45 degrees. The vendor indicated that an error in the sensor’s software caused this undercounting and it has since been repaired. Refer to the figures in Appendix E for
summarized findings of volume performance versus height for each base for each lane. Similar figures are also included for speed data.

**Figure 21: Count Accuracy and Speed Relationship (SmarTek Lanes 1 and 3)**

### 3.6 **Multiple Technologies**

Two sensors were evaluated that use multiple technologies to detect traffic: ASIM DT 272 and ASIM TT 262. The ASIM DT 272 utilizes a combination of ultrasonic and passive infrared and the ASIM TT 262 uses ultrasonic, passive infrared and microwave technologies to detect traffic. Passive infrared and microwave sensors are described elsewhere in this report. Following is a brief overview of ultrasonic applications.

Pulse ultrasonic sensors emit pulses of ultrasonic sound energy and measure the time for the signal to return to the sensor. 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 sensor may be monitoring the reflection of any signal.

#### 3.6.1 **Passive Infrared/Pulse Ultrasonic– ASIM DT 272**

**Sensor Description**

ASIM Technologies Ltd of Switzerland manufactures the ASIM DT 272. The sensor is designed with two technologies, pulse ultrasonic and passive infrared. The sensor emits ultrasonic sound waves and measures the echo time to determine the distance between the sensor and the object. The measurement is initiated by the passive infrared part of the detector and confirmed by the ultrasonic portion. The DT 272 is a single lane detector and can be installed both overhead and sidefire. The sensor is designed to detect vehicles at a short distance. The maximum detection distance is 39 feet (12 m) for a horizontal and
vertical detection distance but about 20 feet (6 m) for a diagonal sidefire mounting. The power supply range is between 10.5 VDC and 15 VDC, as well as different AC versions. Communication can be accomplished via the IF 485 interface. Count and presence data is available over the relay loop emulation output, which was collected by the ADR for this test. Different output options are available as well. Traffic parameters available through serial communication include volume and height classification.

Wiring: The connections between the DT 272 sensor and ADR terminal leads were completed by following the instruction in the Installation Manual and within some vendor assistance.

Calibration: The interface software “Inst272.exe” provides calibration functions and can be used to monitor real-time traffic through analog signal waves on screen. The calibration procedure is relatively simple. The calibration parameters defined in the manual need to be understood in order to adjust parameters. Most parameters have default values that offer a reasonable starting point. A DOS-based software interface was used in the test, but a Windows-based interface is now available.

Data Collection: The DT 272 sensor was connected to the ADR and the relay outputs were collected for this test. Serial data was not collected.

Test Description

The DT 272 was first tested in the overhead installation on the bridge at a height of 21 feet on October 3, 2001. It was installed facing the pavement with a five-degree tilt toward the approaching traffic. On November 8 and 18, 2001, the sensor was tested at base 2 and 3 on the sidefire tower at a height of 4 feet. A mounting height of four feet was the only height that would provide acceptable sidefire performance. The presence test was conducted at the intersection on March 15, 2002.

Test Results at Mounting Location No. 1 -- Freeway Overhead and Sidefire

Installation: The DT 272 installation is simple with the U-bracket provided by the vendor. It only took 30 minutes to attach the sensor to the catwalk.

Detection Accuracy:

Volume: The 24-hour test results reveal good count performance at the overhead and sidefire freeway installations. The absolute percent difference between sensor and loop data was 8.7 percent for overhead mounting. Even though the DT 272 demonstrated unstable performance in counting for sidefire tests, the data collected on December 18, 2001 revealed good results with an absolute percent difference of 0.8 percent.
Test Results at Mounting Location No. 2 – Intersection Sidefire Pole

Installation: The DT 272 sensor was installed on a light pole at a height of four feet (1.2 m) and aimed at the side of a vehicle. Installation was easily performed using a U-bracket and some mounting accessories.

Data Collection: Presence was evaluated by monitoring the sensor’s output while observing the traffic. A “beep” sound was emitted whenever a vehicle passed in front of the sensor, allowing the observer to document the sensor’s performance.

Detection Accuracy:

Presence: Comparison between the DT 272 output and manual observations reveals 100 percent accuracy. The gaps between vehicles were accurately detected as discontinuous presence outputs.

3.6.2 Assessment Summary

The ASTM Dual Technology sensor was found to perform effectively in a variety of configurations. The installation and calibration are simple. However, the sensor confronted unstable detection problems during the test. Further investigation revealed that the internal count was good but the data collected by ADR undercounted. The test indicated that there might be an incompatibility between the sensor relay outputs and ADR; this compatibility was not encountered with other sensors.

3.6.3 Passive Infrared/Pulse Ultrasonic/Doppler Radar – ASIM TT 262

Sensor Description

ASIM TT 262 is also made by ASIM Technologies Ltd of Switzerland. It is a Triple-Technology sensor that uses ultrasonic, passive infrared and Doppler radar to enhance accuracy and reliability. The microwave detects the frequency shifts of microwave radiation reflected by a moving vehicle in order to measure medium to high vehicle speeds (7.5 MPH to 158 MPH). The ultrasonic uses high frequency acoustic wave and its travel time to measure the profile (height) of a vehicle while the passive infrared is used to detect a vehicle with the speed form 0 to 7.5 MPH. The radar and infrared automatically verify each other. The combination of the technologies is intended to provide optimal performance in all traffic conditions. The sensor is powered by 12 VDC. The TT 262 is a single lane detector and can only be installed overhead facing down to the pavement surface. Communication is made via a two-way RS 485 communication interface. Available detected traffic data includes count, speed, presence and vehicle classification. Relay outputs were not available on the particular unit that was tested.

Wiring: The TT 262 wiring is very simple with only two communication cables connected between the sensor and IF 485 interface module.
Calibration: The interface software “Inst265.exe” is used to adjust parameters and monitor real-time traffic through analog signal waves on the screen. The calibration procedure is very simple and the engineering screen is easy to understand. Finalizing the parameter setup was a fairly quick process. A DOS-based software interface was used in the test, but a Windows-based interface is now available.

Data Collection: The TT 262 sensor can only provide data in real-time. The program generates a text file, which records vehicle information such as speed, class ID and occupancy with time stamps. Extra effort was then required to aggregate the real-time data into 15-minute interval data.

Test Description
The TT 262 was first tested in an overhead installation on the bridge at a height of 21 feet on October 3, 2001. It was installed facing down to the pavement with a five-degree tilt toward the approaching traffic. On March 7, 2002, the sensor was tested, again, at a height of 17 feet in the same location. The sensor is not intended for sidefire applications.

Test Results at Mounting Location No. 1 -- Freeway Overhead Bridge
Installation: The installation is simple with the U-bracket provided by the vendor. It took about 30 minutes to attach the sensor to the catwalk.

Detection Accuracy:

Volume: The 24-hour test data revealed that the TT 262 installed overhead at the freeway provided good results. The absolute percent difference between sensor and baseline data was 2.8 percent at 21 feet and 4.9 percent at 17 feet height.

Speed: TT 262 provided good speed detection. The absolute average percent difference between the sensor and loop data was 4.4 percent at 21 feet and 3 percent at 17 feet height.

3.6.4 Assessment Summary
The triple technology sensor showed excellent performance. The installation and calibration are simple. The engineering interface provides real-time traffic monitor, which is helpful for calibration.

3.7 Video
Video sensors use a microprocessor to analyze the video image received from the camera. 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 was obtained from the video sensors at the freeway test site. In Phase I, 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 sensor performance. In Phase II, the emphasis is on testing sensors in a variety of mounting locations, so these environmental effects were not analyzed.

Installation and maintenance of video sensors 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. Considerable build up can be 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 may be necessary to maintain optimum performance during the winter months.

The most significant weather impacts observed during Phase I of the project 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. This phenomenon was not observed with the two video sensors evaluated in Phase II.

3.7.1 Video – Traficon

Sensor Description

Traficon NV of Belgium makes the Traficon suite of video sensors. A typical Traficon detection unit consists of a number of VIP (Video Image Processor) cards. The VIP card uses video signals captured by a camera as inputs, digitizes video images and uses detection algorithms to obtain different traffic parameters. A data monitor board (VIP/D) is used to monitor real-time traffic flow, collect traffic data and emulate a loop detector with auto-diagnostic LED indicators. A monochrome Philips camera with a 1/3-inch lens was used in this test. Menu-driven setup can be done by using a VIP keypad or a portable PC. Remote control setup via the VIEWCOM is also available. The camera and the VIP/D board are both powered by 24 VDC. Each camera can monitor multiple lanes of traffic with multiple detection zones. The camera can be mounted either overhead or to the side of the roadway. RS 232 or RS 485 protocol is used for communication. Application specific algorithms provide different types of traffic information such as
presence, volume, speed, gap time, density, occupancy and vehicle classification. The communication board handles the compression of images and transmission of data, alarms or images.

The cameras must be mounted to a relatively rigid structure to minimize camera movement. In general, the higher the camera is 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.

**Wiring:** The wiring for the camera and VIP card are simple. There are only two cables from the camera: power and video. An optional communication cable can be connected to allow the camera to pan and tilt. The video cable brings video signals to the video processor card. The VIP/D card is integrated into a standard 19-inch rack together with the communication board. The video image is output to a television through a video cable.

**Calibration:** The Trafcon system is calibrated through the interface displayed on a television screen. The VIP data monitor card displays the setup manual on television screen, which is controlled by the setup keypad. The interface is user-friendly. The calibration procedure involves camera aiming and zooming, initial parameter setup, sample data collection and parameters/camera adjustments. The time needed for an optimal calibration is a function of experience. Once familiar with the procedure, calibration can be conducted easily. During setup, detection lines/zones are superimposed onto the appropriate position in the video image. As a vehicle crosses these detection lines, it is detected. Critical calibration items include calibration of the detection zone, speed zone, camera height, focal distance and CCD sensor type. Camera angle and zoom level to the detection area are important because they determine if the coverage of detection areas on screen is large enough to enable accurate placement of the detection zones. Paint marks were sprayed on the pavement at ten-foot intervals to help locate the speed detectors on the screen. The length of the calibration zone needs to be consistent with the actual distance marked on the pavement and the shape of the zone should match the road geometry on the screen. The speed zones need to be carefully aligned with lane orientations. Camera height can be determined internally based on the calibration zone size, the focal distance of the camera lens and sensor type. When one parameter is adjusted, there are several corresponding parameters that need to be adjusted to maintain proper calibration. During the test, sample data was sent to vendor for review in order to ensure proper calibration.
Data Collection: The VIP data monitor card provides both individual vehicle data and aggregated flow data. The vehicle data includes volume, average vehicle speed, classification and flow data including traffic flow speed and zone occupancy. Data type can be selected through the interface manual. During the test, vehicle data was collected by the ADR.

Test Description

The Traficon camera was first mounted on the Penn Avenue bridge catwalk at a height of 21 feet on May 29, 2001. During a vendor visit to the project site on June 6, 2001, new firmware was installed and the software was upgraded so that the output contact closure was available. In August 2001, the sensor was calibrated and sample data was sent to vendor for review. In accordance with the test plan, the camera was moved to the sidefire tower and tested at five heights and three bases from November 27, 2001 to February 28, 2002. On March 22, 2002, the camera was mounted on the light pole at intersection at a height of 37 feet. It was aimed to face oncoming traffic on two lanes of the northbound approach.

Test Results at Mounting Location No. 1 -- Freeway Overhead Bridge

Installation: The Traficon camera installation was quite simple with the mounting accessories supplied by the vendor. The camera was mounted on the top of a notched coupling, which allowed the camera to pan and tilt. It took about one hour to install the camera, including wiring and powering. The camera was installed facing departing traffic. The vendor claimed that the sensor would perform better if the camera could be mounted toward approaching traffic, but this was not possible given the current test site configuration.

Detection Accuracy:

Volume: The Traficon sensor was tested at two heights on the bridge. The sensor showed excellent performance on March 11, 2002 when it was at a height of 21 feet. The absolute percent difference between the sensor data and loop data were under 5 percent for all three lanes. On March 7, 2002, the sensor was tested at a 30-foot height. Test results reveal that the sensor performed well during off peak periods with absolute percent differences fewer than 5 percent, but undercounted traffic during the peak periods with the absolute percent differences of some 15-minute intervals ranged between 10 percent and 50 percent. The undercounting may have resulted from a snow flurry on that day or un-optimal calibration.

Speed: The Traficon sensor performed well for speed detection at a height of 21 feet on March 11, 2002. The absolute average percent difference was 3 percent in lane one, 5.8 percent in lane two and 7.2 percent in lane three. During the March 7 evaluation under snowfall conditions,
the sensor was found to underestimate speed during the rush hour periods for all three lanes at a height of 30 feet. The range of absolute average percent difference was between 8.9 percent and 13 percent for three lanes.

**Test Results at Mounting Location No. 2 -- Freeway Sidefire Tower**

**Installation:** Similar to overhead installation, the Traficon camera was easy to mount to the sidefire tower for freeway test. Final adjustment for aiming and zooming were needed to calibrate the sensor.

**Detection Accuracy:**

*Volume:* The Traficon sensor was tested on all three bases with five different heights for bases one and three, but only three different heights for base two. At the first base (15 feet from the first lane), the sensor performed well for all five heights. The absolute percent differences between the sensor data and baseline data were under 5 percent consistently for all three lanes at all five heights. At base two (25 feet from the first lane), the data reveal that the performance was better at higher positions than at lower positions. Most of the absolute percent differences were under 10 percent. From lane one and two, the absolute percent differences changed from over 10 percent at 35 feet to 5 percent or less at 45 feet. At base three (35 feet from the first lane), the sensor provided good performance for lane one with less than 5 percent absolute differences for all the heights. The results indicate that the similar trend as at base two for lane two and three. The absolute percent differences for five heights were decreased from 10 percent to 15 percent at 25-30 foot height to fewer than 5 percent at 45-foot height. Refer to the figures in Appendix E for summarized findings of volume performance versus height for each base for each lane. Similar figures are also included for speed data.

*Speed:* At base one, the sensor demonstrated good performance in speed detection for lane two and three. The absolute average percent differences were under 8 percent for lane two and between 8 percent and 12 percent for lane one. At base two, test data reveal that the absolute average percent differences were under 8 percent at a height 40 feet but ranged between 12 percent to 20 percent at 35 feet and 45 feet height. The absolute average percent differences at five heights ranged from 2 percent to 12 percent for three lanes at base three.
Test Results at Mounting Location No. 3 – Intersection Overhead Pole

Installation: The Traficon camera was mounted on a light pole at the intersection at a height of 32 feet. A bucket truck was needed for this installation because, unlike the freeway test site, this was the only way to reach the sensor location. At least three people were needed to complete the work; two to mount and aim/zoom the camera and another person to perform the calibration. Calibration had to be done while the other personnel were in the bucket truck because modifications to camera aiming were required. The vendor indicated that the position of the camera at this location was not ideal, and that the sensor would perform better if it were mounted higher and further from the detection zone.

Detection Accuracy:

Volume: The Traficon sensor monitored both lanes of the northbound approach at a height of 37 feet facing oncoming traffic. The test data reveal that the sensor over-counted traffic in the right turn lane by 17 percent and undercounted traffic by 13 percent in the through lane. The vendor indicated that a different VIP card is designed for use in intersection applications and that the results would be improved by using this card.

3.7.2 Video – Autoscope

Sensor Description

The Autoscope Solo by Image Sensing Systems uses machine vision technology to produce traffic measurements. The system consists of an Autoscope Solo Machine Vision Processor (MVP), a communication interface panel and a Solo mini-hub that is integrated into a standard rack card. The Autoscope Solo MVP combines a video camera with electronic lens control, digital image processing and two communication ports to create an advanced video processor that detects vehicles and collects traffic data within the camera housing. The Mini-hub uses detector rack hardware to communicate with the MVP and a standard controller. Communication is made via two RS-485 ports (a coaxial cable is not required because the video image is compressed). The MVP is powered by 24 VDC. It can monitor multiple lanes of traffic with multiple detection zones. The sensor 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.

Wiring: The communication cable between the Autoscope Solo and mini-hub includes both video images and communication signals. Each wires is color-coded in order to identify its function. Special care was made to terminate the cable leads in accordance with the Installation Guide. The advantage of this approach is that the video image can be compressed for export to the interface panel and a coaxial cable is not needed.
**Calibration:**

Calibration is conducted through an interface with a personal computer. The interface is user-friendly. The calibration procedure involves camera aiming and zooming, initial parameter setup, sample data collection and parameters/camera adjustments. The time needed for optimal calibration is a function of experience. After a couple of times the process can be done efficiently. During setup, detection lines/zones are superimposed onto the appropriate position in the video image. As a vehicle crosses these detection lines, it is detected. Critical calibration items include calibration of detection zone, speed zone and camera height. Camera angle and zoom level to the detection area are also important because they determine if the coverage of detection areas on screen is big enough to enable accurate placement of the detection zones and speed zones. Paint marks were placed on the pavement at ten-foot intervals to assist placement of the detection zones and speed zones in the interface. The length of the calibration zone needs to be consistent with the actual distance marked on the pavement and the shape of the zone should match the road geometry on the screen. The size of the speed zones needs to be adjusted to reach the optimum setup based on the collection of sample data.

**Data Collection:**

The Autoscope Solo provides relay outputs to the ADR to allow volume and speed data collection. Additional parameters are available through the serial interface.

**Test Description**

The Autoscope Solo was installed overhead on the bridge on May 24, 2001. The first formal data collection period was conducted on October 3, 2001. On October 16 the sensor was moved to the sidefire tower and tested at varying heights and offsets as identified in the test plan. The mini-hub was inadvertently damaged on two occasions during the course of moving the camera when power supply wiring came in contact with communication wiring. The vendor provided replacements to help continue the test. The sensor was moved to the intersection in March 2002 and mounted on the light pole at a height of 37 feet. The intersection test was completed on March 22, 2002.

**Test Results at Mounting Location No. 1 -- Freeway Overhead Bridge**

**Installation:**

The Autoscope Solo was installed using a vendor supplied mounting bracket that is designed to attach to a vertical pole. The installation was simple, requiring about an hour to install the Solo unit. The vendor claimed that sensor would perform better if the camera could be mounted toward approaching traffic, but this could not be accommodated.
Detection Accuracy:

**Volume:** Time constraints only allowed testing at one height on the bridge. The sensor demonstrated excellent performance on October 3, 2001 at a height of 30 feet. The absolute percent differences between the sensor data and loop data were under 5 percent for all three lanes.

**Speed:** The sensor performed well for speed detection. The absolute average percent difference was 7 percent in lane one, 3.1 percent in lane two and 2.5 percent in lane three.

**Test Results at Mounting Location No. 2 -- Freeway Sidefire Tower**

**Installation:** The Autoscope Solo installation on the sidefire tower is as same as on the catwalk. The procedure itself is simple, but special care is needed to connect the wire leads. Final adjustment for aiming and zooming were needed in the process of sensor calibration.

Detection Accuracy:

**Volume:** The Autoscope Solo was tested at all three bases with five different heights at each base. The test data reveal that the sensor provided accurate volume detection at base one. The absolute percent differences at five heights were less than 5 percent for all three lanes and most of them were around 2 percent. At base two, lane one data was consistently good with 5 percent or less difference from the baseline. The detection accuracy for lane two and three varied between 2 percent and 7 percent. A 15 percent difference appeared only at a 25 height for lane three. At base three, data revealed that the absolute percent differences for most heights were between 3 percent and 10 percent. The trend indicates that the higher the mounting and the closer to the roadway, the better the performance. Refer to the figures in Appendix E for summarized findings of volume performance versus height for each base for each lane. Similar figures are also included for speed data.

**Speed:** At base one, the sensor performance was good in speed estimation for all three lanes. The absolute average percent differences were under 8 percent for all cases and most were under 5 percent. At base two, test data revealed that the absolute average percent difference for most cases was fewer than 6 percent for all three lanes. Similar to base one, the absolute percent difference at five heights were under 8 percent for three lanes and most of them were under 5 percent.

**Test Results at Mounting Location No. 3 – Intersection Overhead Pole**

**Installation:** Similar to the Traficon sensor, the Autoscope Solo was mounted on a light pole at the intersection at a height of 32 feet. A bucket truck was needed for this installation because, unlike the freeway test site, this
was the only way to reach the sensor location. At least three people were needed to complete the work; two to mount and aim/zoom the camera and another person to perform the calibration. Calibration had to be done while the other personnel were in the bucket truck because modifications to camera aiming were required. The vendor indicated that the position of the camera at this location was not ideal, and that the sensor would perform better if it were mounted higher and further from the detection zone.

Detection Accuracy

*Volume:* The intersection location, the Autoscope monitored the two-lane northbound approach at a height of 37 feet facing oncoming traffic. The data reveal that the sensor tended to over count in the right turn lane by 18 percent absolute difference. It also indicated a 19 percent absolute difference in the through lane.

### 3.7.3 Assessment Summary

The Traficon and Autoscope Solo video sensors evaluated in this test were found to perform very well in a wide variety of mounting locations and under varying levels of traffic congestion. There was no significant difference in performance, installation, calibration or reliability between the two sensors. In general, the performance of each sensor was improved when mounted high and close to the roadway. The amount of occlusion is minimized when mounted in this fashion.

As with most video systems, proper camera aiming and field-of-view are critical to optimal performance. The calibration process involves setting initial parameters, analyzing sample data and making any camera adjustments. The time for calibration is a function of personal experience. Both sensors tested have a user-friendly interface, enabling the sensors to be closely monitored to assure that they were operating correctly throughout all test periods.

Video sensors require additional installation and calibration time when compared to other traffic detection technologies. However, video sensors also provide a wide range of traffic parameters and can provide operators with an image of the roadway.

### 3.8 Sensor Cost

A sensor’s capabilities, performance and cost are three of the most important features to consider when evaluating. Cost, the most quantifiable attribute, is a function of the technology utilized, system configuration and the site application requirements. Cost can vary significantly based on the technology applied in sensor design. Some technologies, such as video, required a more complex design and therefore higher cost. System configuration can also result in different costs. A simple detector unit may only have a single sensor such as detectors manufactured by ASIM Technologies. In this case, the cost of a detector unit itself is the only expense. Some detectors have a processing
component that is separate from the sensor, such as most video detectors. The cost for most video detection systems include the cost of at least one camera and a processor. Finally, the site application is a dynamic factor in cost determination. Intersection applications and freeway applications require a different number of sensors and sensor configurations, resulting in different costs. For example, at least four cameras are needed for an intersection application for a video detector and one camera is needed for freeway application. In addition, the exact cost of a magnetic probe detection system is a function of the installation requirements, such as difficulty installing conduit, number of probes needed per lane and the distance between the sensor and the data collection system. Finally, some vendors provide discount prices for buying more sensors. All these factors cause cost variations for a given application.

Operation and maintenance costs are a function of long-term performance and cannot be accurately accessed given the project’s seven-month field test. Table 4 shows the vendor-recommended retail costs for all the sensors tested in this project. Notice, the price listed here may change in the future, vendor-authorized dealers should be contacted for final pricing.

**TABLE 4**

**SENSOR COST SUMMARY**

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Sensor</th>
<th>Unit Cost</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASIM Technologies Ltd</td>
<td>ASIM IR 254</td>
<td>$700</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASIM DT 272</td>
<td>$700</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASIM TT 262</td>
<td>$1,600</td>
<td></td>
</tr>
<tr>
<td>Image Sensing Systems, Traffic Control Corporation (Local Distributor)</td>
<td>Autoscope Solo</td>
<td>$7,000 (Intersection Application)</td>
<td>Cost includes Solo unit, Minihub, interface panel and cable</td>
</tr>
<tr>
<td></td>
<td>Autoscope Solo</td>
<td>$6,155 (Freeway Application)</td>
<td>Cost includes Solo unit, interface panel and cable</td>
</tr>
<tr>
<td>Schwartz Electro-Optics, Inc.</td>
<td>Autosense II</td>
<td>$6,000 - $7,500</td>
<td>Depending on configuration /functionality desired</td>
</tr>
<tr>
<td>SmarTek Systems, Inc.</td>
<td>SmarTek</td>
<td>$3,500</td>
<td>$3,080/unit for quantities over 10</td>
</tr>
<tr>
<td>Traficon NV</td>
<td>Traficon</td>
<td>Contact Vendor</td>
<td></td>
</tr>
<tr>
<td>3M ITS</td>
<td>Canoga Detector C822F (2 channel)</td>
<td>$546</td>
<td>Installation Kit $114/each Carriers (50/package) $354.90/package C30003 Home-Run Cable $390/1,000’ spool</td>
</tr>
<tr>
<td></td>
<td>Canoga Detector C824F (4 channel)</td>
<td>$703.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>702 Microloop Probe</td>
<td>$159.50/probe (+ $.39/ft for lead-in cable)</td>
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<td></td>
<td>701 Microloop Probe</td>
<td>$137.50/probe (+ $.39/ft for lead-in cable)</td>
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</tbody>
</table>
4. CONCLUSIONS

A comprehensive evaluation such as this produces a significant amount of data and observations. The challenge in this process is to summarize the relevant findings and also organize the detailed test results so those interested can readily access them. Obvious questions about which sensor performed best are difficult to answer because sensor performance must be evaluated in light of a number of different points. The following list highlights some of the considerations that must go into interpreting the test results:

- The level of expertise required and time spent installing and calibrating a sensor can become more important than the sensor’s initial cost.
- A reliable sensor can reduce the amount of maintenance work that must be done.
- A sensor that can detect multiple lanes can do the work of several single-lane sensors.
- A sensor that can be mounted overhead or to the side of a roadway offers more flexibility in its mounting location.
- A sensor with serial communication capability can allow for remote adjustment of calibration parameters and trouble-shooting.
- A sensor that employs wireless communication technology can simplify the data retrieval process.
- A solar or battery-powered sensor can be used to obtain temporary counts in a location without an accessible source of power.
- Some sensors offer much more traffic information than just volume or speed.
- Some sensors are impacted by weather conditions or do not operate as well when the traffic is congested.
- A sensor’s intended use affects its performance requirements. For example, a sensor used to actuate a signal must meet a different set of performance criteria than a sensor used to collect historical traffic data.
- Some sensors 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 sensors. As a result, this report cannot identify a single sensor or technology as being the best. What this report can do, however, is present a series of summary tables that provide an overview of the sensor performance in a few key areas. Table 5 provides a summary of each sensor’s volume and speed performance during one typical 24-hour test period. This “typical” test period represents a sensor’s performance at the freeway test site when mounted at the vendor’s recommended mounting height and offset from the roadway.
<table>
<thead>
<tr>
<th>Vendor</th>
<th>Sensor Model</th>
<th>Technology</th>
<th>Mount Location</th>
<th>Lane</th>
<th>Volume Accuracy (1)</th>
<th>Speed Accuracy (1)</th>
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</thead>
<tbody>
<tr>
<td>ASIM Technologies Ltd</td>
<td>ASIM IR 254</td>
<td>Passive Infrared (PIR)</td>
<td>Overhead</td>
<td>1</td>
<td>10.0%</td>
<td>10.8%</td>
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<td>ASIM DT 272</td>
<td>PIR/Ultrasonic</td>
<td>Overhead</td>
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<td>8.7%</td>
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<td>ASIM TT 262</td>
<td>PIR/Ultrasonic/Radar</td>
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<td>2.8%</td>
<td>4.4%</td>
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<tr>
<td>Image Sensing Systems</td>
<td>Autoscope Solo</td>
<td>Video</td>
<td>Sidefire</td>
<td>1</td>
<td>2.3%</td>
<td>5.7%</td>
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<tr>
<td>Traffic Control Corporation (Local Distributor)</td>
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<td></td>
<td></td>
<td>2</td>
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<td></td>
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<td>2.0%</td>
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<td>Schwartz Electro-Optics, Inc.</td>
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<td>Active Infrared</td>
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<td>1</td>
<td>0.7%</td>
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<td>SmarTek Systems, Inc.</td>
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<td>Sidefire</td>
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<td>Traficon NV</td>
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<td>7.2%</td>
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<td>3M</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>2.3%</td>
<td>1.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Under Bridge</td>
<td>1</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

Note:
(1). Volume and speed accuracy are measured by the absolute percent difference between sensor data and baseline loop data with 15-minute interval.
(2). The results in this table represent a single test at an optimal mounting location for each sensor.
This phase of research has provided a comprehensive assessment of sensor performance in a wide variety of mounting configurations. The NIT test facility’s overhead catwalk and adjustable sidefire tower allow sensors to be evaluated in numerous mounting situations. The evaluation fully examined the various mounting conditions by exceeding vendor-recommended mounting ranges.

Several interesting results have been realized by examining the mounting impact on sensor performance. Some results are readily intuitive, such as the optimal performance of video sensors occurring when the cameras are located closest to the freeway and as high as feasible. Such a location places the camera on top of the traffic as much as possible, thereby minimizing the effects of occlusion caused by vehicles blocking the view of vehicles in adjacent lanes. Beyond the “higher-the-better” finding is the first complete evaluation of the extent to which detection accuracy is affected by installation at locations further from the roadway and at lower heights. For example, the Autoscope detection accuracy in the closest lane (lane one) ranges from approximately 2 percent to 5 percent error as the camera is moved further from the side of the roadway, regardless of height. However, in the furthest lane (lane three) the detection accuracy ranges from approximately 2 percent to 8 percent as the camera is moved further from the side of the roadway.

Mounting location was also found to have a significant effect on the SmarTek passive acoustic sensor. In this case, the sensor performed best when installed at a 45-degree angle to the roadway (equal distance for both vertical height and horizontal offset between the sensor and centerline of the roadway). This location allows the sensor to receive the strongest acoustic signal when listening for the sound emanating from the tire and pavement interface. For example, the performance in lane one at a height of 40 feet varied from 17 percent error when 15 feet from the roadway to 8 percent when 35 feet from the roadway.

It is hoped that this detailed information on various mounting locations will be of use to traffic data practitioners in identifying acceptable mounting locations for sensors. Refer to the relevant figures in Appendix E for further information on all of the mounting scenarios that were evaluated.

One of the goals of this project is to explore practical considerations that influence the selection of a particular sensor. For example, the ease of installation and flexibility in mounting locations are important elements in selecting a sensor to install quickly and move from location to location. Simple sensors, such as many of the microwave sensors available on the market, have a “point-and-shoot” type of setup. Other sensors, such as the 3M Microloop, SmarTek, Autosense and ASIMs require some type of adjustment once the sensor is mounted. In most cases, this adjustment is performed over a serial communication line. The Autoscope and Traficon video sensors require extensive calibration over serial communication line, making them less suited for temporary applications, but also offer a wider array of traffic parameters. Table 6 provides further summarized findings of sensor performance for reliability, ease of installation, etc.
### TABLE 6
**SUMMARY OF SENSOR PERFORMANCE**

<table>
<thead>
<tr>
<th>Sensor Model</th>
<th>Technology</th>
<th>Freeway Test Site</th>
<th>Ease of Installation</th>
<th>Ease of Calibration</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Speed Performance</td>
<td>Volume Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak</td>
<td>Off Peak</td>
<td></td>
</tr>
<tr>
<td>Autosense II</td>
<td>Active Infrared</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
</tr>
<tr>
<td>3M Canoga</td>
<td>Magnetic</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>ECM Loren (1)</td>
<td>Microwave</td>
<td></td>
<td>+</td>
<td>+/-</td>
<td>+/-</td>
</tr>
<tr>
<td>Smartek</td>
<td>Passive Acoustic</td>
<td>+</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>ASIM IR 254 (2)</td>
<td>Passive Infrared (PIR)</td>
<td>+/-</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>ASIM DT 272 (3)</td>
<td>PIR/Ultrasonic</td>
<td>N/A</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>ASIM TT 262</td>
<td>PIR/Ultrasonic/Radar</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Autoscope</td>
<td>Video</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Traficon</td>
<td>Video</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

**Notes:**

+ Denotes a sensor that performed satisfactorily in the stated condition.

+/- Denotes a sensor that meets some but not all the criteria for satisfactory performance in the stated condition.

– Denotes a sensor that does not perform satisfactorily in the stated condition.

(1) The ECM Loren did not function in the test. No data available.

(2) ASIM IR 254 was difficult to calibrate for sidefire installation because of alignment complications.

(3) Data collection problem presented difficulty in fully evaluating the ASIM DT 272.
Weather impact is also a major concern in sensor applications. An assessment of weather impact on sensor performance was not formally addressed in this phase of the project for several reasons. First, numerous project delays resulted in field test activities beginning in October 2001. Testing ended in March 2002, providing primarily winter test conditions. Secondly, the upper Midwest experienced one of the mildest winters on record. Lastly, the field test plan called for an aggressive regime of testing under numerous different mounting scenarios. The addition of weather analysis would have complicated the test process. In this phase no significant correlation was observed between weather conditions and sensor performance. However, extensive field testing during Phase I resulted in a wide variety of weather conditions and correlations with sensor performance. Refer to the Phase I Final Report for more information.
5. NEXT STEPS

Evaluation activities continue at the NIT test site. A brief follow-up study will examine non-intrusive applications to bicycle and pedestrian detection. Field tests will be conducted during the late summer and early fall of 2002. Of particular interest is sensor performance in volume data collection at a nearby bicycle and pedestrian trail. Vendors are currently being solicited to participate in the study. This research is funded by the FHWA.

A future project phase seeks to design, build and test a Portable Non-Intrusive Technology (PNIT) traffic detection system. This project will address the challenges of collecting temporary count data along high-volume roadways that make the placement of road tubes difficult and unsafe for personnel. The proposed PNIT system will monitor traffic on multi-lane, high volume facilities without exposing personnel to traffic. Mn/DOT is leading this state pooled fund study with assistance from the FHWA.

The goal of the PNIT Project is to provide data collection practitioners with a cost-effective design of a PNIT system and an independent assessment of a variety of detection technologies. The project will document prior PNIT efforts conducted in Virginia, New York and Minnesota, prepare a detailed design specification for a portable system and conduct field tests with a variety of sensors. In addition, Application Guidelines will be developed to demonstrate how the portable system can be applied to real-world applications. The guidelines will assist transportation agencies in selecting detection techniques and mounting locations for specific needs. The Application Guidelines will include the following elements:

- Where to install the portable system for most effective detection (i.e., distance from roadway)
- How to take advantage of existing roadside infrastructure (i.e., roadside signs, overhead catwalks)
- Crash-worthiness concerns
- Pros and cons different sensors
- Pros and cons different power supplies (i.e., solar power)
- Ease of installation, maintenance and operation.
- System costs, including all components and sensors
- Considerations for use in specific applications

If project funds allow, a traveling demonstration will bring the PNIT system to agencies that have participated in the pooled fund study. The demonstration will be conducted with a van containing the PNIT system and several non-intrusive sensors. The demonstration will allow participating states to have their data collection personnel attend and gain first hand experience with the system operation.

The PNIT project utilizes the experience and facilities that the Minnesota Department of Transportation and SRF Consulting Group, Inc. have acquired through previous NIT evaluations.
Agencies interested in participating in the pooled fund study are encouraged to contact Farideh Amiri, the Mn/DOT NIT Project Manager, at (651) 296-8602.
6. REFERENCES

1. AASHTO, ITE, NEMA (1999), “National Transportation Communications for ITS Protocol (NTCIP),” *NTCIP 1209 Vol. 01-09*.

2. AASHTO “Guidelines for Traffic Data Programs”.


5. ASTM Standards: E 867 Terminologies on Vehicle Pavement Systems


7. Dan Middleton and Rick Parker, April, 2000, “Initial Evaluation of Selected Detectors to Replace Inductive Loops on Freeways”, *FHWA/TX-00/1439-7*


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