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16. Abstract This research supplemented findings of previous research projects on the topic of vehicle detection. Because improvements in performance aspects and in functionality of non-intrusive vehicle detectors continue to occur at an ever increasing pace, there were reasons to continue testing of the most viable products and determine their interface potential with other components of the Texas Department of Transportation's (TxDOT's) existing system. Like previous vehicle detector research, this research tested the latest and most promising non-intrusive vehicle detector technologies. The ones included in this research were: video image vehicle detection systems (VIVDS), acoustic, magnetic, inductive loops, and microwave radar. Besides evaluating detectors, the research scope also included investigating an interface with TxDOT's current Advanced Traffic Management System (ATMS) using contact closure inputs to current Local Control Units (LCUs) for collecting vehicle count, speed, and occupancy data. Findings of this research indicate that, of the detectors tested, the following technologies appear to be most promising for freeway applications based on cost, accuracy, and ease of setup: microwave radar and magnetometers. One of the VIVDS units tested was also accurate but its cost and ease of setup were inferior to the other two. Neither of the two technologies is affected by weather and they are capable of consistently achieving 95 percent count accuracy (or better) and can detect speeds to within 5 mph of true speeds.			
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INVESTIGATION OF VEHICLE DETECTOR PERFORMANCE AND ATMS INTERFACE

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CHAPTER 1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this project was to identify and investigate the count, speed, and occupancy accuracy of promising detectors that have the potential of replacing inductive loops and to determine how best to interface with the Texas Department of Transportation (TxDOT) Advanced Traffic Management System (ATMS).

1.2 BACKGROUND

Most vehicle detection today relies on inductive loop detectors; however, problems with installation and maintenance of loops have made it necessary to evaluate alternative vehicle detection systems. Several “non-intrusive” detection systems are becoming more prominent, being viewed as cost-effective replacements of inductive loops. Therefore, as new detectors are introduced or as existing detectors are improved, there needs to be continued research to investigate performance attributes. Past research indicates that testing needs to occur in a variety of traffic, weather, and lighting conditions to arrive at definitive conclusions that are useful to TxDOT.

The Texas Transportation Institute (TTI) has been involved in detector research for more than 10 years, with research projects 0-1715, 0-1439, and 0-2119 making recent contributions to the detector knowledge base (1, 2, 3). Early TTI research focused primarily on inductive loops and video image detection systems. Then, TTI field-tested other devices in low-volume conditions, so continuing tests in the more demanding environment of I-35 in Austin, Texas, adds substantially to what was already known from previous research.

1.3 OBJECTIVES

The project objectives were to:

- identify promising new or relatively untested detectors,
- conduct field tests of selected detectors to identify prospects for implementation, and
- determine the best means of interfacing with the TxDOT ATMS.

1.4 ORGANIZATION OF THE REPORT

This research report consists of six chapters organized by topic. [Chapter 2](#) provides a summary of literature sources based on a recent review. [Chapter 3](#) presents a summary of the improvements necessary to the test beds at S.H. 6 in College Station, Texas, and on I-35 near downtown Austin. [Chapter 4](#) provides some of the results from field-testing, primarily at the I-35 test bed. [Chapter 5](#) presents findings from the investigation of the most feasible interface

with the TxDOT ATMS. [Chapter 6](#) presents conclusions and recommendations based on this research and provides input on implementation of the findings. Appendices [A](#), [B](#), and [C](#) contain the detector specification, the detector selection guide, and data plots, respectively.

CHAPTER 2.0 LITERATURE REVIEW

2.1 INTRODUCTION

Researchers updated the literature search for each year of the research project. The results reflect the latest in vehicle detection deemed appropriate for TxDOT freeway applications. The emphasis, in this case for other than the Background section below, was on the time interval from 2003 to 2006 since previous TxDOT-sponsored research documented earlier research.

2.2 METHODOLOGY

This task included a recent comprehensive literature search to complement the research team's current knowledge base. It emphasized new research on this subject since recent research by TTI also included a literature search. Also, members of the TTI research team actively participated in networking activities throughout the course of the project to share research findings and learn from the experience of others, including involvement at conferences; e.g., the 2004 and 2006 North American Travel Monitoring and Exposition Conferences (NATMEC). Through these efforts of acquiring information, the research team was able to thoroughly evaluate both the existing and emerging detection systems.

2.3 LITERATURE REVIEW

Since the first known vehicle detector was introduced in 1928 at a signalized intersection, there have been hundreds of attempts to improve and create systems that monitor vehicle presence and passage at strategic locations on the nation's streets and highways. Without accurate and reliable detectors, traffic management decisions based upon real-time or historical data are compromised. Many agencies use post processing for quality assurance as opposed to quality control. Quality assurance attempts to "fix the data" or identify defective data rather than ensuring the accuracy and reliability of the equipment. Quality control emphasizes good data by ensuring selection of the most accurate detector, then optimizing detector system performance. The latter applies more to this project than the former.

Researchers organized the following findings on individual detectors by detection technology. The initial information comes primarily from other field-testing by the Minnesota Guidestar Program, the Hughes Aircraft study, and from earlier TTI research. The primary detection technologies are:

- video image vehicle detection systems,
- passive infrared,
- active infrared,

- magnetic,
- microwave radar,
- passive acoustic, and
- inductive loops.

Detection technologies discussed below are primarily non-intrusive, although the section begins with loops because they are still the most prominent detection system used in Texas and elsewhere.

2.3.1 Background

The first known installation of a vehicle detection device occurred at a Baltimore intersection, forming the first semi-actuated signal installation. The detector required drivers on the side street to sound their horn to activate the device, which consisted of a microphone mounted in a small box on a nearby utility pole. Another device introduced at about this same time was a pressure-sensitive pavement detector using two metal plates acting as electrical contacts forced together by the weight of a vehicle passing. This treadle-type detector proved more popular than the horn-activated detector, enjoying widespread use for over 30 years and becoming the primary means of vehicle detection at actuated signals (4).

Ongoing problems with the contact plate detector led to the introduction of an electro-pneumatic detector. It was not a final solution either because of its cost to install. Also, it was only capable of passage or motion detection. Inductive loops were introduced as a vehicle detection system in the early 1960s and have become the most widespread detection system to date (4). However, the well-documented problems with inductive loops have led to the introduction of numerous non-intrusive devices utilizing a variety of technologies to replace many of the failing inductive loops.

By the late 1980s, video imaging detection systems were marketed in the U.S. and elsewhere, generating sufficient interest to warrant research to determine their viability as an inductive loop replacement. In 1990, the California Polytechnic State University began testing 10 commercial or prototype video image processing systems that were available in the United States. Evaluation results indicated that most systems generated vehicle count and speed errors of less than 20 percent over a mix of low, moderate, and high traffic densities under ideal conditions. However, occlusion, transitional light conditions, and high-density, slow-moving traffic further reduced the accuracy of these new systems (5).

Hughes Aircraft Company conducted an extensive test of non-intrusive sensors for the Federal Highway Administration (FHWA). The objectives of the study, *Detection Technology for IVHS* (6), included determining traffic parameters and accuracy specifications, performing laboratory and field tests of non-intrusive detector technologies, and determining the needs and feasibility of establishing permanent vehicle detector test facilities. This research went beyond testing of video imaging systems, testing a total of nine

detector technologies and including both freeway and surface street test sites in a variety of climatic and environmental conditions. Conclusions indicated that video imaging systems were not one of the better performers in inclement weather.

In another study sponsored by FHWA, the Jet Propulsion Laboratory (JPL) conducted research to identify the functional and technical requirements for traffic surveillance and detection systems in an Intelligent Transportation System (ITS) environment. The report entitled *Traffic Surveillance and Detection Technology Development, Sensor Development*, (7), published in 1997, presented details on the development and performance capabilities for seven detection systems. JPL focused on video imaging, radar, and laser detection systems and utilized the work performed by Hughes (6, 8) to assess current technology capabilities.

The Minnesota Department of Transportation (MnDOT) and SRF Consulting Group, Inc. (SRF) conducted a two-year test of non-intrusive traffic detection technologies. This test, initiated by FHWA, had a goal of evaluating non-intrusive detection technologies under a variety of conditions. The researchers tested 17 devices representing eight technologies. The test site was an urban freeway interchange in Minnesota that provided signalized intersection and freeway main lane test conditions. Inductive loops provided baseline calibration. This initial test began in November 1995 and ended in January 1997 (9, 10, 11). A subsequent research project used this same site on I-394, investigating nine non-intrusive detectors from 2000 to 2002. This report provides details on the more recent research activities in a later section.

A critical finding of this MnDOT research was that mounting video detection devices is a more complex procedure than that required for other types of devices. Camera placement is crucial to the success and optimal performance of this detection device. Lighting variations were the most significant weather-related condition that impacted the video devices. Shadows from vehicles and other sources and transitions between day and night also impacted count accuracy (11).

The Texas Transportation Institute has been involved in detector research for more than 10 years, with early research addressing inductive loops and more recent research emphasizing non-intrusive detectors. Most of the research included field investigations, and some also included a state-of-the-practice review to identify success stories. Even though installation and maintenance practice for inductive loops should be well established due to product maturity, performance and service life attributes were still deficient at the outset of this series of research activities. One of the early detector research projects developed a *Traffic Signal Detector Manual* primarily for inductive loop installers. The manual presents installation procedures that ensure reliable performance and suggested practices to reduce loop installation time and maintenance costs (12). Other TTI research investigated the use of acoustic and active infrared detectors at traffic signals for reducing stops and delays to trucks, finding that inductive loops were still more reliable for these applications, and especially in inclement weather and in poor lighting conditions (13, 14).

2.3.2 FY 2003-2004 Literature Findings

More recent TTI research projects investigated the accuracy, reliability, cost, and user-friendliness of various non-intrusive detectors in seeking viable replacements for inductive loops. In Research Project 0-1715, TTI tested the Accuwave detector (microwave), the Nestor TrafficVision (VIVDS), the PIR-1 (passive infrared), the Electronics Integrated Systems, Inc. (EIS) Remote Traffic Microwave Sensor (RTMS) (microwave radar), and the SmartSonic (acoustic) detector at the S.H. 6 test bed. Tests on higher-volume urban freeways in Houston involved the Nestor TrafficVision (VIVDS), the Autoscope 2004 (VIVDS), and the RTMS (1). In Research Project 0-1439, TTI tested the VideoTrak-900® by Peek (VIVDS), the non-invasive microloop by 3M™ (magnetic), and the SAS-1 by SmarTek (acoustic) (2). In Research Project 0-2119, TTI tested the Autoscope Solo Pro (VIVDS), Iteris Vantage (VIVDS), SAS-1, and RTMS (3). TTI usually began field-testing new devices in the low- to moderate-volume conditions at its freeway test bed on S.H. 6 in College Station with subsequent more demanding tests at another test bed on I-35 in Austin.

This report also draws largely from another significant detector research effort conducted by MnDOT in two phases. Phase I was a two-year field test of non-intrusive detectors, completed in May 1997. The FHWA and MnDOT sponsored the research conducted by SRF Consulting. Phase I testing involved 17 sponsors and eight technologies and a variety of environmental and traffic conditions (freeway and intersection). Volume and speed data were the primary parameters tested, with classification tests also included on some devices. Both Phase I and Phase II tests used a site on I-394 near downtown Minneapolis. In order to improve on the facilities available in the first project, MnDOT built a permanent test shelter at the site. Following the completion of the structure in April 2001, the research team installed the data acquisition system, purchased the detectors to be tested, and pre-tested the detectors through the summer of 2001. The official freeway data collection lasted from October 2001 to early March 2002. They conducted the intersection test in late March 2002 (9, 10, 11, 15).

2.3.2.1 Inductive Loop Detectors

More recent research activities related to detectors have built upon the early research covered in the background section of this report. Because this research focused on a variety of detectors, there should be a comparison of newer detectors with the most commonly used detector in current practice—the inductive loop. If non-intrusive detector accuracy compares favorably with loops and their costs and ease of use are similar, there are many agencies that would choose the non-loop option. Reasons for not choosing loops include difficulties in closing heavily traveled lanes for maintenance activities, hazardous exposure of workers to traffic, and in some cases long-term maintenance costs of loops. The Minnesota Guidestar project noted above (9, 10, 11) used six 6 ft by 6 ft loops installed in previous tests by Hughes for baseline comparison of counts and speed accuracy. Therefore, the inductive loops were only approximately four years old when Minnesota testing occurred. Initial loop accuracy tests showed that the loops in lanes 1 and 2 on the freeway undercounted by 0.1 percent, while the high-occupancy vehicle (HOV) lane loops undercounted by

0.9 percent. Speed tests indicated that lane 1 loops underestimated true speed by 6.1 percent, and lane 2 loops underestimated speed by 1.9 percent.

Peek ADR-6000. TTI initially tested the Peek ADR-6000 vehicle classification system (using Idris technology) in TxDOT Research Project 0-2119, partly because of its potential as a single device that could collect both planning data and real-time freeway traffic data. TxDOT is still interested in the ADR-6000 for both purposes, but it appeared to require further evaluation when Project 0-2119 came to an end. The ADR-6000 uses inductive loop signatures for its classification algorithm, so its speed, count, and classification results exceeded previous experience from the more typical classifiers using loops and axle sensors (e.g., piezoelectric sensors). TTI designed the test site architecture in Project 0-2119 and in this project such that the Peek system contact closure output fed into a Local Control Unit (LCU), which in turn communicated with the Austin District Traffic Operations Center. The ADR stored classification data internally to be downloaded later to a site computer or to other computers via the Internet using file transfer protocol (FTP) (3).

The sites selected for the test were the I-35 test bed site near downtown Austin, which frequently experienced stop-and-go traffic, and the S.H. 6 test bed site in College Station. The S.H. 6 site offered free-flow conditions. TTI developed and equipped these two freeway test beds for this research and for future TxDOT-sponsored research with equipment such as equipment cabinets, computers, baseline inductive loops, charged couple display (CCD) cameras, Digital Subscriber Line (DSL) communication, and baseline inductive loops.

Results in this section came from only the I-35 test bed. TTI findings indicated that the ADR-6000 was very accurate as a classifier, counter, and speed detection device, and as a generator of simultaneous contact closure output. However, its recent introduction into the U.S. market and being adapted from a toll application are factors in its need for further refinement. [Table 1](#) shows the classification result for a dataset of 1923 vehicles, indicating only 21 errors and resulting in a classification accuracy of 99 percent (ignoring Class 2 and 3 discrepancies). This data sample occurred during the morning peak and included some stop-and-go traffic. For count accuracy, the Peek in this same dataset only missed one vehicle (it accurately accounted for vehicles changing lanes). [Figure 1](#) shows the close agreement of the ADR with two other test systems using one-minute speeds from the Peek, an overhead Doppler radar system, and an Autoscope Solo Pro. The graphic indicates discrepancies only at slow speeds (below about 15 mph) where the Doppler radar is known to drop out and the Autoscope speed accuracy decreases slightly. This research noted the need for Peek to continue refinements to the ADR-6000 to improve its stability in the harsh environment of a field equipment cabinet and to improve its user interface (3).

Researchers expect the future of the ADR-6000 in Texas and elsewhere in similar applications to be a function of its cost, willingness of agencies to continue installing inductive loops, and willingness of multiple agencies to develop agreements to share maintenance responsibilities (e.g., for shared data). The fact that it can serve the dual role is expected to be a positive factor, especially at more demanding locations with extremely high volumes and where it can serve both the traffic operations and traditional data needs.

Table 1. Peek ADR-6000 Classification Accuracy Comparison.

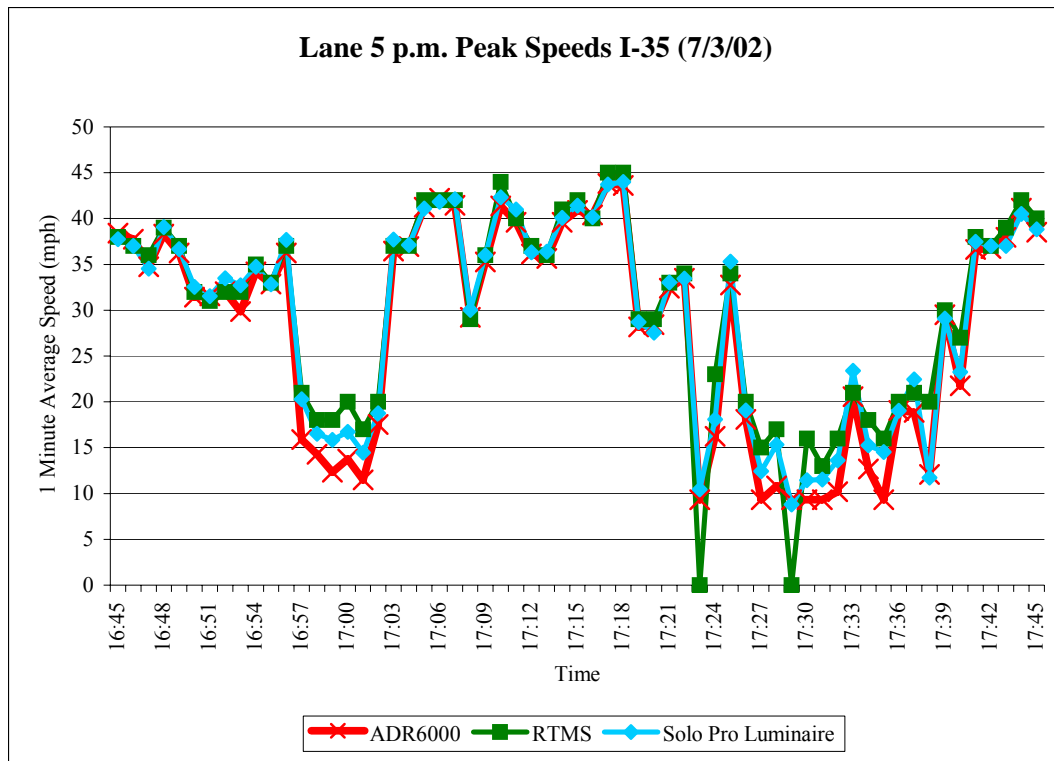
	Vehicle Classification												Errors	
	1	2	3	4	5	6	7	8	9	10	11	12		Total
Lane 1 Count	0	330	118	1	9	0	0	2	15	0	1	0	476	
Errors	0	0	0	0	1	0	0	0	2	0	0	0		3
Lane 2 Count	0	299	84	0	16	3	1	11	23	0	1	0	438	
Errors	2	1		3	1				1					8
Lane 3 Count	2	306	96	1	11	3	0	7	6	0	0	0	432	
Errors		1			2	1			1					5
Lane 4 Count	0	312	88	1	14	1	0	4	2	0	0	0	422	
Errors			1	1	1	1								4
Lane 5 Count	0	106	36	0	5	3	0	0	5	0	0	0	155	
Errors		1												1
Totals	4	1356	423	7	60	12	1	24	55	0	2	0	1923	
Total Errors	2	3	1	4	5	2	0	0	4	0	0	0		21

Source: Reference (3).

2.3.2.2 Video Image Vehicle Detection Systems

The Minnesota DOT and SRF Consulting completed a two-phase test of non-intrusive traffic detection technologies. The overall tests, initiated by FHWA, had a primary goal of providing useful evaluation on non-intrusive detection technologies under a variety of conditions. In phase I, researchers tested 17 devices representing eight different technologies, including VIVDS. The test site was an urban freeway interchange in Minnesota that provided both signalized intersection and freeway main lane test conditions. Inductive loops served as the baseline calibration system. Phase I of the tests ran from November 1995 to January 1996 and Phase 2 ran from February 1996 to January 1997 (9, 10, 11).

In Phase I, MnDOT researchers tested four VIVDS; the three included herein are: the Peek VideoTrak-900, the Autoscope 2004, and the Eliop Trafico EVA 2000. A critical finding of this research was that mounting video detection devices is a more complex procedure than that required for other types of devices. Camera placement is crucial to the success and optimal performance of the detection device. Lighting variations were the most significant weather-related condition that impacted the video devices. Shadows from vehicles and other sources and transitions between day and night also impacted count accuracy (11).



Source: Reference (3).

Figure 1. Speed Accuracy of the ADR-6000.

The Peek Transyt VideoTrak-900 exhibited count accuracy at the freeway test site within 5 percent of the baseline. However, when the device was moved to the intersection, periodic failures began to occur and continued throughout the testing. Researchers also observed that overcounting occurred during the light transition periods from day to night and vice versa. Like the VideoTrak-900, the Autoscope 2004 also monitored input from up to four cameras and performed within 5 percent accuracy at both freeway and intersection test sites. Light changes during transition periods also resulted in undercounting by the Autoscope (11).

Researchers found that the Eliop Trafico EVA 2000 had counts that were within 1 percent of the baseline loop system. Calibration of this system was difficult due to a complicated user interface; however, the system was not adversely impacted by any weather condition and was the only video system that was not affected by light transitions. The EVA 2000 was not tested at the intersection because it was not recommended for that use (11).

Duckworth et al. (16) conducted tests of various traffic monitoring sensors on a highway near Boston. The researchers found that VIVDS provided the best performance in the areas of detection, speed estimation, and vehicle classification. However, they noted that VIVDS had limitations in poor lighting and certain weather conditions, and was the most

expensive sensor tested. In 1996, Courage et al. (17) assessed the state-of-the-art in video image detection technology and possible applications; however, they did not assess accuracy or cost.

Autoscope 2004. In Research Project 0-1715, TTI tested the Autoscope 2004 on the three eastbound lanes of U.S. 290 in Houston near Pinemont. Lane 1 Autoscope counts from 6:00 a.m. to midnight during the five-day test period (February 1999) were generally within 10 percent of baseline counts. Many of the 15-minute counts were within 5 percent of baseline. Counts after dark were the exception, with the Autoscope overcounting by as much as 30 to 40 percent. The lane 1 counts should have been the most accurate of the three lanes, and a better camera and an improved position closer to the lane should improve its accuracy. Lane 2 counts were more erratic than lane 1 counts. Daylight errors were both positive and negative in the range of +20 percent to -50 percent. Nighttime errors were even worse. Lane 3 daylight errors were in the +20 to -30 percent range, and nighttime errors were again worse (1).

Autoscope Solo. The Autoscope Solo is a video imaging system whose cameras can be mounted either overhead or to the side of the road. MnDOT tests of the Autoscope 30 ft over the center of the lanes indicated excellent performance. The absolute percent volume difference between the sensor data and loop data was under 5 percent for all three lanes. The detector also 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. For other mounting locations beside the roadway, the detector performed best when mounted high and closest to the roadway (15).

Autoscope Solo Pro. At the time of this research, the Autoscope Solo Pro was the latest version of the integrated camera and processor. TTI tested this detector both in College Station on S.H. 6 (all low- to moderate-volume free-flow conditions) and in Austin on I-35 (high-volume with some stop-and-go traffic). The results reported in this section come from the I-35 test bed and are based on five-minute samples of count and speed data. The I-35 site has five southbound lanes with lane 1 (the median lane) being farthest from the detector. For these tests, the Solo Pro was 35 ft above the pavement and 6 ft from the nearest lane (3).

The Autoscope Solo Pro count accuracy was within 5 to 10 percent of the baseline counts during free-flow conditions, but it generally diminished in all lanes when 5-minute interval speeds dropped below 40 mph and especially during stop-and-go conditions. On all four of the monitored lanes, it overcounted during free flow, but almost always within 10 percent of baseline counts. During the peak periods, however, it undercounted. On lane 1, its error was always within 10 percent. On lane 2, its undercounts were about half within 10 percent and half between 10 and 20 percent. On lane 3 (closer to the camera), its undercounts were two-thirds within 10 percent and one-third between 10 to 20 percent of baseline counts. On lane 4, the Autoscope had 9 out of 10 within 10 percent and one out of 10 between 10 and 20 percent. Speed and occupancy of the Solo Pro were the best of any non-intrusive devices tested by TTI in these evaluations. Speeds were almost always within 0 to 3 mph of the baseline system. Its 15-minute cumulative occupancy values differed from

loops by as much as 3.9 percent, but during most intervals its difference was less than 1 percent (3).

Iteris Vantage. TTI tested the Iteris Vantage on I-35 in Austin as part of Research Project 0-2119 immediately following its initial release for freeway applications. It had the highest standard deviation during free flow of all test devices on both lanes 1 and 3. Overall, the Iteris count accuracy was not as dependent on prevailing freeway speeds as some other devices. It did not have a significant bias toward overcounting or undercounting. Its lane 1 morning peak counts were between -1 and -22 percent during slow speeds (20 to 30 mph); then it overcounted by as much as 10 percent when speeds increased. It mostly overcounted in lane 1 during the afternoon peak with a range from -4 to +10 percent. Lane 2 Iteris morning peak counts were all within the range of 0 to -10 percent except one and that one was at +5 percent. In the afternoon, its range was -5 to +10 percent, and all but four of its intervals were within ± 5 percent. Lane 3 Iteris morning peak counts were all within the range of +2 to -7 percent. In the afternoon peak, the Iteris was +5 to -10 percent. Lane 4 counts were not available (3).

For speed accuracy, the Iteris standard deviation was among the lowest of the devices tested on both lanes 1 and 3. Its mean values of speed differences were lowest on lane 3, perhaps indicating better calibration than on lane 1. The Iteris Vantage speed estimates were both higher and lower than the baseline speeds but usually within 5 mph in lane 1 during the morning peak. During the afternoon peak, it was always within 5 mph on lane 1. On lane 2, its morning peak speed estimates exceeded the baseline by as much as 15 mph. During the afternoon peak, it was always within 5 mph on lane 2. On lane 3 during the morning peak, its speeds were excellent in all intervals showing speeds within 0 to 2 mph of the baseline. During the afternoon peak, it was within 5 mph of the baseline. On lane 4, the Iteris was consistently within 5 mph of baseline during the morning peak. Speeds during the afternoon peak were not available (3).

Of the three non-intrusive devices tested for occupancy output in lanes 3 and 4, the Iteris Vantage was the second most accurate. Its 15-minute cumulative occupancy values differed from loops by as much as 8.1 percent, but during most intervals its difference was less than 6 percent.

Traficon NV. MnDOT Phase II tests mounted the Traficon VIVDS directly over the lanes at heights of 21 ft and 30 ft facing downstream. The preferred orientation was facing oncoming vehicles, but site features precluded this orientation. At the 21-ft height, the absolute percent difference between the sensor data and loop volume data was under 5 percent for all three lanes. At the 30-ft height, its off-peak performance was similar but it undercounted during congested flow showing an absolute percent difference of some 15-minute intervals from 10 percent to as high as 50 percent. Reasons suspected for the reduced accuracy were snow flurries and sub-optimal calibration. Its speed accuracy at 21 ft indicated good performance. Its absolute average percent difference was 3 percent in lane 1, 5.8 percent in lane 2, and 7.2 percent in lane 3. During the snowfall, its speed accuracy declined to a range of 8.9 percent to 13 percent (15).

VideoTrak-900 by Peek. TTI evaluated the Peek VideoTrak in 2000 as part of Research Project 1439. Count accuracy for the VideoTrak was significantly worse after dark compared to accuracy during daylight hours. Therefore, the results in [Table 2](#) represent the time periods between 7:00 a.m. and 5:30 p.m. The drop in accuracy indicated by comparing [Table 3](#) with [Table 2](#) was likely due to wet pavement (headlight reflections) and not due to reduced visibility since the rainfall rate was low to moderate. Adjustments by Peek technicians via remote access still left it with consistent overcount errors at night in the right lane; they were as high as 40 percent even in dry weather (2).

Speed results for the VideoTrak indicate a mean of +1.4 mph and a standard deviation of 6.9 mph. Because speed accuracy was significantly worse during nighttime hours (due probably to no street lighting), TTI did not provide data for those hours. The performance of the VideoTrak during rain was also worse than for periods of no rain. The speed data from the VideoTrak also indicated more dispersion about the sample mean than for other devices tested and a bias toward overestimating speeds (2).

Table 2. VideoTrak Daytime Count Error Rates on S.H. 6 during Dry Weather.

Error Range (%)	Lane	
	Left	Right
0 to 10	268 of 294 (91.2 %)	278 of 294 (94.6 %)
10 to 20	22 of 294 (7.5 %)	16 of 294 (5.4 %)
20 to 30	4 of 294 (1.3 %)	0

Source: Reference (2).

Table 3. VideoTrak Daytime Count Error Rates on S.H. 6 during Wet Weather.

Error Range (%)	Lane	
	Left	Right
0 to 10	6 of 18 (33.3 %)	9 of 20 (45.0 %)
10 to 20	6 of 18 (33.3 %)	8 of 20 (40.0 %)
20 to 30	6 of 18 (33.3 %)	2 of 20 (10.0 %)
30 to 40	0	0
40 to 50	0	1 of 20 (5.0 %)

Source: Reference (2).

2.3.2.3 Microwave Radar Detectors

Minnesota Guidestar Phase I researchers tested one radar device, the RTMS X2 by Electronic Integrated Systems, Inc. This device can be mounted either overhead or in a sidefire position aimed perpendicular to traffic. The RTMS is easily mounted but requires a moderate amount of calibration to achieve optimal performance. MnDOT researchers found that rain affected the performance of the RTMS, although they attributed this degradation to water entering the device and not to limitations of the technology. When the RTMS was

mounted overhead, it undercounted vehicles by 2 percent or less at the freeway site. When it was in a sidefire orientation, it undercounted traffic by approximately 5 percent. Intersection tests did not include the RTMS (11).

Results of TTI field tests at its I-35 test bed in Austin indicated that the RTMS X2 is much more accurate in both counts and speeds in the overhead position although it covers only one lane in that orientation. The more popular orientation is sidefire, so the following discussion focuses on its sidefire accuracy. In sidefire, the RTMS can generate speeds and counts for five lanes with reasonable accuracy. (The tests at the I-35 site used five lanes.) Its advantages also include ease of setup, being mounted only 17 ft above the roadway, and good user interface. Its coverage and initial cost make the RTMS an economical means of monitoring several lanes. In previous research, TTI found it to have the lowest life cycle cost for freeway applications of those detectors included in that research (3).

More specifically, the TTI research found that the RTMS undercounted in all lanes during both peak and off-peak intervals. Its five-minute counts in lane 1 were all in the -10 to -25 percent range. (The detector location was nearest lane 5, so lane 1 was farthest away.) Researchers did not evaluate lane 2. In lane 3, 95 percent of the time intervals were within 5 percent of baseline. In lane 4, 98 percent of the time intervals were within 15 percent of baseline counts. These findings indicate that distance from the detector and occlusion affected count accuracy. Lane 1 was slightly worse than lane 3, and lane 4 was slightly worse than lane 3, suggesting either calibration differences or middle lanes naturally being better than either extreme. Aggregated speed estimates by the sidefire RTMS differed from baseline speeds by as much as 15 mph during peak periods, but it was usually within 5 to 10 mph of baseline speeds during the off-peak. This research did not include occupancy tests on the RTMS (14).

In the overhead position, the RTMS was even more accurate in counting vehicles, but it only covers one lane. In TTI tests, the overhead RTMS (Doppler mode) generated excellent speeds until prevailing traffic speeds dropped below about 15 mph. It is a mature product and is not significantly affected by weather or lighting conditions (3).

The Detector Evaluation and Testing Team (DETT) of the California Department of Transportation (18) tested two radar detectors, the RTMS X3 and the Wavetronix SmartSensor. The test site was the Caltrans test facility on I-405 near the University of California at Irvine, which uses the seven northbound lanes for tests. Traffic volume at this site is about 3 million vehicles per week. Another technology tested at this site was the Inductive Signature Technologies (IST) product that has the capability of tracking vehicles using inductive loop signatures. The team collected both 30-second and 5-minute aggregate data at this site. Results indicate that the ground truth inductive loops overcounted by 1.0 to 1.5 percent. This overcounting is due at least in part to lane changers that cross sensors in two adjacent lanes.

The California tests indicated that with proper installation and calibration either detector can deliver better than 95 percent overall vehicle count accuracy at 5-minute and 30-second intervals and 95 percent speed accuracy at 5-minute intervals. Neither detector

was found to be suitable for determining occupancy based on a very strict Caltrans specification. One of the comments from researchers was that the RTMS requires considerable effort to achieve acceptable data accuracy, requiring expert know-how and a lot of time to set up and calibrate. According to the research team leader, the Wavetronix only required 15 to 20 minutes total to set up, whereas a factory representative took about one hour per lane for the RTMS. Also, the technology can be very accurate in the center of a roadway but the presence of trucks and heavy traffic can cause the detectors to miss vehicles as well as to create false readings in side lanes (18).

2.3.2.4 *Passive Acoustic Detectors*

In MnDOT phase I tests, the SmartSonic TSS-1 detectors were relatively easy to install and calibrate. Low temperatures and the presence of snow on the roadway, which may have muffled sound, were both correlated with undercounting by the devices. When mounted on the freeway bridge, SmartSonic devices undercounted daily traffic from 0.7 to 26.0 percent. This undercounting was attributed in part to the echo-filled environment underneath the bridge. Researchers found that both SmartSonic devices undercounted vehicles during freeway testing and overcounted at intersection testing. In limited testing of speed accuracy, the acoustic detection system was ± 10 percent when compared to inductive loop detection systems. Power requirements for the system are low, 5 to 6 watts, which allow the use of solar panels (11).

MnDOT phase II tests included the SAS-1 by SmarTek. SRF Consulting bench-tested the sensor in the lab in March 2001, then mounted it on the sidefire tower in May 2001. These tests used a total of five heights and three offsets during the actual field tests between October 2001 and January 2002. Additional testing occurred at the intersection in March 2002. Results indicated that at the first base (15 ft from the first lane), the detector provided better results for lanes 2 and 3 than for lane 1. The 24-hour data show that the absolute percent differences for lanes 2 and 3 were under 8 percent at all heights, and between 12 percent and 16 percent for lane 1 with heights less than 30 ft. Results were good for free-flow traffic conditions, but the detector undercounted during congested flow when speeds dropped. Test data showed that 15-minute absolute percent differences were between 0 and 5 percent during off-peak, and varied from 10 percent to 50 percent during congested periods, depending on site geometry. In speed detection, the detector performed well at base one. The absolute average percent differences were under 8 percent for most mounting heights and between 12 percent and 16 percent for lane 1 at heights less than 30 ft. Overall test results show that the detector performs best when mounted with equal height and horizontal offset between the detector and the centerline of multiple lanes (45-degree angle) (15).

TTI tested two SmartSonic detectors at its S.H. 6 test bed in College Station as part of Research Project 0-1715. The detector usually overcounted vehicles between midnight and 6:00 a.m. at an error rate as much as 50 percent higher than loop counts on six out of seven count days. On the day of undercounts, the magnitude of error was 35 to 50 percent during those same hours. Midday accuracy for the SmartSonic was usually within 5 percent of loop counts (1).

The first full test of the SAS-1 by TTI was at its S.H. 6 test bed as part of Research Project 1439 (2). The only factor found to affect the SAS-1 count accuracy in this series of tests was rainfall. The detector’s performance declined during wet weather, as indicated by a comparison of Tables 4 and 5 below. The vendor, who was involved on-site in the initial setup, discovered an error in the lane sensitivity setting that might have accounted for the undercounting that occurred during rain. Unfortunately, there was no other wet weather during these tests to verify the assumed improvement.

Table 4. SAS-1 Count Error Rates on S.H. 6 during Dry Weather.

Error Range (%)	Lane	
	Left	Right
0 to 10	353 of 378 (93.4 %)	376 of 378 (99.5 %)
10 to 20	25 of 378 (6.6 %)	2 of 378 (0.5 %)
20 to 30	0	0

Source: Reference (2).

Table 5. SAS-1 Count Error Rates on S.H. 6 during Wet Weather.

Error Range (%)	Lane	
	Left	Right
0 to 10	4 of 20 (20.0 %)	4 of 20 (20.0 %)
10 to 20	12 of 20 (60.0 %)	3 of 20 (15.0 %)
20 to 30	4 of 20 (20.0 %)	13 of 20 (65.0 %)

Source: Reference (2).

The second project at TTI to test the SmarTek SAS-1 detector was Research Project 0-2119. The initial equipping and setup of the I-35 test bed occurred in this project, requiring a significant expenditure of project resources, but creating an excellent site for this and future research endeavors pertaining to non-intrusive detectors. The SAS-1 height above the freeway was 35 ft and its offset from the nearest lane (lane 5) was 6 ft. Its count accuracy for lane 1 (farthest) dropped during congested flow compared to free flow, but on lane 3 the accuracy was similar for the two conditions. The SAS-1 generally undercounted almost all intervals. In lane 1 during the a.m. peak and while speeds were over 40 mph its count range was 0 to -10 percent. During slower speeds, its range was -12 to -32 percent. Its range for lane 1 afternoon peak intervals was +2 to -20 percent with all but two intervals between 0 and -10 percent. The SAS-1 lane 2 ranges for the morning and afternoon peaks were +5 to -18 percent and 0 to -10 percent, respectively. Lane 3 counts fell in the range of +6 to -12 percent during the morning peak and -2 to -14 percent during the afternoon peak. In lane 4, it undercounted during both the morning and afternoon peak by the range of -3 to -15 percent and 0 to -12 percent, respectively (3).

The speed accuracy of the SAS-1 was similar in congested flow and free flow on lane 1. For lane 3, its mean and standard deviations indicate its accuracy was more consistent in free flow than in congested flow. The SAS-1 consistently overestimated speeds in lane 1 during the morning peak by 5 to 10 mph. During the afternoon peak, it overestimated speed by as much as 20 to 25 mph during very slow speeds then improved to within 5 mph as speeds reached free-flow conditions. On lane 2 during both the morning and afternoon peaks, the SAS-1 was almost always over the baseline system by 0 to 5 mph with a maximum of 10 mph. On lane 3 this detector was consistently within 2 to 5 mph of the baseline system. On lane 4, its morning peak speed estimates were consistently within 5 mph and its afternoon peak speed estimates were less consistent but still within ± 5 mph (3).

This research also compared the lane occupancy output of the SAS-1 with the baseline loop system in lanes 3 and 4. Its 15-minute cumulative occupancy values differed from loops by as much as 14.7 percent, but during most intervals the difference was less than 4 percent (3).

2.3.2.5 Active Infrared Detectors

Preliminary testing by public agencies indicates very promising results for monitoring vehicle speeds and classifications. Active infrared systems appear to operate during day/night transitions and other lighting conditions without significant problems. Some infrared sensors can be placed at the roadside or overhead on sign structures. The only weather conditions that appear to be problematic are heavy fog and heavy dust. Disadvantages of infrared sensors include: cost; inconsistent beam patterns caused by changes in infrared energy levels due to passing clouds, shadows, fog, and precipitation; lenses used in some devices may be sensitive to moisture, dust, or other contaminants; and the system may not be reliable under high-volume conditions. England uses infrared detectors extensively for both pedestrian crosswalks and signal control. Infrared detection systems are also used on the San Francisco-Oakland Bay Bridge to detect presence of vehicles across all five lanes of the upper deck of the bridge, thereby providing a measure of occupancy (1).

An active infrared device detects vehicle presence by emitting a laser beam toward the road surface and measuring the time required for the reflected signal to return. The presence of a vehicle will reduce the return time for the reflected signal to the detection unit. Phase I of the Minnesota Guidestar project evaluated one active infrared device, the Schwartz Electro-Optics (SEO) Autosense I, and the project only tested this detector on the freeway. In addition to detecting stationary and moving vehicles by presence, the Autosense I can obtain vehicle speed and vehicle profile (which researchers can use for classification) (11).

The Autosense I system was very accurate at counting traffic at the freeway location; however, some weather conditions reduced its accuracy. Heavy snowfall, as well as rain and freezing rain, caused the detector to both overcount and undercount vehicles. During snow, the undercounting was attributed to vehicles traveling out of the detection zone, while overcounting was probably the result of falling snow reflecting the laser beams causing false detections. These discrepancies were attributed to the change in reflectivity properties of the pavement (11).

In research aimed at reducing the number of trucks stopping at isolated signalized intersections, TTI tested the SEO Autosense II as one of the options for detecting and classifying vehicles. One of the detector's strengths was its ease of setup and being able to begin data collection immediately. However, one of its weaknesses was its lack of ruggedness for field applications. The Autosense II requires mounting almost directly over the lane, which may necessitate installing a special pole and mast arm (13).

The detector's list price of \$10,000 (purchased in 1995) for one lane of coverage may be a constraint for some agencies, but it should maintain its accuracy in most weather and lighting conditions. This statement regarding weather and lighting is based on known characteristics of the technology rather than on the specific sensor because TTI did not test this sensor during inclement weather. Its speed accuracy was not as consistent as desired for the intended application, and it demonstrated a consistent bias toward overestimating speeds compared to the baseline loop system. Its speed bias of approximately 6 mph can be adjusted through software but its data scatter is also undesirably high. Its standard deviation on speed for a sample size of 158 vehicles was 10 mph. The classification accuracy of the Autosense II detector was one of its strengths. In a sample of 160 vehicles, it only missed 3 percent and misclassified 7.5 percent (13).

2.3.2.6 *Passive Infrared Detectors*

Passive infrared devices use a measurement of infrared energy radiating from a detection zone to detect vehicle presence. Passive infrared technology performed well at both freeway and intersection testing locations in Minnesota and is a good technology for monitoring traffic in urban areas. The passive infrared devices tested during the Guidestar test were the Eltec Models 833 and 842, and the ASIM IR 224. Although some atmospheric conditions can affect the amount of energy reaching the detector, it does not necessarily compromise a particular product's accuracy. In fact, the Guidestar researchers found that passive infrared devices were not impacted by weather conditions and were very easy to mount, aim, and calibrate. However, there were significant differences in performances of the devices tested (11).

The Eltec Models 833 and 842 are self-contained passive infrared detectors that are easy to mount and calibrate. The Eltec models, which are designed to be mounted either overhead or to the side of the roadway, can be used to monitor either oncoming or departing traffic. However, repeatability was an issue, and in some instances, it had significant fluctuations in count accuracy. The best performance of the vehicle occurred during a 24-hour test when the device counted within 1 percent of baseline data (11).

The ASIM IR 224, which is designed to be mounted either overhead or slightly to the side of the roadway, must face oncoming traffic. The IR 224 was easy to mount and calibrate, and repeatability was good. One device was observed to undercount vehicles during snowfall; however, this miscounting may have been the result of vehicles traveling outside of the sensor's detection zone. The results of this device during an optimal 24-hour

count period at both the freeway location (within 1 percent of baseline data) and the intersection (within 2 percent of baseline data) were among the best results obtained (11).

Both the Hughes Aircraft Company (6) and Duckworth et al. (16) included passive infrared detectors in field tests. However, neither gave the detectors tested exceptionally high marks in their evaluations and conclusions.

2.3.2.7 Microwave Detectors

The MnDOT research tested four different Doppler microwave devices, but the research team presented detailed data for only two. All four devices were easily mounted and calibrated, and none of the devices seemed to be affected by weather conditions. The devices tested revealed differences in performance. Both the Peek PODD and the Whelen TDN-30 required mounting overhead or slightly to the side of the roadway. Under optimal conditions, the Peek PODD was able to count vehicles at the freeway site within 1 percent of the baseline, provided that the device was properly aimed. During one of the procedures, it detected vehicles in the adjacent lane. The PODD was unable to collect good data for the intersection site. The primary role of the Whelen TDN-30 was to collect speed data, but it can also count vehicles. It undercounted vehicles at the freeway site by approximately 3 percent but was unable to collect meaningful data at the intersection site (8).

In August 1998, TTI tested the Accuwave 150 LX detection accuracy on S.H. 6 (free-flow traffic) even though it is designed for signalized intersections. TTI experienced two challenges in these tests. The first challenge was establishing an appropriate orientation of the detector in an attempt to capture only one lane. Installers finally had to count both lanes then use time stamps from other detectors to eliminate unwanted counts. The second problem concerned the sampling rate used by TTI's National Instruments setup. Field engineers varied the sampling rate between 350 milliseconds (msec) and 450 msec to test its effect, and this sampling rate almost certainly affected accuracy. Moderate to heavy rain caused the Accuwave to experience continuous detections, so results were not accurate. The detector returned itself after the rain stopped. During intervals with no rain during the midday period, Accuwave counts were usually within 10 percent of loop counts. During non-midday periods and no rain, its count error was in the 30 to 40 percent range (1).

2.3.2.8 Pulse Ultrasonic Detectors

The Minnesota research team tested two pulse ultrasonic devices, the Microwave Sensors TC-30 and the Novax Lane King. Overhead mounting of the device provides optimal signal return and vehicle detection; however, sidefire mounting is possible for some devices. Pulse ultrasonic devices are relatively easy to mount; however, the ease of calibration varies with devices. Weather conditions did not impact the performance of the devices (11).

The TC-30, which may be mounted either overhead or sidefire, was found to provide an accurate vehicle detection count at the freeway test site and a tendency to overcount at the intersection test site. The TC-30 was easy to mount and calibrate. Researchers observed that vehicles stopped in the detection area were counted multiple times, resulting in the

overcount. The Novax Lane King can also be mounted either overhead or in a sidefire configuration. The Lane King was easy to mount; however, calibration was extensive for optimum performance. The Lane King was extremely accurate in counting vehicles at the freeway site, but at the intersection site, overcounting occurred as the result of double counting. The two pulse ultrasonic devices interfered with one another when mounted next to each other (11).

2.3.2.9 Magnetic Detectors

There was other limited information on detectors or techniques being tested or implemented for monitoring traffic. These systems may be applicable in more limited situations where those discussed above might not be as appropriate.

Passive magnetic devices measure the change in the earth's magnetic flux created when a vehicle passes through the detection zone. For example, the 3M microloop detection system is a passive sensing system that is based on the earth's magnetic field. When a vehicle passes through the detection zone, it temporarily distorts the earth's magnetic field (15). A passive magnetic device must be relatively close to the vehicles it is detecting; therefore most applications require installation below the pavement. The Minnesota Guidestar Phase I test device was the Safetran IVHS Sensor 232E, with two probes installed in conduit underneath the roadway. Operators can use the device's output to generate volume, speed, and occupancy data. Installation of the passive magnetic devices was difficult and required several days. Probe performance appeared to be compromised by water in the conduit and in the handhold area. The erratic performance, observed during periods of intermittent rain, could be due to intermittent grounding problems. Vehicles straying from the normal lanes resulted in overcounting during periods of snow (11).

The 3M magnetic detector system consisted of three components:

- Canoga Model 702 Non-Invasive microloop probes,
- Canoga C800 series vehicle detectors, and
- 3M ITS Link Suite application software.

The microloop probes can monitor traffic from a 3-inch non-metallic conduit 18 to 34 inches below the road surface or from underneath a bridge structure. Installers must use a magnetometer underneath bridges to determine proper placement of the probes; otherwise optimum performance requires a trial-and-error process. Probes installed in a "lead" and "lag" configuration under pavements or bridges can monitor speeds by creating speed traps in each lane. One of the requirements of this system is that the probes remain relatively vertical, so keeping the horizontal bores straight is critical. Probes placed in a non-vertical orientation can lead to speed errors. MnDOT tests under pavement indicated excellent volume and speed results. The absolute percent volume difference between sensor and baseline was under 2.5 percent, which is within the accuracy capability of the baseline loop system. For speeds, the test system generated 24-hour test data with absolute percent

difference of average speed between baseline and test system from 1.4 to 4.8 percent for all three lanes (15).

TTI tested 3M microloops at its S.H. 6 test bed in College Station as part of Research Project 0-1439. At this relatively low- to moderate-volume site, TTI found that, for a six-day count period, 3M microloops were almost always within 5 percent of baseline counts. In the right lane, all except two 15-minute intervals out of the 330 total intervals were within 5 percent of baseline counts. The remaining two were within 10 percent of baseline counts. Therefore, microloop counts were within 5 percent of baseline counts 99.4 percent of the time in the right lane (dual probes). In the left lane (single probes), 94.5 percent of the 15-minute intervals were within 5 percent, 4.5 percent were between 5 and 10 percent, and in 1.0 percent there was a more than 10 percent difference from baseline (2).

2.3.2.10 *Bicycle and Pedestrian Detectors*

MnDOT and FHWA sponsored yet another component of the Evaluation of Non-Intrusive Technologies for Traffic Detection (19) to research and compare the effectiveness of non-intrusive detectors for detecting pedestrians and bicycles. Accurate detection can prevent potential crashes involving bicyclists or pedestrians with motorized vehicles. The bicycle and pedestrian detection project focused primarily on intersections that possessed crosswalks for bicyclists and pedestrians. This project included the following types of non-motorized applications: curbside pedestrian detection, crosswalk pedestrian detection, intersection approach bicycle detection, and use of historical data.

Project Objectives

The project had the following objectives:

- identify the applications that could utilize non-motorized traffic detection,
- identify similar projects that had been conducted in non-motorized traffic detection, and
- conduct a field test to evaluate participating sensor performance.

MnDOT/FHWA Research Methodology. This project involved a literature search as well as field tests to determine promising detection technologies for bicycle and pedestrian detection. Hughes and Huang (20) evaluated an automated pedestrian detection system that supplements the existing pushbutton crossing system to reduce conflicts between pedestrians and vehicles and inappropriate crossings at signalized intersections. There was a significant reduction both in vehicle-pedestrian conflicts and the likelihood of inappropriate pedestrian crossings when the automated system complemented the pushbutton system. There was no significant difference between microwave-based detectors and infrared-based detectors.

Maki and Marshall (21) conducted a case study on bicycle detection using inductive loops of varying shapes and winding patterns. The combination deemed most appropriate,

developed by the 3M Company, could detect both bicycles and motorized vehicles. The configuration is an 8-ft by 8-ft square shape with wire running in three parallel diagonals.

Noyce (22) conducted a study of bicycle and pedestrian detection in 2001. The research evaluated some ITS technologies that might serve the needs of their research, choosing the Autosense II. Field tests found that the Autosense II was very effective in detecting and classifying bicycles and detecting pedestrians. It correctly detected 97 percent of bicycles and 92 percent of pedestrians. The results also identified video imaging as a technology that is capable of detecting and classifying pedestrians and bicycles.

The study by SRF also identified other commercially available detection systems for bicycles and/or pedestrians, although it did not test most of them. Selected systems from the SRF list are as follows:

- ASIM – Dynamic Pedestrian Detection: It can optimize traffic flow through green phase extension and monitor vehicle presence. The typical mounting location is atop a signal head and aimed to cover both the crosswalk and curbside waiting areas.
- Microwave Sensors – Pedestrian Detection: MS Sedco markets a series of pedestrian detectors that can detect pedestrians in both the crosswalk and curbside areas. The products use two technologies—infrared and ultrasonic. Their mounting location can be overhead or beside the road.
- PUFFIN – Automated Pedestrian System: Pedestrian User Friendly Intelligent Crossing (PUFFIN): This detection system came from AGD System Ltd in the United Kingdom, and it uses either an above-ground detection sensor (e.g., radar) or an in-ground pressure-sensitive mat.
- Traffic 2000 Limited – Pedestrian Detection: This system is a curbside pedestrian detector that uses a pressure-sensitive plate to detect pedestrians. The detection plate uses a screened piezoelectric cable transducer to sense pedestrians.

Field Tests. NIT Phase II began with development of an evaluation test plan in 2001. It also developed a vendor database that was useful in this study of bicycle and pedestrian detection. Researchers reviewed this database to select the sensors that should be able to detect bicycles or pedestrians. Another aspect was vendor willingness to participate. The result was five vendors who agreed to participate in the test, including one international vendor. With the addition of existing inductive loop detectors, the field test and evaluation involved a total of six detector types and five technologies. Table 6 lists the detectors involved and some information pertaining to them.

Researchers determined the following most common applications for the detectors:

- Curbside pedestrian detection: the detection of pedestrians at signalized intersections would automatically place a call to the traffic signal controller for a pedestrian WALK indication.

- Crosswalk pedestrian detection: the detection of pedestrians in the crosswalk of a signalized intersection can extend the pedestrian phase, improving safety.
- Intersection approach bicycle detection: the detection of bicycles on an approach would supplement detection of motorized vehicles on the same approach.

Table 6. Detectors Evaluated by MnDOT in Field Tests.

Vendor Sensor	Technology	Pedestrian or Bicycle Detection	Installation	Power Requirement (volts)
ASIM DT 272	Passive Infrared/ Ultrasonic	Pedestrian/ Bicycle	Sidefire	12 – 24 (DC)
Diamond TTC-4420	Infrared	Pedestrian/ Bicycle	Sidefire	Internal Power 6 (DC)
MS Sedco SmartWalk 1400	Microwave	Pedestrian/ Bicycle	Sidefire	12 – 2 (AC or DC)
ISS/TCC Autoscope Solo	Video Imaging	Pedestrian/ Bicycle	Sidefire	24 (AC for Solo) 110 – 220 (AC) for Interface Panel
3M Microloop	Magnetic	Metal Bicycle	Under Pavement	12 – 24 (DC)
Inductive Loop Detector	Inductance	Metal Bicycle	Under Pavement	24 (DC)

Source: Reference (22).

The test site for the field study was the Cedar Lake Trail, located within one-half mile of the NIT test site on I-394 (see [Figure 2](#)). This was a bicycle and pedestrian commuter facility with one pedestrian lane and two bicycle lanes. An existing loop detector count station provided a source of power and a cabinet to house data collection equipment. These same loop detectors served as another source of data for the tests.

SRF engineers encountered some problems with the outdoor tests, requiring modifications to their initial test plan. The cold October weather was a factor that reduced the number of persons on the trail selected for the test. This factor required data collection personnel to provide the detections themselves by riding a bike, walking, or jogging through detection zones. The lack of security for detection systems was another factor requiring a shorter duration study during daylight only and collection of data only when SRF personnel were on-site. Due to these challenges, SRF developed a two-day test plan, using the first day to collect sample or trial data and the second day to collect official data. Test personnel collected approximately 300 observations. The tests involved two bicycles; one had a ferrous metal frame and the other had a non-ferrous metal frame. The tests involved 100 one-way trips through the detection zone with the ferrous metal bicycle, 51 one-way trips with the non-ferrous metal bicycle, and 100 one-way walk trips.

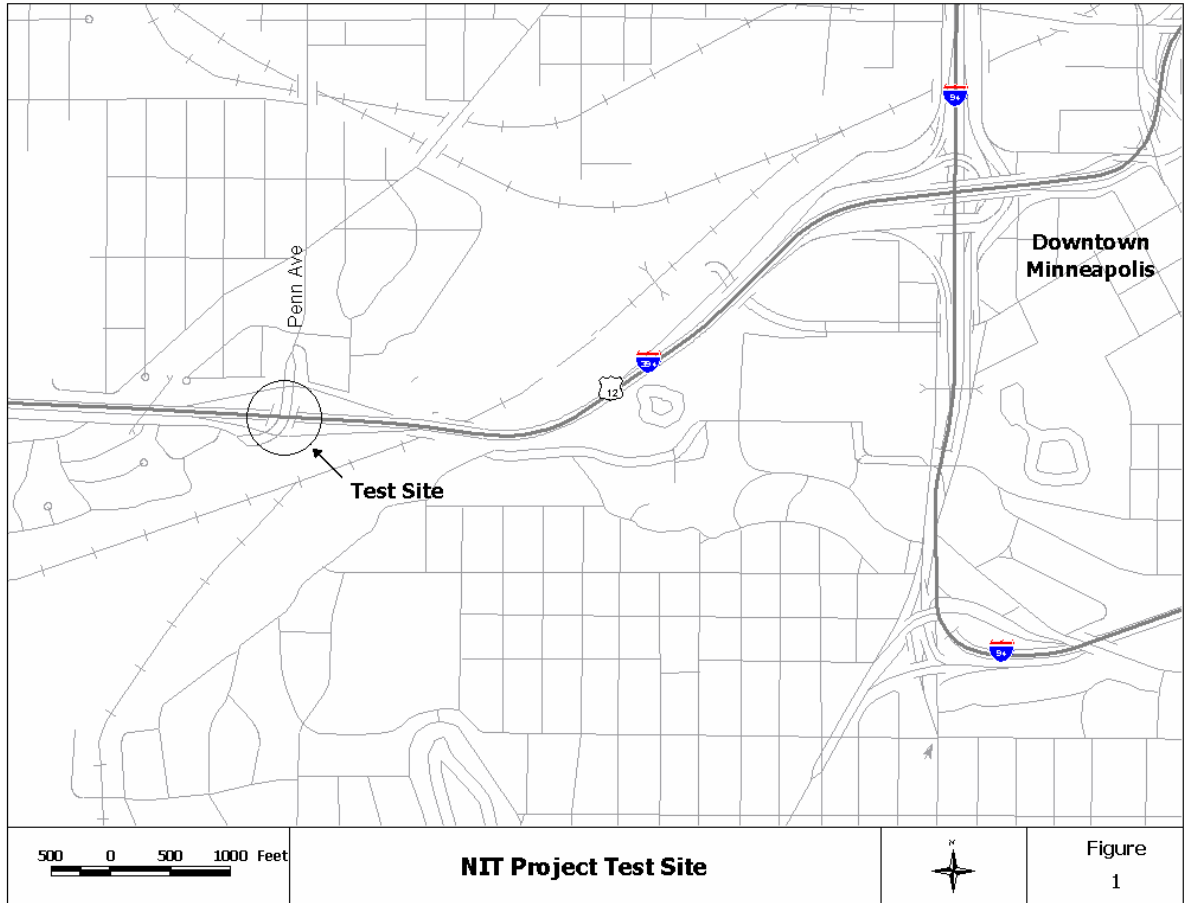
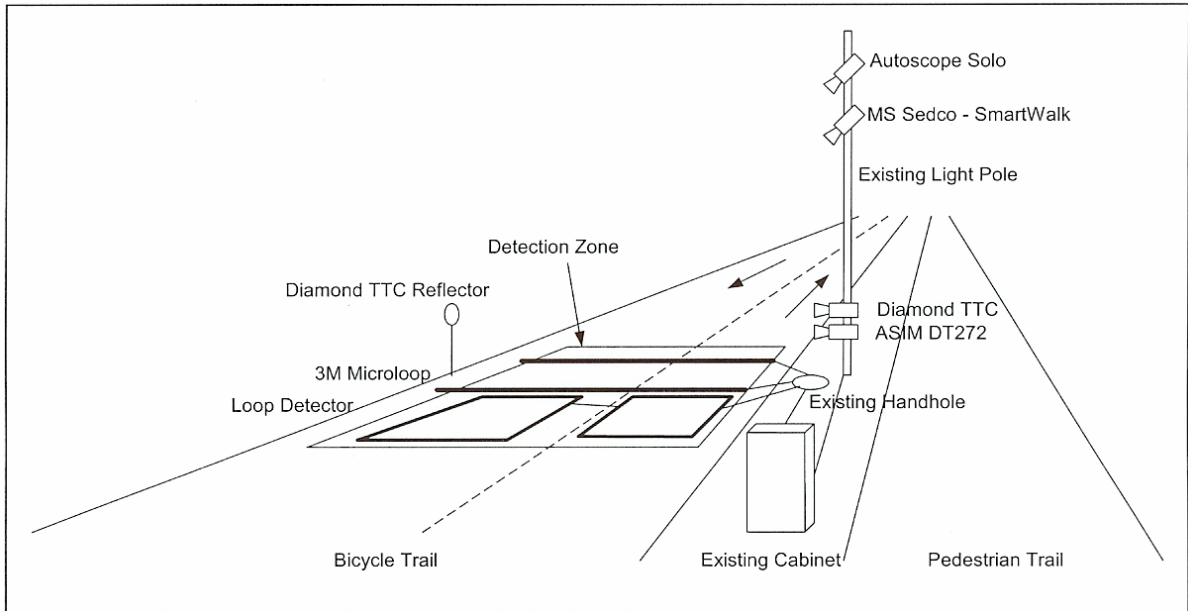


Figure 2. I-394 Test Site Used for MnDOT Detector Tests.

Figure 3 indicates the field setup for the detector tests. Four detectors required a pole for mounting detectors beside the trail, and one required a reflector on the opposite side of the trail. The pole-mounted detectors used the same area for detection for comparison purposes. The Diamond TTC sensor used a 3-inch reflector on the top of a wood stick located on the opposite side of the trail to receive and reflect the infrared beam. Table 7 summarizes the detector mounting locations and the technologies used by each. Tables 8, 9, and 10 show the results of these tests. The baseline data came from human observers.



Source: Reference (22).

Figure 3. MnDOT Bike and Pedestrian Test Layout.

Table 7. Sensor Mounting Locations.

Detector	Technology	Mounting Height (ft)
ASIM – DT 272	Passive IR/Ultrasonic	3
Diamond – Traffic Counter	Infrared	4
MS Sedco – SmartWalk	Microwave	10
Autoscope Solo	Video Image	12
3M Microloop	Magnetic	In Pavement
Inductive Loop	Magnetic	In Pavement

Source: Reference (22).

Table 8. Ferrous-Metal Bicycle Results.

Test Device	Baseline	Sensor Count	Percent Difference
Loops	100	100	0
Autoscope Solo	100	101	1
MS Sedco – SmartWalk	100	96	4
ASIM – DT 272	100	101	1
Diamond – Traffic Counter	100	96	4
3M – Microloop Lane 1	50	49	2

Source: Reference (22).

Table 9. Non-Ferrous (Aluminum) Bicycle Results.

Test Device	Baseline	Sensor Count	Percent Difference
Loops	51	51	0
Autoscope Solo	51	51	0
MS Sedco – SmartWalk	51	50	2
ASIM – DT 272	51	51	0

Source: Reference (22).

Table 10. Pedestrian Results.

Test Device	Baseline	Sensor Count	Percent Difference
Autoscope Solo	100	100	1
MS Sedco – SmartWalk	100	100	0
ASIM – DT 272	100	100	0
Diamond – Traffic Counter	100	93	7

Source: Reference (22).

2.3.3 FY 2005-2006 Literature Findings

To update the previous literature review, project staff reviewed primarily the 2005 Transportation Research Board (TRB) 84th Annual Meeting Compendium of Papers CD-ROM (23). Another potential source was the FHWA Detector Clearinghouse, which the New Mexico State University hosts. Not all sources produced useful information. From these sources, the prominent topics included determining vehicle speeds from single inductive loops, vehicle re-identification using inductive loops and, to a lesser degree, performance of vehicle detectors.

Since a number of previous studies had compared aggregate data from one or more detectors to concurrent measurements from another device (perhaps a ground truth device), Coifman (24) chose to compare actuations of individual vehicles at one detector to concurrent measurements of the same vehicle at another detector. He used four inductive loop sensor models and the RTMS. More specifically, the research used the following loop detection units: Peek GP6 and Reno A&E Model 222 inductive loop detectors, along with the reportedly higher performing 3M and IST Model 222 detectors. The research used the Berkeley Highway Laboratory to collect data from all five of the detectors using Videosync, the software package developed by Caltrans Division of Research and Innovation, as the primary tool for data reduction. This software allows the direct comparison between concurrent detector and video data.

Each of the sensors exhibited problems. Study conclusions stated that agencies could identify and correct most of the problems with additional fine-tuning in the data processing by the controller or data aggregator, but most operating agencies do not attempt to accomplish the correction. Therefore, the study findings should represent conventional practice. Some of the errors could be corrected by improved controller logic, but some would

require a trip to the field to correct. The Reno detector tended to flicker on for short periods in absence of a vehicle in the detection zone, which could be correctable in the controller software. Other errors resulted from lane-changing maneuvers over the detection zone. IST and Peek tended to detect such vehicles in both lanes, while the Reno and 3M sensors tended to underestimate the on-time of vehicles changing lanes in one lane while not detecting them in the other. The RTMS showed systemic errors in its performance—manifested as differences between nearest (small detection zone) and farthest lanes (occlusion). This systematic change in on-time would be an important consideration for applications that rely on occupancy. Also, the RTMS count and on-time are typically noisier than loops, although pluses and minuses tend to cancel each other. Detection zone sizes varied across all detectors, from the larger detection zones of the RTMS and even across the four models of loop detectors whose in-pavement dimensions were the same. These variations will impact the values generated for occupancy. Of course, the sizes of loop detection areas are a function of sensitivity settings, but perhaps equally important are site-specific factors (24).

Another literature source by Coifman (25), again using the Berkeley Highway Laboratory, investigated aggregate data from the RTMS sensor. The study evaluated the performance of the RTMS in sidewire mode relative to loop detectors in the freeway setting. The documented results first reported the aggregated data by the RTMS using its internal controller emulation and compared these results with data from nearby dual-loop detectors. The RTMS measures of flow and occupancy are noisier than loop detectors, although the RTMS estimates for speeds are almost as good as those from single-loop detectors. The second aspect of the study considered aggregate measurements from contact closure data and compared RTMS results against the dual-loop detectors. For reference, the research also compared one loop against the adjacent loop in the same lane in a trap loop configuration. In the flow measurements, the RTMS was within 10 percent of values generated by the loops with the loops being within 3 percent of each other. Occupancies were not as accurate, ranging from 13 percent to 40 percent, again compared to the inductive loops.

A research project conducted by the Ohio Research Institute for Transportation and the Environment (ORITE) investigated the use of a custom-built trailer fitted with two microwave radar detectors to monitor traffic along selected segments of roadway. The trailer consisted of a steel frame with a solar panel plus battery box containing four deep-cycle gel batteries and a power controller. The solar unit was rated at 225 watts and outputs 12V DC; it was also equipped with a charge controller capable of regulating up to 15 amps of current. As equipped, the system can run for 8 days on batteries without sunlight. The trailer had two telescoping poles capable of reaching heights of 20 ft; it had four sockets so that the poles could be erected on either side of the trailer. It also had anti-theft devices such as detachable tongue and special lock-nuts on the wheels (26).

During a traffic monitoring session, the ORITE trailer used one Wavetronix SmartSensor model SS105 attached to each pole, with each detector pointed in the same direction and operating in parallel. The available information did not specify the separation distance, but photos indicated a separation of about 8 ft. The available information also did not discuss the possibility of interference between the two detectors, which would likely occur at that spacing and orientation. ORITE typically operated both detectors in the sidewire

orientation. The trailer also housed a controller, which was a small computer used to collect the data from each sensor and combine the data into a single text file. Storage of the text file is on the computer's hard drive and on a 256 MB flash memory card. Setup of the entire operation takes about 45 minutes—30 minutes for the trailer and about 15 minutes for the sensors (26).

The data collected by the system include: time stamp, lane number, and moving average speed (based on the last 16 vehicles) from the first sensor followed by a similar dataset from the second sensor. Next came an average of the two running speeds, vehicle length, and speeds for each sensor. Vehicle classes for this research were: Class 0 (0 to 20 ft), Class 1 (21 to 40 ft), and Class 2 (at least 41 ft). A portion of the ground truth came from videotape with time-stamped video synchronized with the same laptop the radar units were synchronized with. The baseline vehicle speeds came from a Kustom Signals TR-6 radar unit (26).

Results indicate that the Wavetronix system misses some vehicles due to occlusion and it sometimes registers phantom vehicles from extraneous radar echoes (e.g., from a truck in an adjacent lane). On one of the test days, the number of phantoms was 7.03 percent, but on other days, the number of phantoms and misses was always less than 5 percent, and often under 1 percent. Speeds measured by the Wavetronix system (based on the moving average technique) usually correlated well with true speeds. These moving average speeds were a combination of the speeds detected by both sensors. The largest difference was 3 mph. The standard deviations in data measured by the trailer were always higher than those from the hand-held radar unit, generally by a factor of 2 to 3. The smallest difference was 0.1 mph (2.0 mph Wavetronix vs. 1.9 mph for radar), and the largest difference was 3.8 mph (4.2 mph Wavetronix vs. 1.1 mph radar) (26).

Other results based on vehicle length (or classification) were not as accurate. For example, one dataset had 8 percent true vehicles with lengths over 40 ft while the Wavetronix data indicated 21.4 percent with lengths over 40 ft. Some results were better and some were worse, but the authors conclude that the system does not reliably estimate the number of trucks in the traffic stream. Weather was not a factor in any of the tests, so no conclusions were available on the effects of weather on detector performance (26).

Cheung et al. (27) investigated the use of single wireless magnetic detectors as an alternative to inductive loops for traffic monitoring on freeways as well as at intersections. Their advantages appear to include cost, ease of deployment and maintenance, and enhanced measurement capabilities. Components of this magnetic detector include “sensor nodes,” which communicate with an “access point.” A sensor node is comprised of a magnetic sensor, a microprocessor, a radio, and a battery. A 5-inch diameter “smart stud” encases the sensor node or magnetic sensor, which is glued to the pavement in the center of a lane.

The paper covers two experiments, with the first and longer one being a two-hour monitoring session on Hearst Avenue in Berkeley, California, downstream of a signalized intersection. During this two-hour session, 332 vehicles passed through the detection zone. The single magnetic sensor achieved a detection accuracy of 99 percent (100 percent if

motorcycles are excluded), and average vehicle length and speed estimates that appear to exceed 90 percent (27).

For vehicle classification, a single dual-axis magnetic sensor measures the earth's magnetic field in both the vertical direction and along the direction of the lane, each sampled at 64 Hz. A simple algorithm uses the information to classify the vehicle into six types: passenger vehicles, SUV, van, bus, mini-truck, and truck. Of the sampled vehicles, the detector correctly classified 24 out of 37 vehicles (63 percent). Combining classified vehicles into the FHWA classification scheme suggests an 83-percent accuracy rate for the FHWA scheme. The sample size was small, but the results appear to be promising. The sensor correctly classified all buses, vans, and passenger vehicles, but it had problems with SUVs and mini-trucks. Further experiments are needed to determine its accuracy with trucks. It is important to note that adding length as a measured feature of the single magnetic sensor would probably improve the classification accuracy (27).

This research compared this single magnetic detector and its capabilities with inductive loops. In comparison, measuring accurate lengths with loops requires two loops compared to only one magnetic detector. The magnetic detector is easily installed and measures the earth's magnetic field, which is a three-dimensional vector. This detector records the changes in the field caused by different parts of the vehicle and that is how it can classify the vehicle. The size of an inductive loop, on the other hand, is larger, causing it to lose some of the distinctive features from the inductive signature. In other words, magnetic signatures provide more detail on the vehicle to improve its use as a classifier. Other advantages of magnetic detectors include the ability to install them on bridges, where sawcuts (for loops) would weaken the structure. Finally, wireless magnetic sensor networks should be much less expensive to maintain than inductive loops while providing more of the needed information (27).

The authors suggest that both the speed and classification accuracy could be improved significantly by using two magnetic detectors spaced a known distance apart. They predict vehicle classification accuracies in the 80-percent range would be likely. The authors plan on additional tests to further develop the classification accuracy (27).

Martin and Feng (28) developed the traffic detector selection procedure shown in Figure 4. The figure references several tables, the number designations of which are in the referenced document. The selection procedure included the following technologies: inductive loops, magnetic, active infrared, passive infrared, microwave radar, ultrasonic, passive acoustic, and video image vehicle detection systems. This summary will focus on the technologies and the data types selected for Project 0-4750. The selection criteria included: general installation conditions, cost, data accuracy, reliability, and ease of installation and maintenance. Tables 11 through 14 summarize the information pertaining to the detectors of interest to TxDOT.

Table 11. Detector Cost Comparison.

Technology/Sensor	Device Cost	Lanes ^d	Mounting ^d
3M Microloop	2 ch. Canoga Detector \$546 4 ch. Canoga Detector \$704 702 Microloop Probe \$160 701 Microloop Probe \$138 Installation kit \$114 Carriers \$355/pkg Cable: \$0.39/ft	S	3-inch conduit placed under roadway
SmarTek SAS-1	\$3500/unit	M (5 lanes)	S (25-40 ft)
Autoscope	Autoscope Solo ^a Single direction: \$4900	M (32) ^b	O/S
	Autoscope 2020 Single direction: \$4820		
Traficon	\$4000 per camera (camera, VIVDS, housing, lens, cables, surge protection, setup and training) ^c	M (24) ^b	O/S (25-45 ft)

Source: Adapted from Reference (28).

^a Autoscope solo has integrated camera and processor.

^b Maximum number of detection zones per camera.

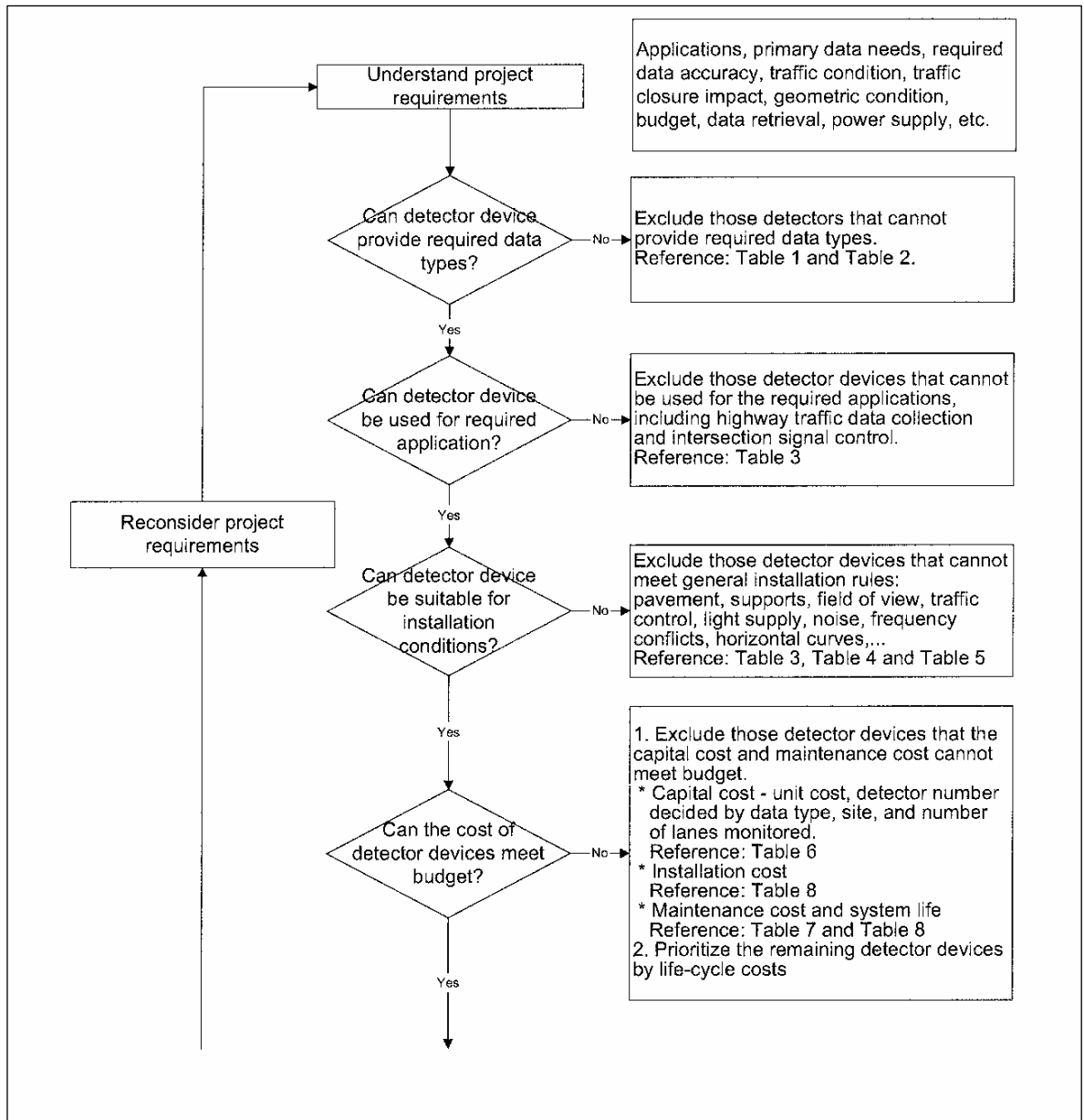
^c A high resolution CCD black/white or color camera. The video camera should provide detailed video without lag, image retention, or geometric distortion.

^d S – Single lane detector, M – Multiple lane detector, O – Overhead, S – Sidewalk.

The Department of Civil and Environmental Engineering at the University of Hawaii at Manoa evaluated eight vehicle detectors (five non-intrusive) at several locations in portable and permanent installations (29). These systems are: 3M microloops, Spectra Research ORADS portable laser sensor, RTMS model X2, SmarTek SAS-1, and Wavetronix SmartSensor SS105. The research retrieved data from these detectors using TrafInfo's Trafmate satellite modem, TrafficWerks cellular system, and conventional 9600 baud modems.

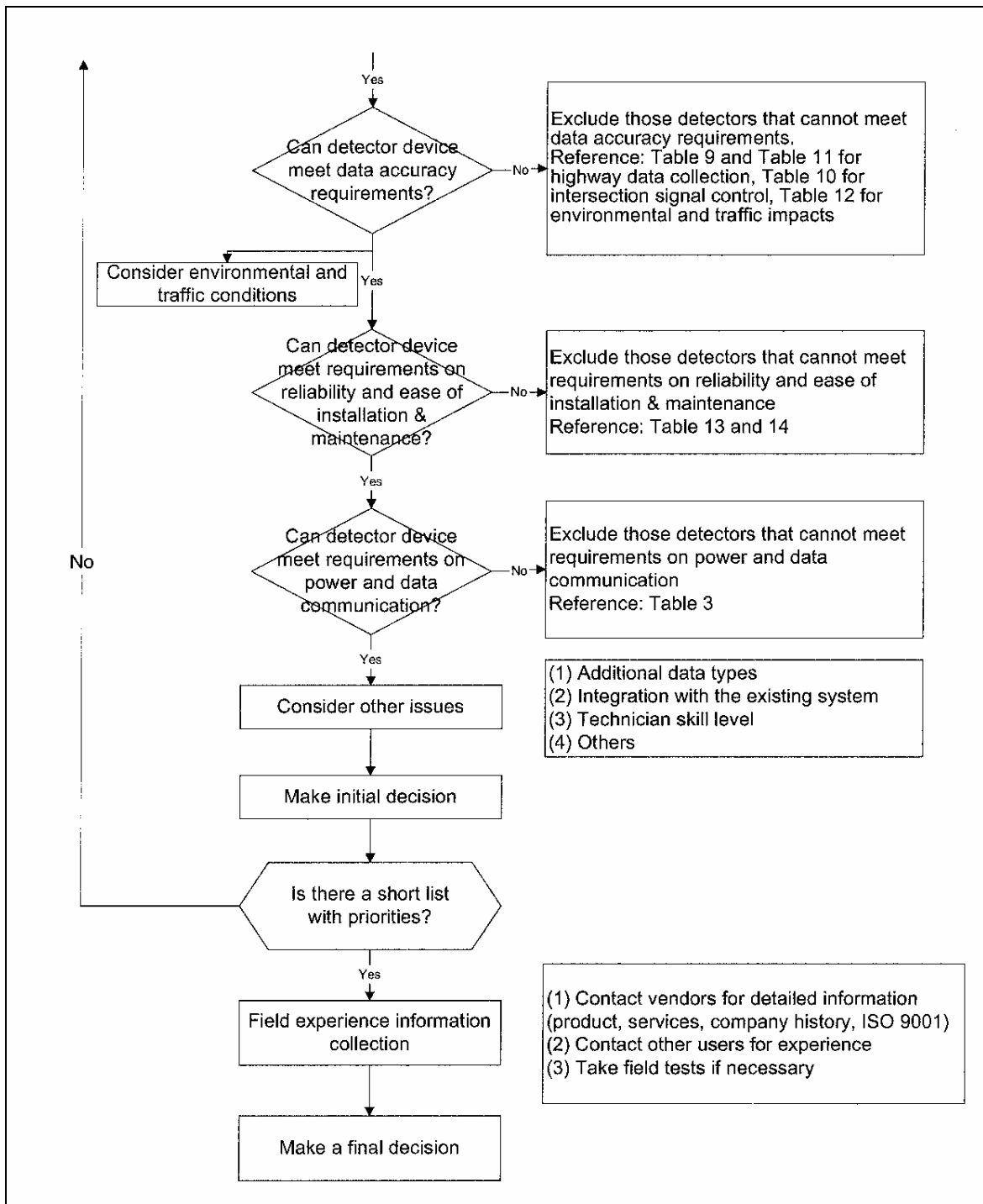
The 3M microloops and ORADS portable laser sensor require installations below or very near the road surface, respectively. Lane closures are not required but personnel are still exposed to traffic. The 3M microloops and Canoga 702 detector card provided excellent volume and speed results. They are expected to have a long life cycle but their initial cost and installation were expensive. The ORADS laser sensor from Spectra Research did well with volume counts but performed poorly in classification. Researchers found that the ORADS laser sensor did not perform well on uneven pavement.

The research included RTMS X2, SmarTek SAS-1, and SmartSensor SS105 in sidewalk mode at various heights and distances from the roadway, and in inclement weather conditions. Researchers found that these three sensors could provide high-quality data at a low cost, with low energy consumption, and simple calibration. Installation required a pole at



Source: Reference (28).

Figure 4. Detector Selection Procedure.



Source: Reference (28).

Figure 4. Detector Selection Procedure (Continued).

Table 12. Detector Error Rates.

Sensor	Mounting Location	Count	Speed ^a	Evaluation Organization
3M Microloop	Pavement	2.5%	1.4%-4.8%	MnDOT
3M Microloop	Bridge	1.2%	1.8%	MnDOT
3M Microloop	Pavement	5%	$\mu = -0.25$ mph $\sigma = 3.6$ mph	TTI
SAS-1	Sidefire	8%-16%	4.8%-6.3%	MnDOT
SAS-1	Sidefire	4.0%-6.8%	3.4%-6.8%	TTI
SAS-1	Sidefire	10%	$\mu = -0.5$ mph $\sigma = 4.8$ mph	TTI
Autoscope Solo	Sidefire	5%	8%	MnDOT
Autoscope Solo	Overhead	5%	2.5%-7%	MnDOT
Autoscope Solo	Sidefire	2.1%-3.5%	0.8%-3.1%	TTI
Traficon	Sidefire	5% (45 ft)	2%-12%	MnDOT
Traficon	Overhead	10%-15% (25-30 ft)	3%-7.2%	MnDOT

Source: Adapted from Reference (28).

^a μ = mean, σ = standard deviation.

Table 13. Detector Ease of Installation and Reliability.

Technology/Sensor	Ease of Installation ^b	Ease of Calibration ^b	Reliability ^a
3M Microloop	0	1	2
RTMS	2	1	1
SmarTek SAS-1	2	2	2
Autoscope Solo	2	1	2
Traficon	2	1	2

Source: Adapted from Reference (28).

^a Reliability level is based on the performance shown in tests.

^b 2: Performs satisfactorily in the stated condition; 1: Meets some but not all criteria for satisfactory performance; 0: Does not perform satisfactorily in the stated condition.

Table 14. Estimated Life-Cycle Costs for a Typical Freeway Application.

Detector	Initial Cost	Mounting	Install. Cost	Ann. Mtce. Cost	System Life (yrs)	Life-Cycle Cost/system ^a
3M Microloops	\$13,125 ^b			\$200	15	\$1380
RTMS	\$6600	O	\$2400	\$200	7	\$1700
		S	\$400			\$1370
SmarTek SAS-1	\$7000	S	\$800	\$400	7	\$1700
Autoscope Solo Pro	\$9800	O	\$3000	\$400	10	\$1980
		S	\$1000			\$1730
Traficon	\$8000	O	\$3000	\$400	10	\$1760
		S	\$1000			\$1510

Source: Adapted from Reference (28).

^a Costs are for a total of six freeway lanes, three per direction.

^b Total of 16 lanes and 32 probes.

least 20 ft tall, and offset at least 20 ft from the first lane. Researchers retrofitted a trailer-based “light plant” with the sensors and deep-cycle batteries for power. They deployed this portable, stand-alone unit at various locations where sensor mounting options were limited.

The baseline system for determining the volume, speed, and classification performance aspects of the sensors was usually pre-existing loops, supplemented in some cases with manual counts. Table 15 summarizes the values associated with some qualitative ratings of the detectors. Based on comparisons of volume counts and speeds, the non-intrusive detectors rated as follows:

- The count rating for the RTMS X2 and RTC data unit by EIS was good to very good. The speed rating for the X2 and RT data unit was very good to excellent.
- The count rating for the SAS-1 acoustic sensor and SAS-CT board by SmarTek was good to very good. The speed rating for the SAS-1 and SAS-CT board was very good to excellent.
- The research did not rate the SmartSensor SS105 by Wavetronix by values from the table for either speeds or counts, but described its performance as similar to the RTMS unit.

Table 15. Sensor Performance Descriptions.

Rating	Volume/Classification (% error)	Speed (mph)
Excellent	±1	±3
Very Good	±3	±6
Good	±5	±10
Possibly Adequate	±10	±15
Inadequate	> ±10	> ±15

Researchers recommend the SmartSensor as the top sensor based on ease of setup, lower height requirement, and exceptional feedback and assistance from the vendor. The SmartSensor’s auto-ranging and calibration features made it the quickest sensor to install. The researchers recommended both the SmartSensor and the RTMS for quiet rural locations with power already available. They recommended the SAS-1 for battery or solar power operations due to its minimal power consumption. The SAS-1 was able to detect bicycles in quiet locations, but loud music and other background noises caused the sensor to register a count.

CHAPTER 3.0 DETECTOR TEST PLAN

3.1 INTRODUCTION

The detector test plan's primary purpose was to guide researchers in selection of vehicle detection systems to test. It relied solely on loaned or donated detection units as there were no funds designated for purchasing the detectors. All vendors with equipment of primary importance to the project's Project Monitoring Committee (PMC) were willing to loan equipment. Beyond the loaned equipment, all vendors were also anxious to monitor their equipment using the Internet and to provide firmware updates and other technical support to maintain a high level of operational accuracy.

3.2 METHODOLOGY

The research utilized Project Monitoring Committee meetings scheduled near the beginning of each new fiscal year to discuss the detectors that warranted testing in Texas. Researchers came to these meetings prepared with a list of possible detectors to include in the test plan along with enough information about each system to make a decision, allowing the PMC to decide which ones were worthy of field tests at one or both of the field test facilities. The test plan also included improvements to the two test beds to facilitate implementation of the test plan.

3.3 FY 2003-2004 DETECTOR TEST PLAN

Based upon the literature search, researcher knowledge and experience, and vendor information, TTI researchers developed a tentative detector test plan for discussion by the Project Monitoring Committee. Researchers discussed the pros and cons of each selected detector and encouraged discussion by PMC members regarding including each detector. The information provided below begins with the "year one" plan, which means the plan for the first 18 months of the project. There was some delay near the beginning of this 3 ½ year study due to other activities that preceded selection of test detectors. A similar meeting occurred prior to the start of year two field tests (FY 2005) and to start year three (FY 2006) tests, again, to establish which detectors to include in field tests.

The first project meeting in which the detector test plan was an agenda item for the PMC occurred on May 1, 2003. Researchers had already implemented parts of the test plan for the first 18-month period based on activities in Research Project 0-2119. The test plan for project 0-4750 involved testing detectors both at the Austin I-35 test site and at the College Station S.H. 6 test site. As of November 2003, researchers had installed, calibrated, and begun field-testing the detectors listed in [Table 16](#).

Researchers discussed one other detector as a possible test system—the RTMS X3, especially since TTI had tested the X2 in the previous research project. TTI contacted Electronic Integrated Systems, Inc. and requested their participation by a loaned unit, but the company failed to provide the unit. The baseline system for both sites was the Peek

ADR-6000, but it was also included as part of the test plan because of its fairly recent introduction into the U.S. market and due to earlier problems in its operation. TTI also monitored the Peek ADR-6000 for lanes 2, 3, 4, and 5 (a loop failed in lane 1) in Austin.

Table 16. FY 2004 Detector Test Plan.

Detector	Technology	Test Location (No. Lanes)	
		Austin	College Station
3M Microloops	Magnetic	Site TBD ^a	None
Autoscope Solo Pro	Video Imaging	I-35 (5 lanes)	S.H. 6 (2 lanes)
Peek ADR-6000	Inductive Loop	I-35 (5 lanes)	S.H. 6 (4 lanes)
SAS-1	Acoustic	I-35 (5 lanes)	S.H. 6 (2 lanes)
SmartSensor	Radar	I-35 (5 lanes)	S.H. 6 (4 lanes)

^a TBD: To be determined.

Efforts to acquire the latest Iteris Vantage VIVDS for both locations were unsuccessful early on, but the vendor later provided a unit for installation in Austin on March 25, 2004. Also, Wavetronix provided a second SmartSensor for the S.H. 6 site. There were no tests of 3M microloops due to problems in finding a suitable site to replace the originally targeted U.S. 290 site. Other systems discussed during the May 1, 2003, meeting were single-lane detectors (e.g., for ramps), and wireless detection systems. However, the two wireless systems installed as part of Research Project 0-2119 utilized detectors that have not been the best performers—the RTMS and the SAS-1. Therefore, this research project did not use the wireless units.

In preparation for FY 2005 detector tests, the research supervisor and the project director scheduled a meeting of the PMC for July 20, 2004. During this meeting, the PMC only recommended one new detector in addition to the current list of test devices; it was the Traficon VIVDS. The Iteris video imaging detector became available before this July meeting, but only a short time before the meeting. The tentative plan was to test the Iteris at both test sites. The test plan for FY 2005 also included detectors remaining from previous tests to provide more of a long-term evaluation. There was also discussion regarding testing 3M microloops, possibly on a high-volume roadway in the Austin area.

3.3.1 FY 2003-2004 Improvements to Test Beds

Improvements to the test beds occurred largely to follow the detector test plan. The Austin test bed originated in Research Project 0-2119, and the College Station test bed originated several years prior to that. TTI made several improvements to both test beds during the early months of this research. Figures 5 and 6 show schematics of the two test beds. The following list provides some of the major updates or improvements to the two test beds during the FY 2003-2004 period. It does not include minor maintenance items.

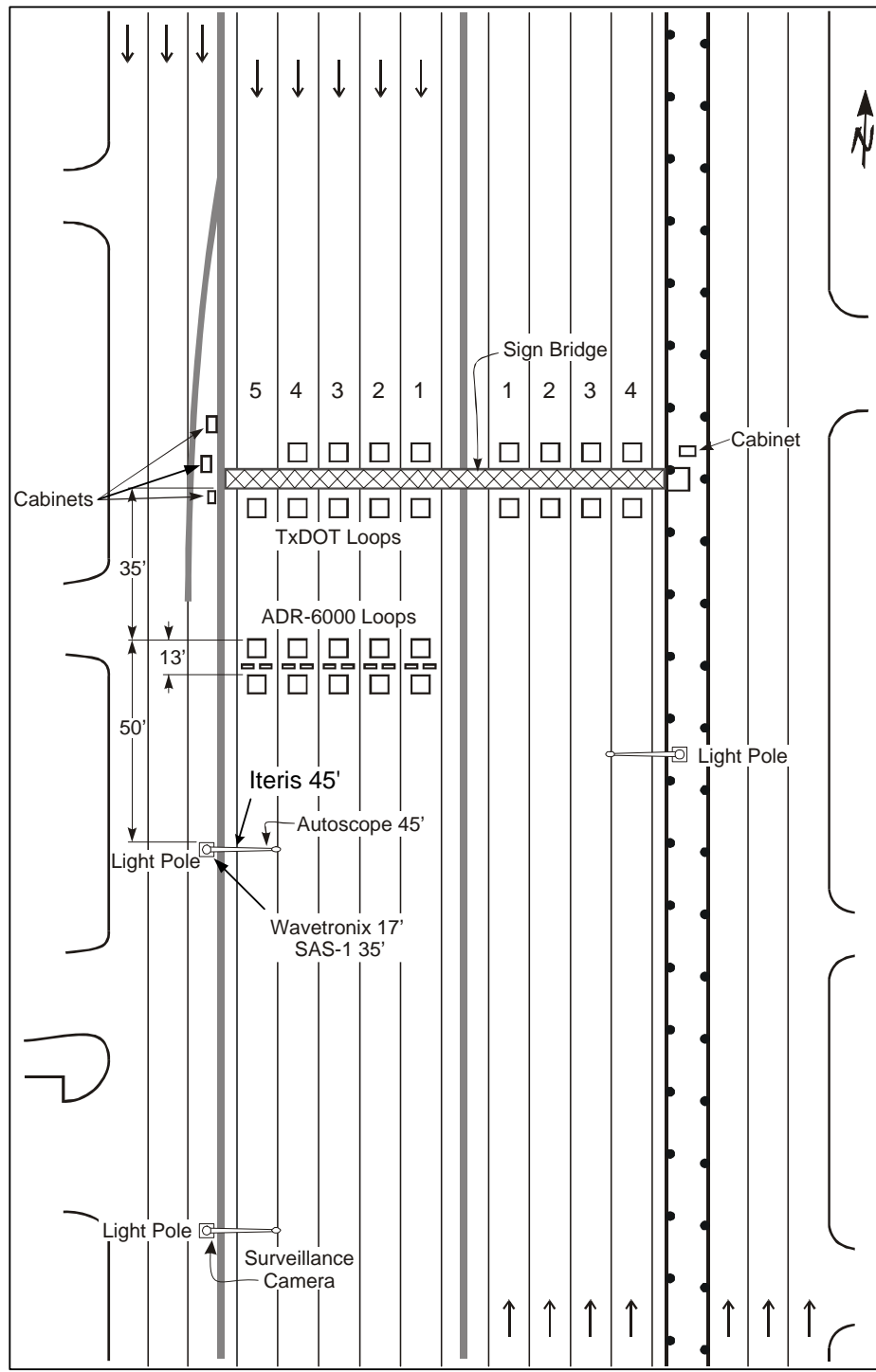


Figure 5. Layout of I-35 Site.

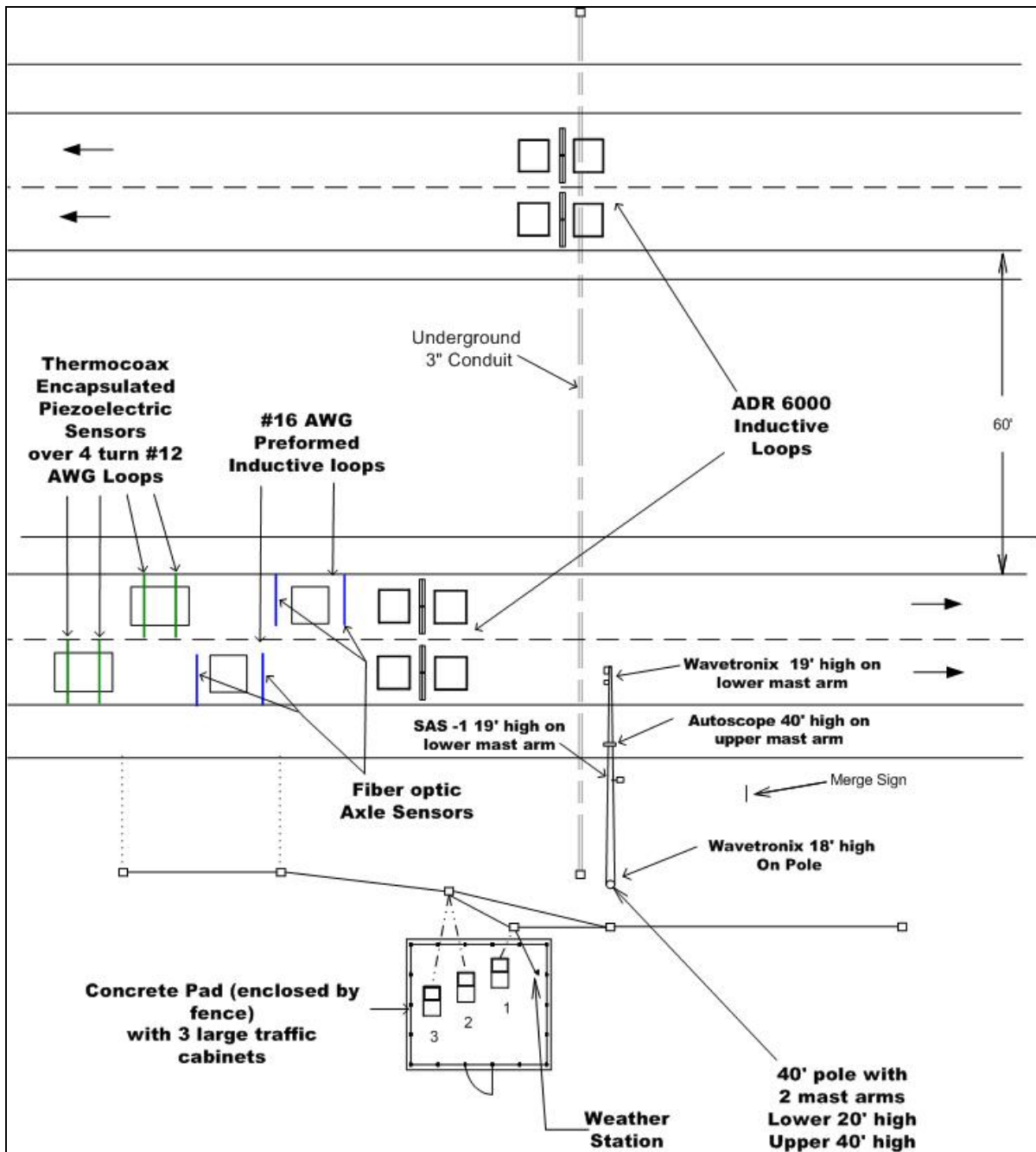


Figure 6. Layout of the S.H. 6 Site.

Some of the major activities related to the FY 2003-2004 test plan follow in chronological order.

- During the week of August 11 through August 15, 2003, TTI replaced a failed CCD camera, replaced a damaged coaxial cable, did maintenance work on the weather

station, set up the firewall, DSL modem, and keyboard video mouse (KVM) switch for the College Station test bed.

- During the week of August 18, 2003, TTI worked with a road boring contractor to install a 3-inch conduit under the full width of S.H. 6.
- During the weeks of September 8 and September 15, TTI made several additional improvements to the S.H. 6 test bed. TTI installed 3M Canoga ITS link, PcAnywhere, and Peek Traffic Operations and Planning Software™ (TOPS) software on a field computer to collect data with the Peek ADR-3000. Finally, TTI installed the repaired weather station and set up the software and network connections for remote access and weather data acquisition.
- From September 30 through October 2, TTI provided support for a crew from the Transportation Planning and Programming Division (TPP) to install four inductive loops per lane for the Peek ADR-6000 in all four lanes on S.H. 6. A Peek representative was on-site to configure the ADR-6000 loop amplifiers and system. The Peek representative and a TTI engineer then went to the Austin I-35 test site to reinstall the ADR-6000 on October 3. The Peek technician then configured the ADR-6000 loop amplifier and system.
- During the week of October 6 through October 10, TTI set up new Internet Protocol (IP) addresses for the S.H. 6 test bed, configured the firewall, weather station, and remote power switch with new IP addresses. Another activity was attempting to get the Peek TOPS version 3.4 to poll data from the ADR-6000. Upon contacting Peek software support, technicians learned they would have to wait for version 3.5.
- During the week of October 20, TTI installed Peek TOPS version 3.5 on the S.H. 6 computer and on one of the Austin computers. They also checked the DSL and configured the firewall, APC remote power switch, and computer and connected the PC to the ADR-6000, the Autoscope Solo Pro, the SAS-1, and the Wavetronix SmartSensor.
- During November 2003, TTI made adjustments to the surveillance camera and cleaned the lens to improve its image.
- During January 2004, TTI reinstalled Peek TOPS software on the industrial computer at S.H. 6 due to a problem with the software. TOPS software is essential for collecting bin data with the ADR-6000.
- During February and March 2004, TTI contacted Peek by telephone several times and e-mailed the classification table asking Peek to modify its ADR-6000 classification algorithm to accommodate the Texas 6 classification scheme.
- In February 2004, TTI researchers discovered a problem with the ADR-6000 in College Station based on it misclassifying large trucks in lane 3. It was not until June

2004 that Peek's service department finally concluded that the count error in lane 3 was due to the axle detector for lanes 1 and 2 not communicating, causing the ADR-6000 processor to recycle back to lanes 1 and 2 several times before proceeding to lane 3. TTI removed the axle detector and sent it to Peek's service department for repair. Peek repaired and returned the axle detector within two weeks and TTI immediately installed and configured it (July 1) with the support of Peek technicians on the telephone.

- In March 2004, TTI researchers ran 3/4-inch rigid conduit for power from the new cabinet on I-35 to the power distribution panel at the base of the sign bridge. They also ran 2-inch rigid conduit between the small existing cabinet and the new larger cabinet.
- In May 2004, researchers removed the weather station in Austin due to ongoing problems and found that most of the weather sensors were not working. TTI disassembled all the weather sensors, finding that the weather station wiring was defective and the sensors needed calibration. TTI sent the temperature, humidistat, wind speed detectors to the weather station manufacturer for calibration and re-cabling. Upon receiving the sensors and other components, TTI reassembled the weather station and tested it before reinstalling it in Austin. TTI researchers also checked the S.H. 6 weather station rain gauge and found that it was not functioning properly due to dirt accumulation in the funnel for the tipping bucket. TTI cleaned the rain gauge and verified its accuracy by comparing it with another gauge.
- Also in May 2004, researchers configured a new industrial computer with a scan converter, video capture card, Windows 2000, and TOPS software and installed it in the I-35 test bed cabinet. TTI configured the hardware firewall for the new computer and found that one computer could not run all five detector applications and simultaneously stream video to the Internet.

3.4 FY 2005 DETECTOR TEST PLAN

Based upon the literature search, researcher knowledge and experience, and vendor information, TTI researchers developed a tentative detector test plan for FY 2005 for discussion by the Project Monitoring Committee. Researchers discussed the pros and cons of each selected detector and encouraged discussion by PMC members regarding including each detector. The information provided below involves only the "year two" plan (FY 2005), which means the 12-month period beyond the first 18 months of the project. The test plan involved testing detectors both at the Austin I-35 test site and at the College Station S.H. 6 test site. As of January 2005, researchers had installed and calibrated, and had begun field-testing of detectors listed in [Table 17](#).

The baseline system for both sites was the Peek ADR-6000, but it was also included as part of the test plan because of earlier problems in its operation. TTI monitored the ADR-6000 for lanes 2, 3, 4, and 5 (the failed loop in lane 1 had not been repaired at that time) in Austin and on all four lanes at S.H. 6 in College Station.

Table 17. FY 2005 Detector Test Plan.

Detector	Technology	Test Location (No. Lanes)	
		Austin	College Station
3M Microloops	Magnetic	TBD	None
Autoscope Solo Pro	Video Imaging	I-35 (4 lanes) ^a	S.H. 6 (2 lanes)
Iteris	Video Imaging	I-35 (4 lanes)	S.H. 6 (2 lanes)
Peek ADR-6000	Inductive Loop	I-35 (4 lanes)	S.H. 6 (4 lanes)
SAS-1	Acoustic	I-35 (4 lanes)	S.H. 6 (2 lanes)
SmartSensor	Radar	I-35 (3 lanes) ^b	S.H. 6 (4 lanes)
Traficon	Video Imaging	I-35 (4 lanes)	S.H. 6 (2 lanes)

^a The I-35 site has a total of five southbound lanes, but lane 1 has a failed inductive loop.

^b The mounting pole was too close to lane 5, so the SmartSensor could only monitor three lanes.

3.4.1 FY 2005 Improvements to Test Beds

Improvements to the test beds occurred largely to follow the detector test plan. TTI made a few modest improvements during this reporting period to both the S.H. 6 test bed in College Station and to the I-35 test bed in Austin as indicated below.

- In September 2004, the license for RealPlayer software used to stream video from test beds expired so TTI changed to the free Microsoft Media Encoder to stream video from test beds.
- Researchers brought the two industrial computers used to stream video from the Austin and College Station test beds to TTI offices for maintenance.
- Researchers reinstalled, repaired, and calibrated the weather station at the Austin test bed.
- Researchers installed 2-inch conduit between the three S.H. 6 cabinets to improve connectivity between cabinets.
- Researchers added new power receptacles in Austin and reworked the wiring to equipment in the cabinet near the end of January 2005.

3.5 FY 2006 DETECTOR TEST PLAN

Changes to the existing detector test plan are a result of decisions by TxDOT to add or remove detectors at the most recent PMC meeting. This plan included installing Sensys Networks magnetometers at both test beds. TTI installed these detectors in lanes 1 and 2 at the I-35 test bed and on lanes 3 and 4 on S.H. 6 in College Station. Researchers investigated two locations on recently opened sections of U.S. 290 (Ben White Boulevard) in Austin for

installing 3M microloops. Challenges with the site included finding nearby connections to power, not having an equipment cabinet on site, and the fact that only one lane of traffic was open. These issues were not resolved by the end of the project so there were no tests of the 3M microloops on a high-volume freeway during this project. Other detectors already installed at the two test beds remained, as indicated in Table 18.

Table 18. FY 2006 Detector Test Plan.

Detector	Technology	Test Location (No. Lanes)	
		Austin	College Station
3M Microloops	Magnetic	TBD	None
Autoscope Solo Pro	Video Imaging	I-35 (5 lanes) ^a	S.H. 6 (2 lanes)
Iteris	Video Imaging	I-35 (5 lanes)	S.H. 6 (2 lanes)
Peek ADR-6000	Inductive Loop	I-35 (5 lanes)	S.H. 6 (4 lanes)
SAS-1	Acoustic	I-35 (5 lanes)	S.H. 6 (2 lanes)
Sensys Networks	Magnetometer	I-35 (2 lanes)	S.H. 6 (2 lanes)
SmartSensor	Radar	I-35 (4 lanes) ^b	S.H. 6 (4 lanes)
Traficon	Video Imaging	I-35 (5 lanes)	S.H. 6 (2 lanes)

^a The I-35 site has a total of five southbound lanes, but lane 1 has a failed inductive loop.

^b The mounting pole was too close to lane 5, so the SmartSensor could only monitor three lanes.

3.5.1 FY 2006 Improvements to Test Beds

The list below provides information on some of the major activities related to test bed improvements or upgrades during FY 2006.

- On November 15, 2005, TTI and the TPP Division repaired the broken loop in Austin in lane 1 and installed Sensys Networks magnetometers in lanes 1 and 2.
- On December 28, 2005, the ADR-6000 in Austin had stopped collecting data, but a simple reboot and reset of its clock remedied the problem.
- On January 3, 2006, TTI discovered that the uninterrupted power supply (UPS) for the Wavetronix servers in the TransLink® Lab had stopped working. Removing the UPS and restoring power fixed the problem.
- On May 30, 2006, TTI discovered a problem with the ADR-6000 in College Station. An investigation revealed that the heat sink, which had been glued onto the central processing unit (CPU), had fallen off and was no longer serving the intended function. This problem led to failure of the CPU, requiring returning the entire unit to Peek. Peek returned the repaired unit on July 7, 2006, and TTI reinstalled it on July 10.

- On April 28, 2006, communication with the S.H. 6 test bed failed due to a network switch locking up. Technicians reset the switch to resolve the issue.
- On July 3, 2006, TTI discovered that all communication with the I-35 test bed had been lost over the weekend due to a faulty network switch. TTI replaced the switch on July 7 to solve the problem.
- On about August 2, 2006, pavement milling and resurfacing operations along I-35 destroyed all baseline loops and SenSys Networks magnetometers at the test bed.

CHAPTER 4.0 FIELD TEST RESULTS

4.1 INTRODUCTION

Field tests are based upon the detector test plan that originated at the May 1, 2003, “kick-off” meeting and was discussed again in subsequent PMC meetings. The result was updates to the test plan early in FY 2005 and early in FY 2006. Test results are available on most of the detectors from the test beds in Austin and College Station. Detectors were available or functioning properly for differing periods of time throughout the research period. Some detectors were already available for this research from a previous detector project (Research Project 0-2119) so, in some cases, TTI requested the latest updates and had to do little in the way of preparation for the start of field tests. However, some installations required contacting the vendors to acquire detectors and completely install the detectors. This section focuses on the field tests, whereas activities related to test bed improvements can be found elsewhere in this report.

4.2 METHODOLOGY

The methodology for the field tests was similar throughout the project. In general, TTI installed detectors with assistance from TxDOT and vendors, with subsequent technical support as needed from vendors. Replacement and some maintenance activities also required assistance from TxDOT, usually in the form of a bucket truck. The data analysis followed data collection followed by posting on the project website. This process used Excel spreadsheets for data analysis and graphics development. Each vendor provided replacement units if failures occurred or if new firmware or hardware became available. The exception to the modification scenario was the Peek ADR-6000, which was not modified during the course of this research. There were occasional problems with both units, but Peek made the necessary repairs and returned the components or the entire system each time their attention was needed.

Tables 19 and 20 provide a summary of major repairs or problems for each detector system that are also covered in the more detailed list of bulleted items that follows the table. The overall goal was to keep all systems operating during the full duration of the project; however, some of the problems caused disruptions in data collection for all detectors. These major problems included power supply issues, site communication fluctuations, and failures in the baseline ADR-6000 system. Examples of simpler day-to-day and week-to-week maintenance that typically took systems off line for a shorter interval included synchronizing the internal clocks of all systems, cleaning camera lenses of video imaging systems, replacing or maintaining individual power supplies, and calibration. The ADR-6000 clock drifted, and required resetting and synchronizing with other systems a minimum of twice a week. Researchers also periodically performed Microsoft and antivirus security updates on all field computers used for streaming video and connected to ADR-6000 systems on a regular basis.

Table 19. Field Test Summary for I-35.

I-35 Detector Data Summary																																				
Detector	FY2004												FY2005												FY2006											
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
Autoscope Solo Pro (VIVDS)			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Iteris Vantage (VIVDS)								*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Peek ADR-6000 (Inductive Loop)			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
SAS-1 (Acoustic)			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Sensys (Magnetometer)																												*	*	*	*	*	*	*	*	
SmartSensor (Micro. Radar)			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Traficon (VIVDS)																*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	

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Table 20. Field Test Summary for S.H. 6.

S.H. 6 Detector Data Summary																																				
Detector	FY2004												FY2005												FY2006											
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
Autoscope Solo Pro (VIVDS)				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Iteris Vantage (VIVDS)																*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Peek ADR-6000 (Inductive Loop)				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
SAS-1 (Acoustic)				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Sensys (Magnetometer)																												*	*	*	*	*	*	*	*	
SmartSensor (Micro. Radar)				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Traficon (VIVDS)																*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	

= Good Compiled Data
 = Data Not Available
 = Raw Data Available
 = Not Installed / No Data Collection

The following chronological list provides an indication of major activities required to keep the various systems operating.

- In October 2003, TTI replaced the communication and power cable and the power supply for the S.H. 6 Wavetronix SS105 in the forward fire mode.
- On October 28, 2003, while making some test bed improvements in Austin, TTI installed new SmartSensor Manager 2.0 software on the computer connected to the sensor but was unable to make the sensor function properly.
- During November 2003, TTI installed a new sidefired Wavetronix SmartSensor SS105 at the I-35 test bed.
- On November 11, 2003, the ADR-6000 stopped collecting data in lane 1 (I-35) due to a broken inductive loop.
- In January 2004, TTI discovered a glitch in the Autoscope Version 6 software and had to upgrade to Version 7. Econolite promised to provide a new Solo Pro II soon with a self-cleaning lens and that it would loan one for the Austin test bed when the new units became available.
- In early February 2004, the TxDOT Bryan District provided a bucket truck and operator to clean the Autoscope Solo Pro lens at the S.H. 6 test bed.
- In February 2004, the ADR-6000 was misclassifying large trucks in the northbound lanes of S.H. 6. Finally, in June, Peek identified the problem. TTI sent the unit to Peek for repair. It was back within two weeks and TTI installed and configured it with the support of Peek technicians on the telephone.
- In March 2004, Iteris replaced the existing video unit on I-35 with a new Rack Vision system and a new wide-angle camera (covers five lanes) moved to the outside edge of lane 5.
- In early May 2004, TTI and TxDOT replaced the Autoscope Solo Pro at the I-35 test bed and at the S.H. 6 test bed with a new Solo Pro II detector from Econolite and upgraded software to version 7.0.3.
- In September 2004, researchers replaced the two S.H. 6 Wavetronix SS105 units with new models—one sidefire and one overhead. TTI replaced the SAS-1 and SS105 in Austin with new models, also at the manufacturer's request.
- In October 2004, TTI researchers noticed that all SmartSensors were missing data at random time intervals. Technicians at Wavetronix guided TTI in correcting the problem by making changes in the sensor setup.

- In November 2004, after very heavy rain, both SAS-1 sensors temporarily stopped detecting vehicles. The manufacturer solved the problem by modifying the material covering the microphones.
- In December 2004, the Austin ADR-6000 stopped working properly, as indicated by the system constantly rebooting. Researchers found that the power supply was defective and shipped it to Peek for repair. In February 2005, TTI reinstalled the ADR-6000. After a short while, this unit still exhibited problems with the power supply so TTI had to ship it to Peek again. TTI reinstalled the repaired unit on February 4.
- In January 2005, TTI installed two Iteris cameras at S.H. 6. TTI also installed two Traficon systems in Austin and one in College Station. One I-35 Traficon camera was for incident detection and the other was for count and speed detection.
- In January 2005, TTI replaced the SAS-1 systems in Austin and in College Station with a newer model that should work in heavy rain.
- Later in January 2005, researchers discovered that the Austin Traficon cameras were not working at night. In March 2005, the vendor discovered that the problem was electrical noise induced from the luminaire when lights were on. Insulating the cameras from the noise solved the problem.
- On February 10, 2005, TTI calibrated the Iteris speeds in College Station by driving a car through each detection zone at a known speed and adjusting the detector speeds to match.
- In early February 2005, the ADR-6000 in Austin had problems so TTI removed it and sent it to Peek for repair. After reinstallation in May 2005, it ran a few weeks and then stopped working again. Researchers checked the power supply voltage in the unit and found it was too low to operate. Adjusting the 5-volt processor power supply solved the problem. It was operational again on April 7.
- In May 2005, TTI loaded new Autoscope software upgrades.
- On May 26, 2005, TTI adjusted the Austin ADR-6000 power supply voltage.
- On June 1, 2005, the ADR-6000 in College Station stopped responding. The issue was resolved by tightening loose connections from the power supply.
- On October 19, 2005, Sensys Networks installed four model VSN240 wireless magnetometers at the S.H. 6 test bed—two in lane 3 and two in lane 4. This installation included an Access Point for communications. One of the original prototype sensors installed there failed after about two weeks of operation.
- On October 21, 2005, the S.H. 6 Traficon camera was readjusted because strong winds blew it out of position. The Iteris camera was also adjusted after discovering water in the enclosure.

- In October 2005, Sensys Networks installed six new model VSN240 wireless magnetometers at the S.H. 6 test bed—three in each of lanes 3 and 4 (southbound lanes).
- On November 15, 2005, TTI and Sensys Networks installed magnetometers in lanes 1 and 2 of I-35 while the lanes were closed to repair the failed inductive loop. From the beginning the Access Point did not indicate a strong signal coming from the six magnetometers and eventually had to be replaced.
- On December 9, 2005, Sensys Networks replaced the faulty Access Point. Once the new Access Point was configured with a static IP address for the test bed DSL and plugged into the Ethernet switch, it indicated good signal strength from all six magnetometers.
- On May 10, 2006, Sensys Networks replaced the Access Point and power supply at the Austin I-35 test bed.
- On May 16, 2006, TTI realigned the Sensys Access Point installed at S.H. 6. The sensor was blown out of alignment by high winds. The realignment restored communication with all magnetometers.
- On May 30, 2006, TTI discovered that the ADR-6000 in College Station had stopped working. This was due to a heatsink malfunction in the CPU module. TTI sent the unit to Peek for repairs and then reinstalled the repaired unit on July 10.
- On June 20, 2006, TTI, SmarTek, and Traficon worked on detectors at the Austin I-35 test bed. The SAS-1 acoustic detector had failed, so the SAS representative replaced the detector and changed its orientation to reduce reflections from the median barrier wall. The Traficon representative installed new firmware on the Traficon units on this date as well and re-established communication.
- On July 3, 2006, TTI and Paradigm installed a new Beta version of the Wavetronix microwave radar High-Definition (HD) SmartSensor on I-35. The sensor was simply swapped out and set to auto-configure.
- On July 11, 2006, TxDOT Austin District personnel brought a bucket truck to the I-35 test bed and cleaned Autoscope, Traficon, and Iteris camera lenses.

4.3 WEBSITE

TTI's communication group developed a project website for sharing project findings with a limited audience using password protection. The website afforded project management committee members the opportunity to view project findings primarily related to detector performance only a few days after collecting the actual data. Due to the availability of the data and graphics on the website, this document contains only summary findings. [Figure 7](#) indicates the information that is available on the website. Several persons expressed an interest in being

able to view live video from each of the two test bed sites, so a link is available if the software program RealPlayer is available on the user's PC.

4.4 FIELD TEST RESULTS

Given the space requirements necessary to show several lighting, weather, and traffic conditions and the corresponding accuracy of the selected detectors, TTI researchers chose to select one day from each of the following periods: FY 2003-2004, FY 2005, and FY 2006. The first period is about 14 months in length and the other two periods are each about 12 months in length. These figures span day-night, peak and off-peak, dawn, and dusk, and include lane 2 in all cases in the direct plots of data. Some of the summary statistics also show other lanes for comparison on the selected dates. Lane 2 results show the effects of occlusion and the presence of trucks. A lane restriction for trucks in Austin prohibited trucks from the median lane (lane 1). The primary dates selected for data display were: August 3, 2004, April 13, 2005, and July 29, 2006. Other dates showed the effects of intense rainfall on detector performance and the accuracy of detectors in calculating occupancy.

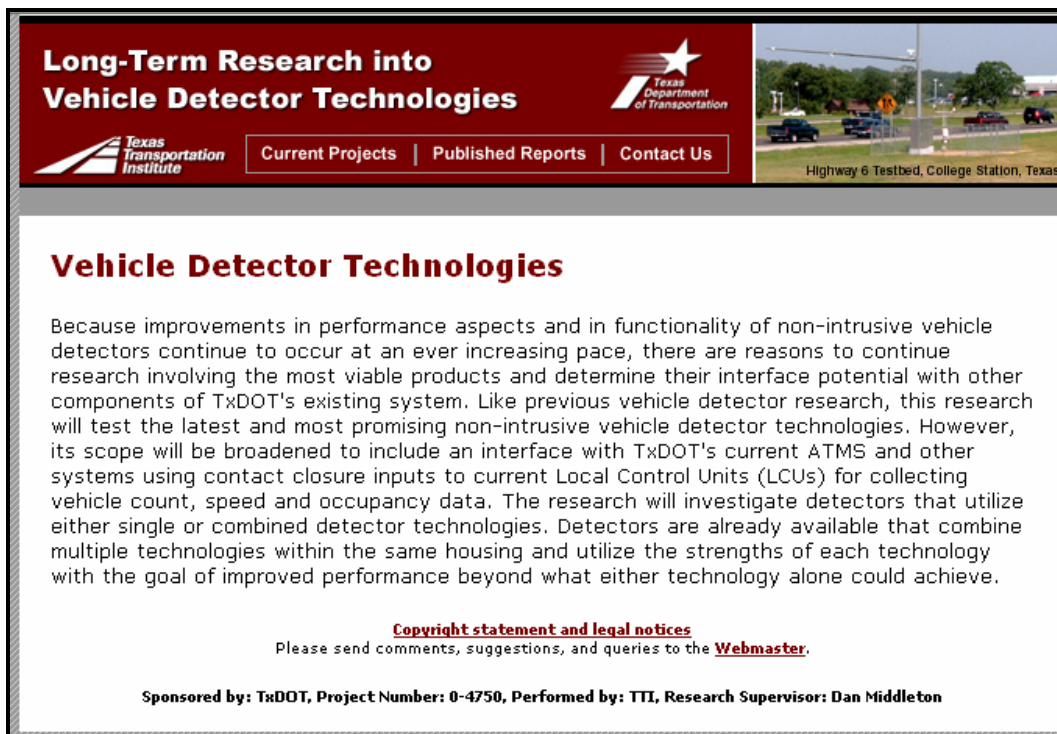


Figure 7. Screen Clip of Project Website.

Table 21 summarizes the time intervals used for plotting the data by time of day (lighting conditions) and by traffic conditions. Early morning and late afternoon lighting conditions would naturally vary somewhat throughout the year, so the reader should use the actual hours, as appropriate, for the season of the year on the data graphics.

Table 21. Summary of Conditions Represented by the Sample Data.

Time Interval	Traffic Conditions	Lighting Conditions
6am – 7am	Off-peak	Dawn
7am – 9am	Peak	Daylight
1pm – 4pm	Off-peak	Daylight
4pm – 8pm	Peak	Daylight/dusk
9pm – midnight	Off-peak	Dark

4.4.1 Example Speed and Count Field Data Results FY 2003-2004

Figures 8 through 20 show graphical speed and count accuracy results for lane 2 on I-35 from the selected date during the FY 2003-2004 period. This set of graphics shows only lane 2 since it would be the most challenging for detectors mounted on the outside of the freeway (the lane 1 baseline system was not functional during this entire period). Similar plots for FY 2005 and 2006 follow. Figures 8 through 14 show the speed accuracy, comparing speeds estimated by the test detectors against the baseline Peek ADR-6000 system (solid orange line). The figures that show the count accuracy also indicate the speed as measured by the baseline system (again with a solid orange line) because non-intrusive detector count accuracy is affected by vehicular speeds.

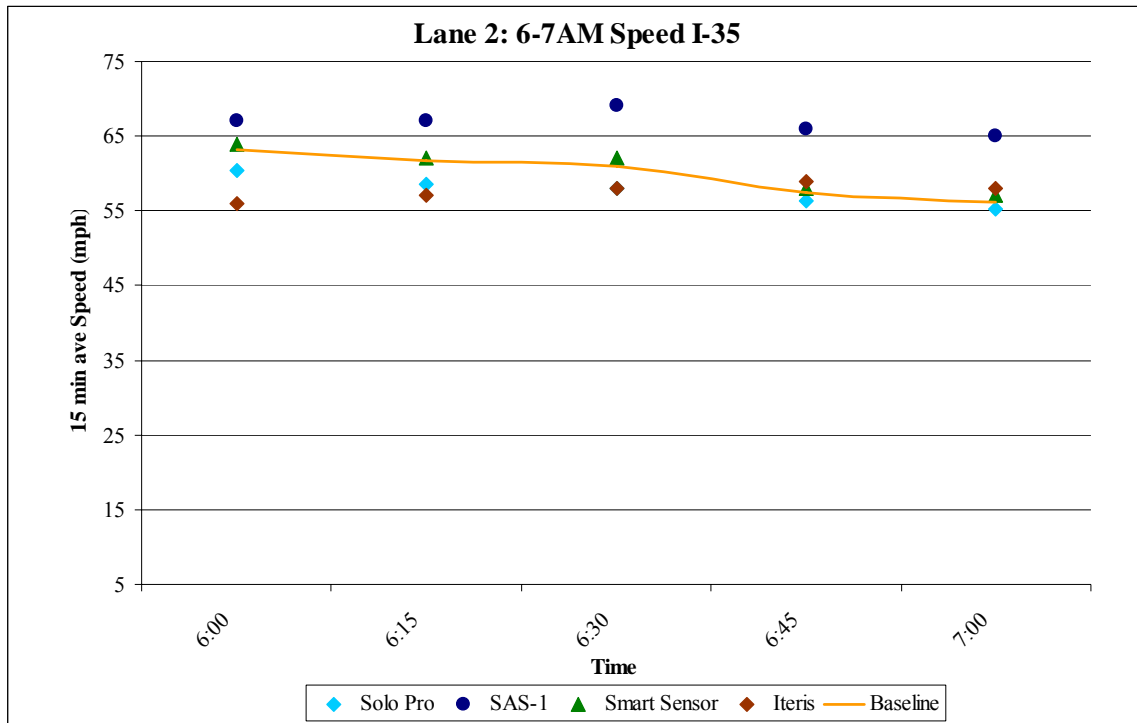


Figure 8. Detector Speed Accuracy I-35 6am-7am August 3, 2004.

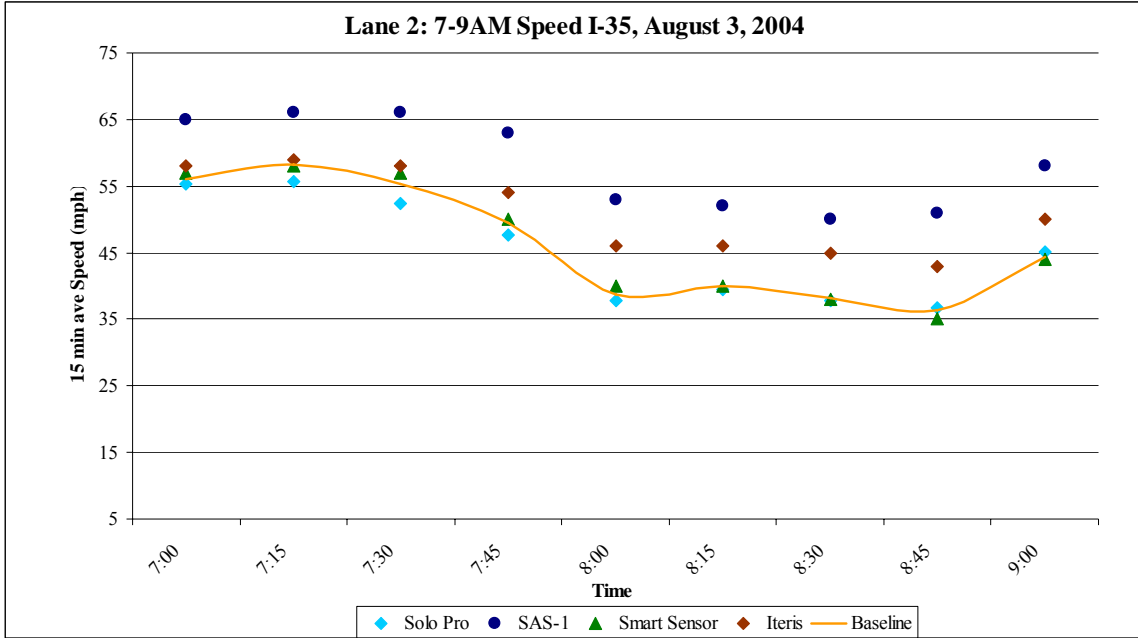


Figure 9. Detector Speed Accuracy I-35 7am-9am August 3, 2004.

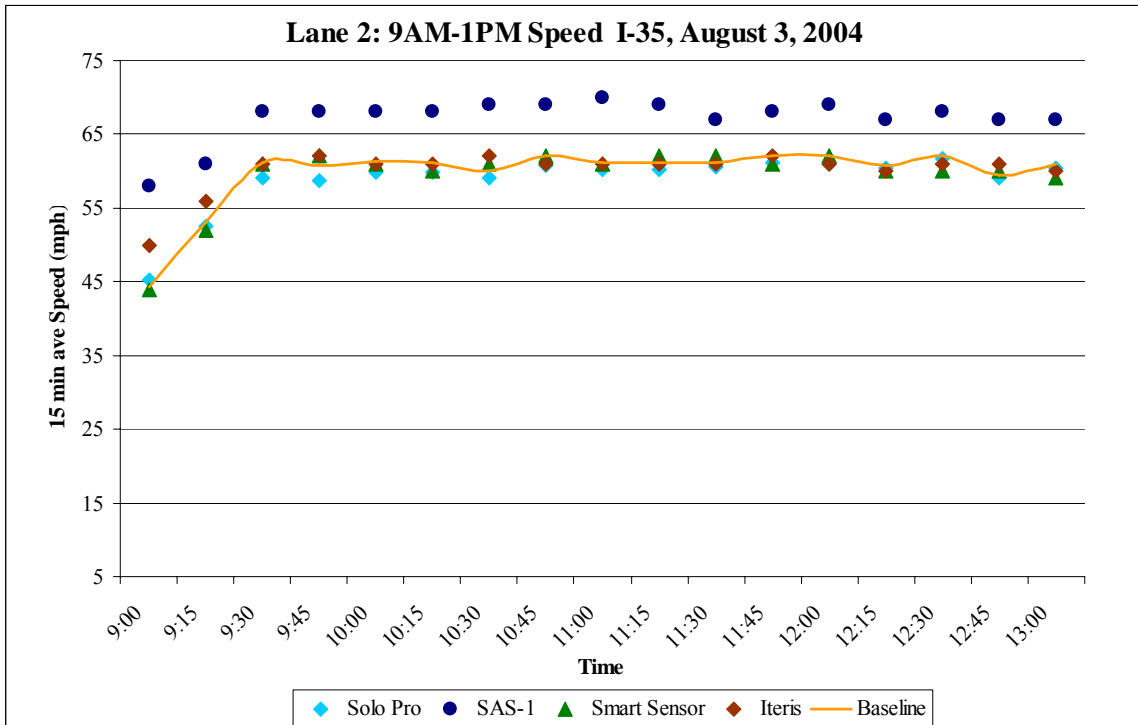


Figure 10. Detector Speed Accuracy I-35 9am-1pm August 3, 2004.

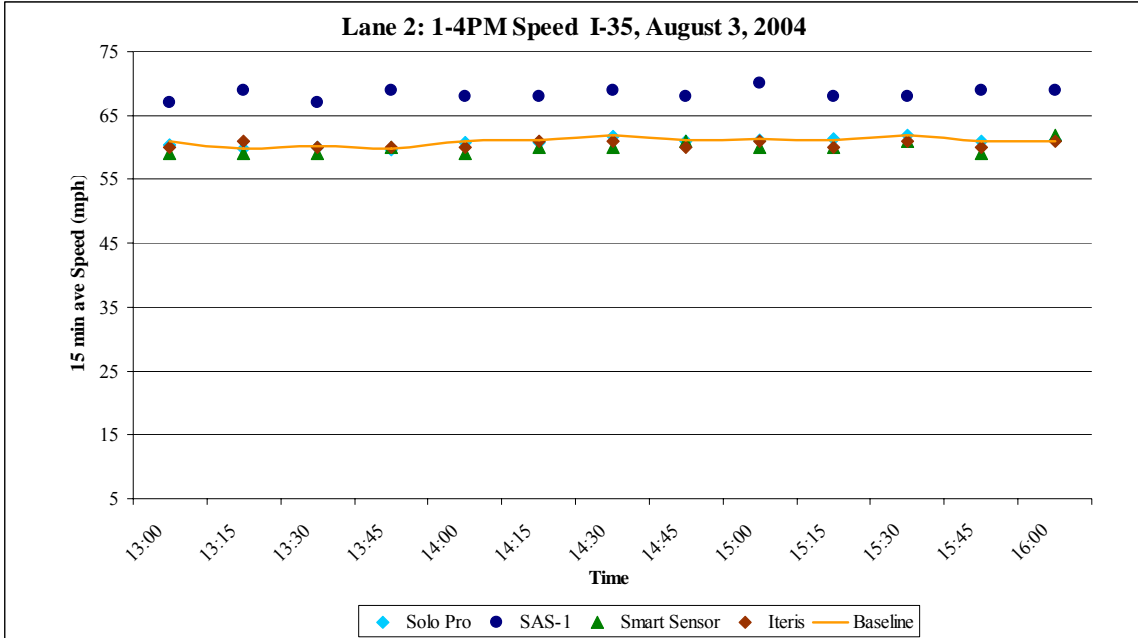


Figure 11. Detector Speed Accuracy I-35 1pm-4pm August 3, 2004.

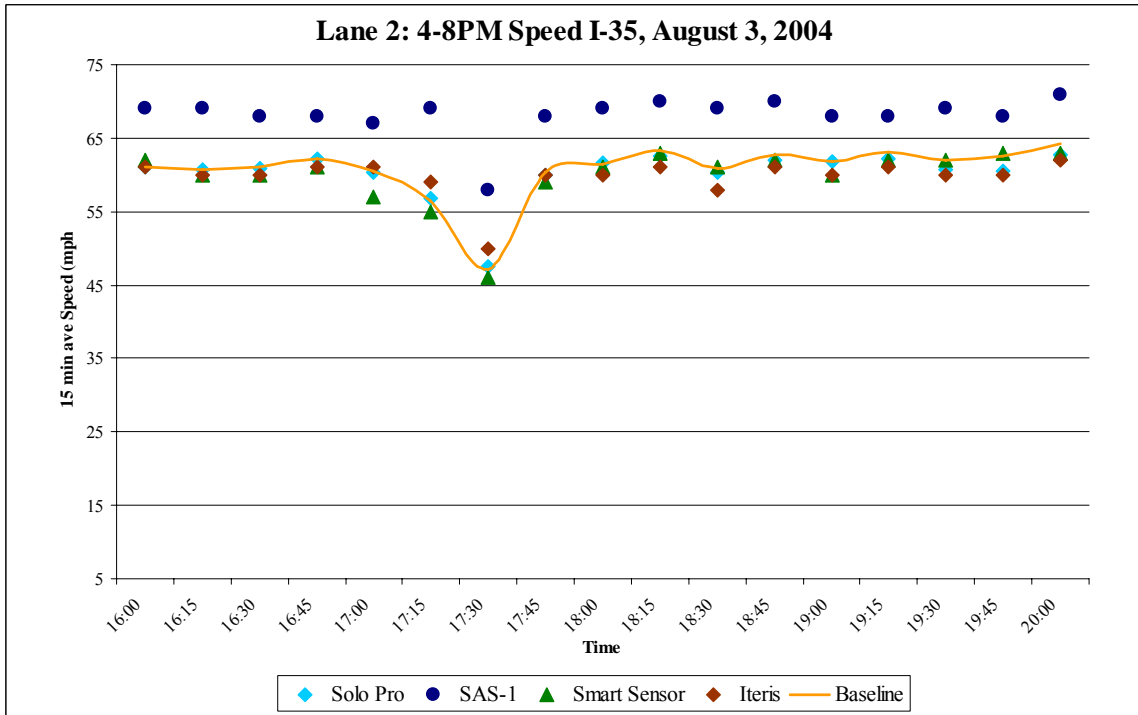


Figure 12. Detector Speed Accuracy I-35 4pm-8pm August 3, 2004.

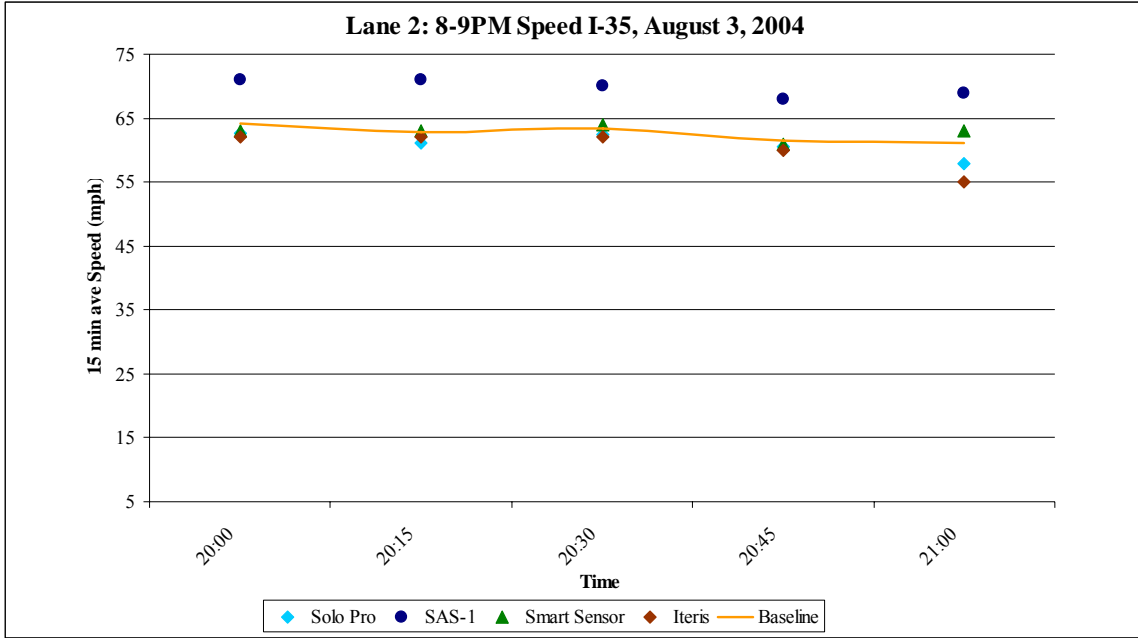


Figure 13. Detector Speed Accuracy I-35 8pm-9pm August 3, 2004.

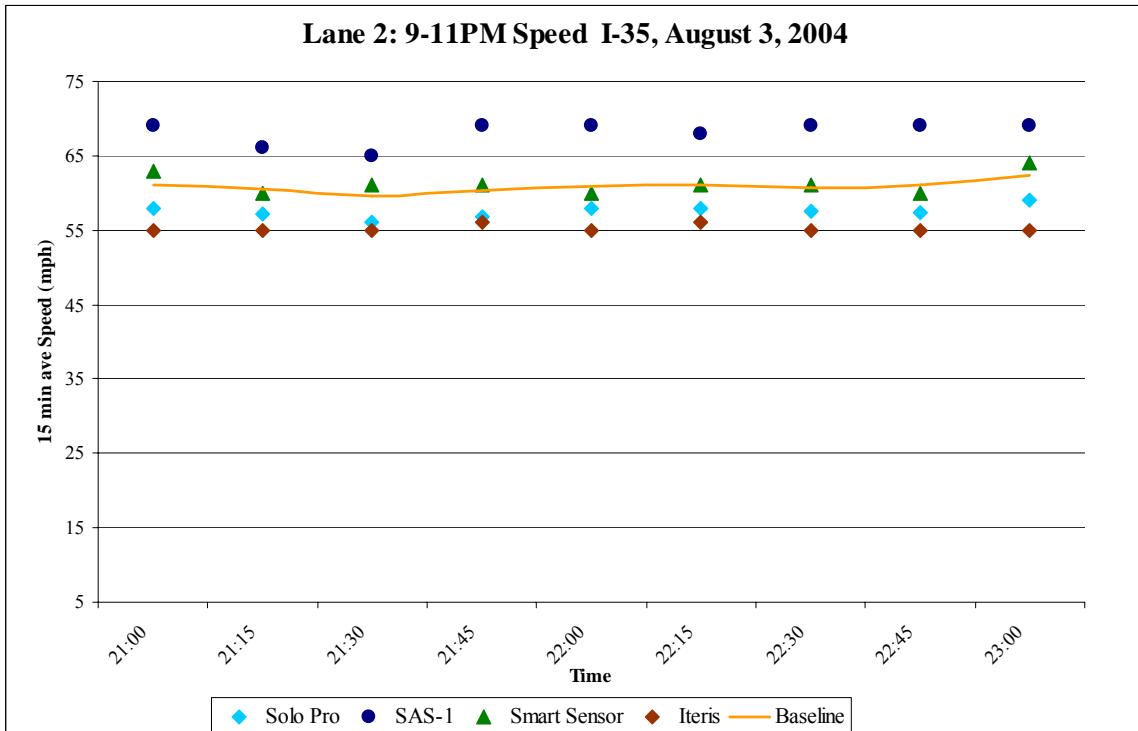


Figure 14. Detector Speed Accuracy I-35 9pm-11pm August 3, 2004.

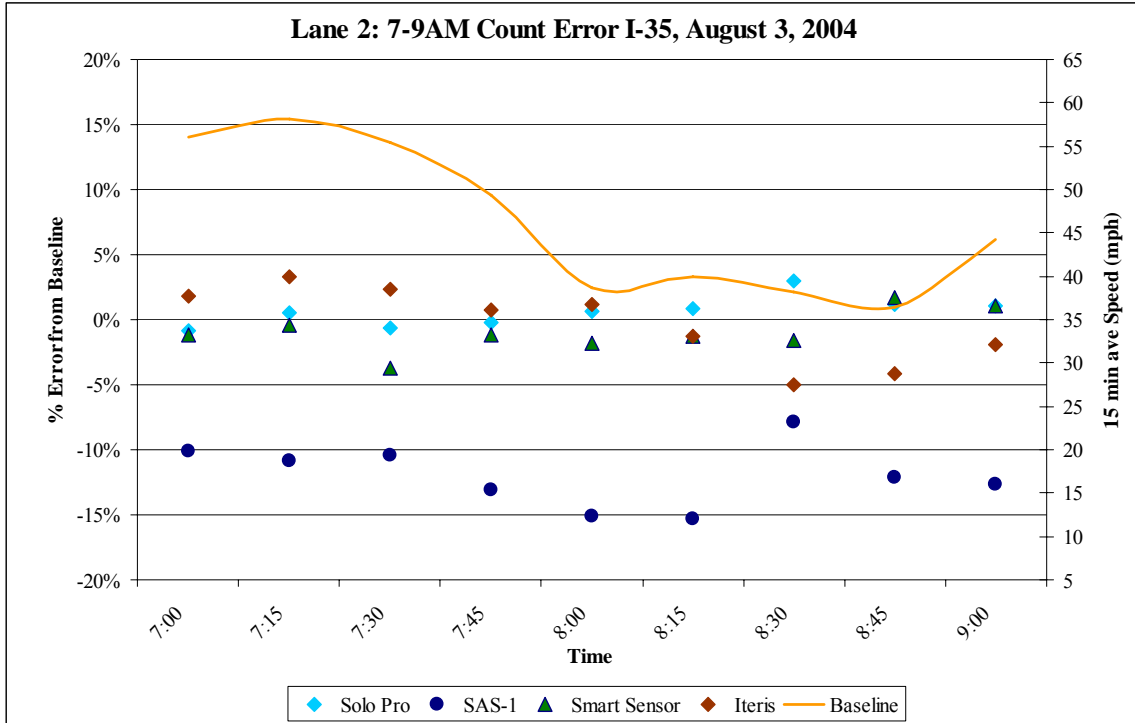


Figure 15. Detector Count Accuracy I-35 7am-9am August 3, 2004.

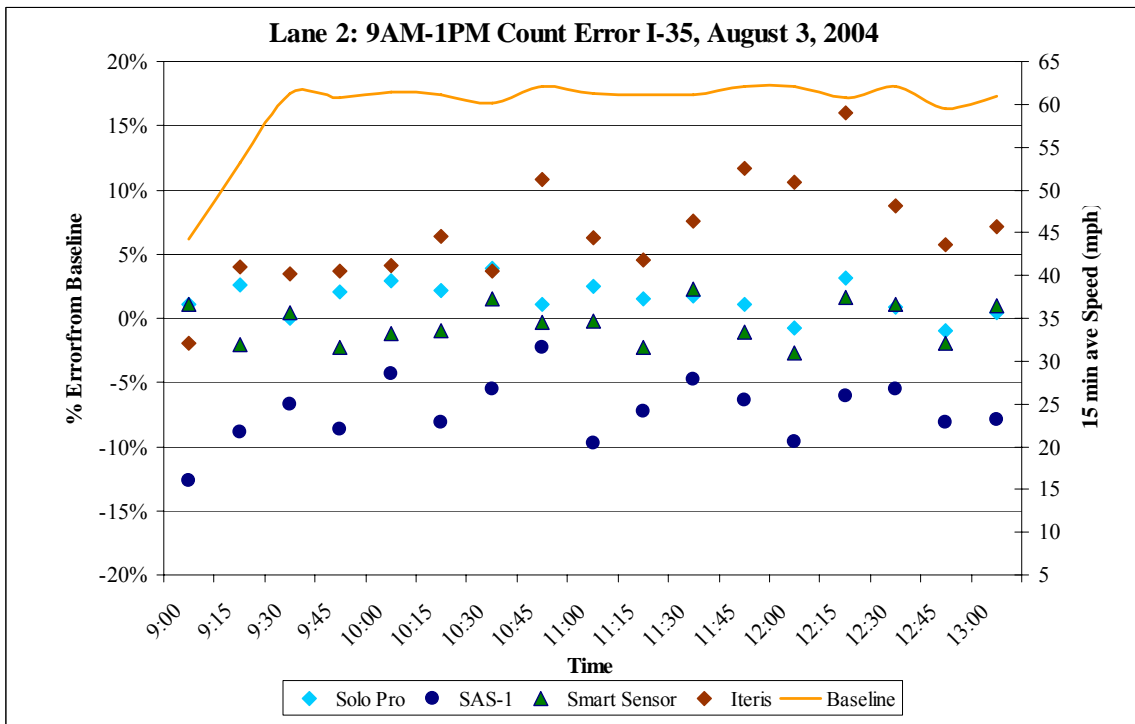


Figure 16. Detector Count Accuracy I-35 9am-1pm August 3, 2004.

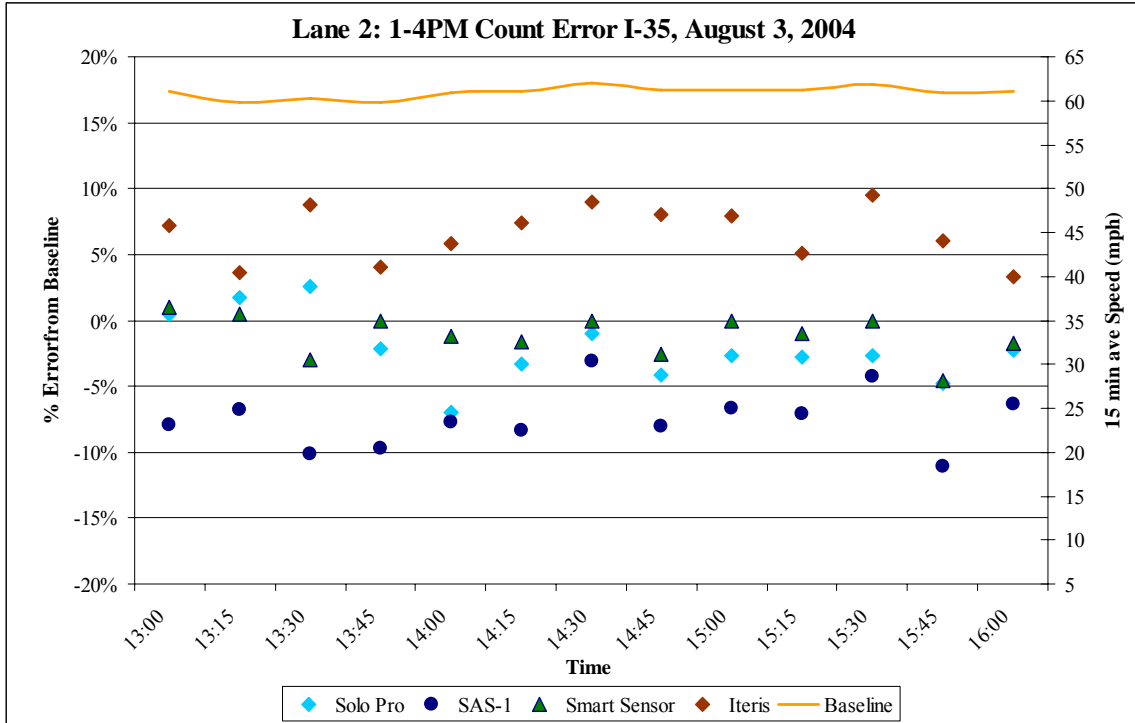


Figure 17. Detector Count Accuracy I-35 1pm-4pm August 3, 2004.

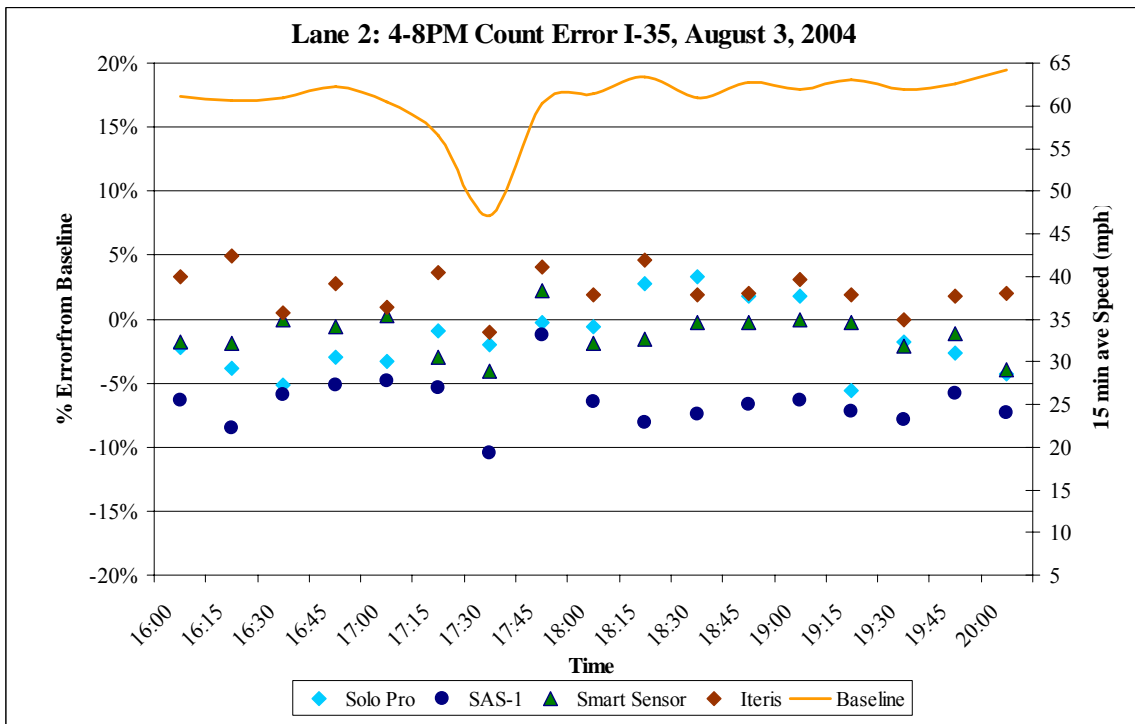


Figure 18. Detector Count Accuracy I-35 4pm-8pm August 3, 2004.

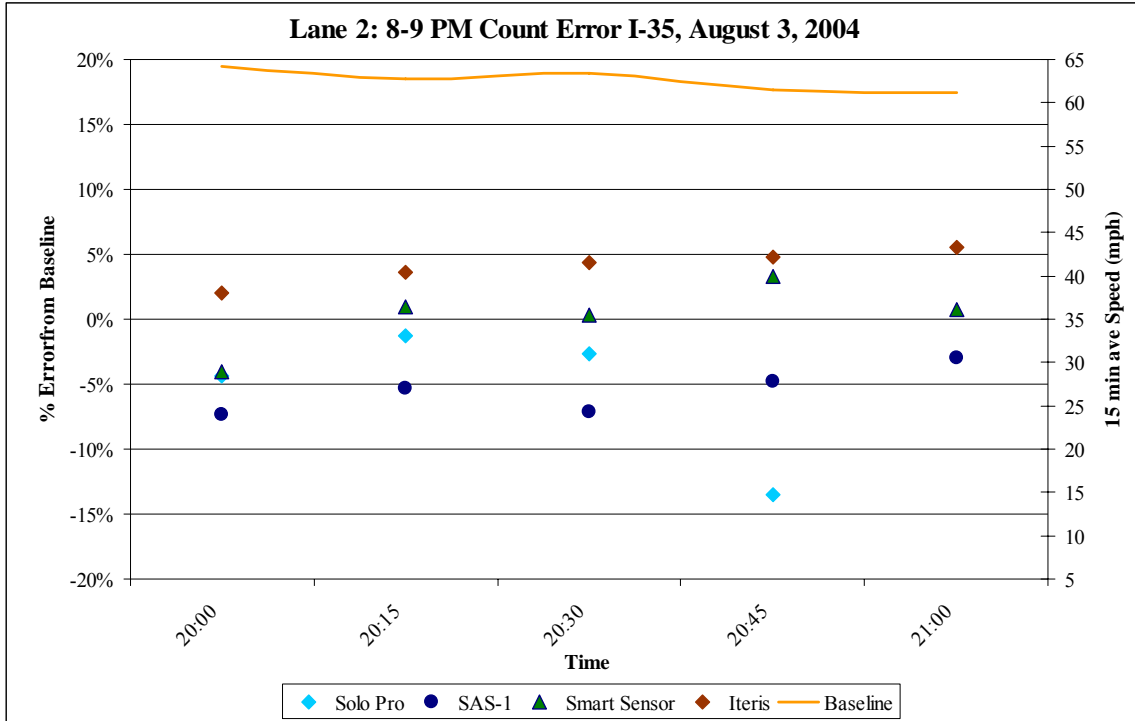


Figure 19. Detector Count Accuracy I-35 8pm-9pm August 3, 2004.

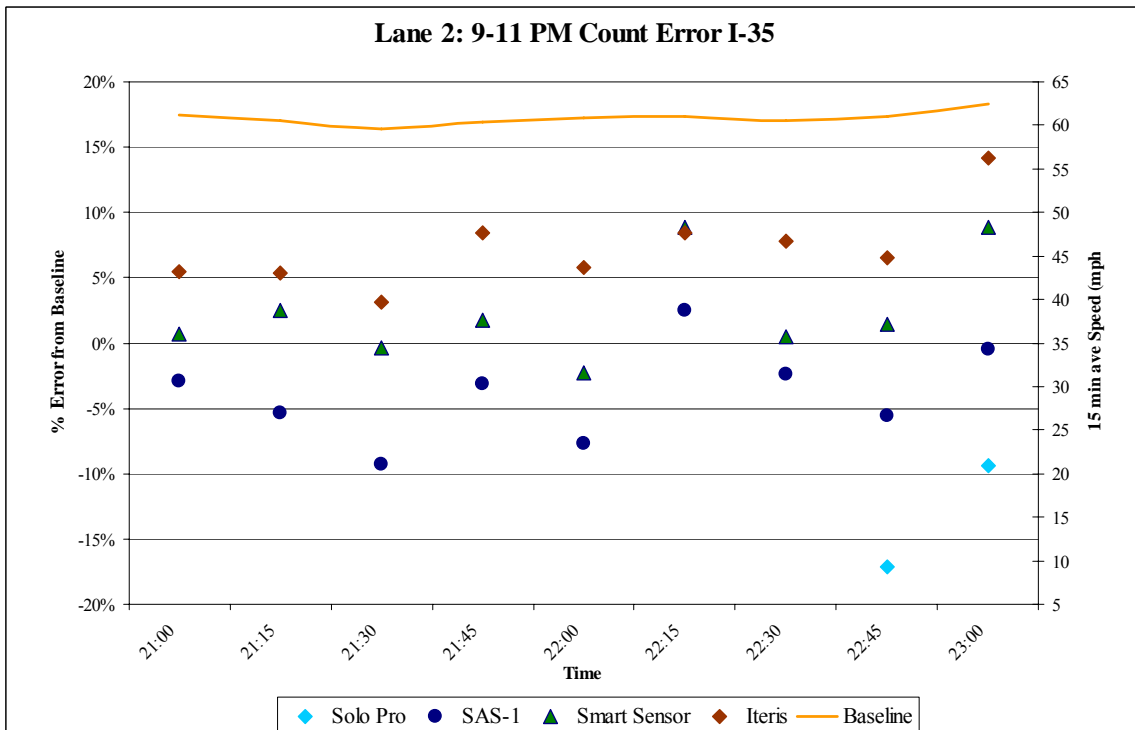


Figure 20. Detector Count Accuracy I-35 9pm-11pm August 3, 2004.

4.4.1.1 Formulas for Calculating the Detector Accuracy (Count Error and Speed Error)

Accuracy can be expressed using one of the following two error quantity values:

1. Mean Absolute Percent Error (MAPE) (see Eq. 1) or
2. Root Mean Squared Error (RMSE) (see Eq. 2).

$$\text{Mean Absolute Percent Error, MAPE(\%)} = \left(\frac{1}{n} \right) \times \left(\sum_{i=1}^n \left| \frac{x_i - x_{reference}}{x_{reference}} \right| \right) \quad \text{Eq. 1}$$

$$\text{Root Mean Squared Error, RMSE} = \sqrt{\left(\frac{1}{n} \right) \left(\sum_{i=1}^n (x_i - x_{reference})^2 \right)} \quad \text{Eq. 2}$$

Where: x_i = the detected data value,
 $x_{reference}$ = the reference (baseline) value, and
 n = the total number of detected data values.

Researchers interpreted the detector accuracy in terms of count error and speed error. The preferred metric for count error is the Mean Absolute Percent Error (MAPE, %) as its range of values is large. On the other hand, the speed error is within a much smaller range of values, so the analysis used Root Mean Squared Error (RMSE). These metrics allow an easy comparison of detectors since smaller values indicate less error compared to the baseline system.

Figures 21 through 24 summarize count and speed performance attributes of the detectors tested at I-35 during FY 2003-2004. For the sake of brevity in the body of this document, samples of data from S.H. 6 are in Appendix C. The figures utilize the MAPE and RMSE to describe these results. The reader should realize that the lane numbering at I-35 is from lane 1 (median) through lane 5 (nearest the pole-mounted detectors). The actual lanes monitored through most of the project were lanes 2 through 5 except for the SmartSensor, which was too close to lane 5 to monitor that lane. For the S.H. 6 data from College Station, lanes 1 and 2 are the northbound lanes, and lanes 3 and 4 are southbound. Only the SmartSensor monitored the northbound lanes on S.H. 6. Most of the data samples were for dry weather.

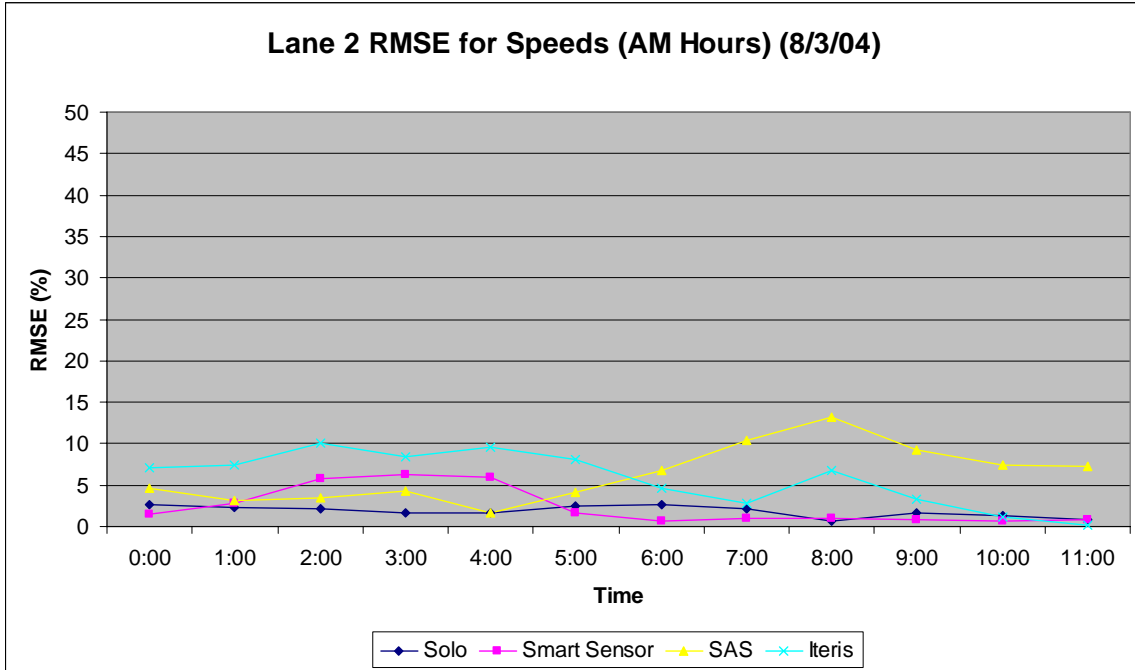


Figure 21. RMSE for Speeds during AM Hours August 3, 2004.

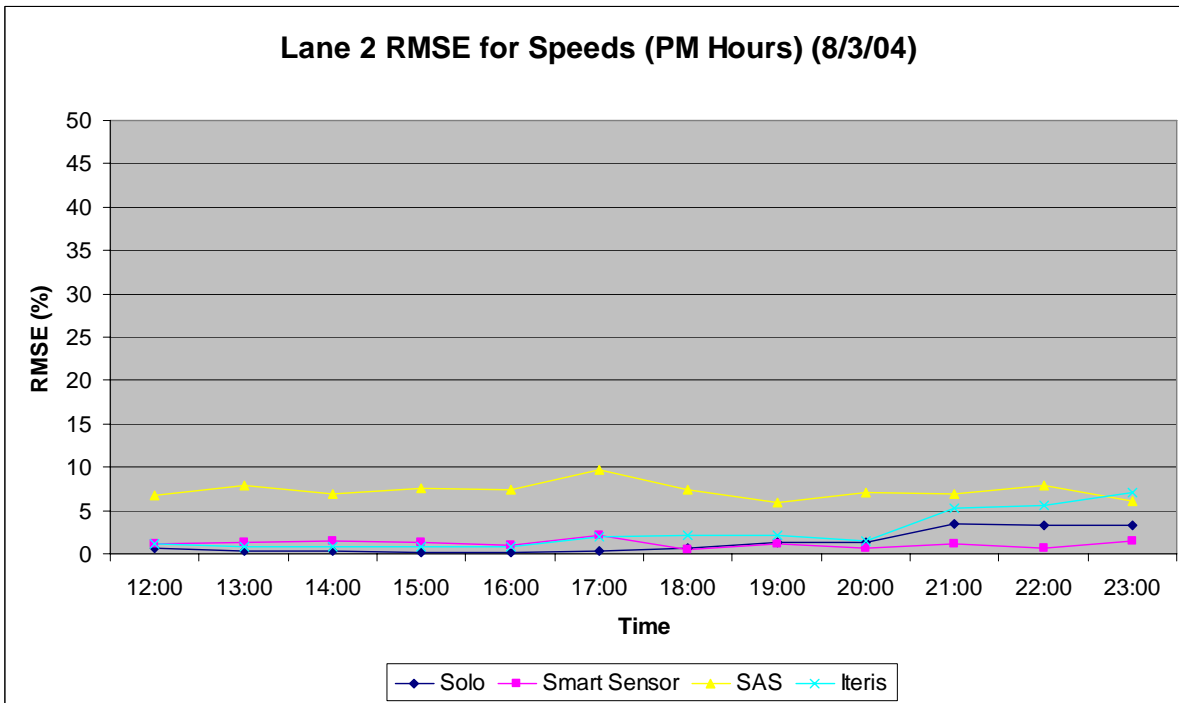


Figure 22. RMSE for Speeds during PM Hours August 3, 2004.

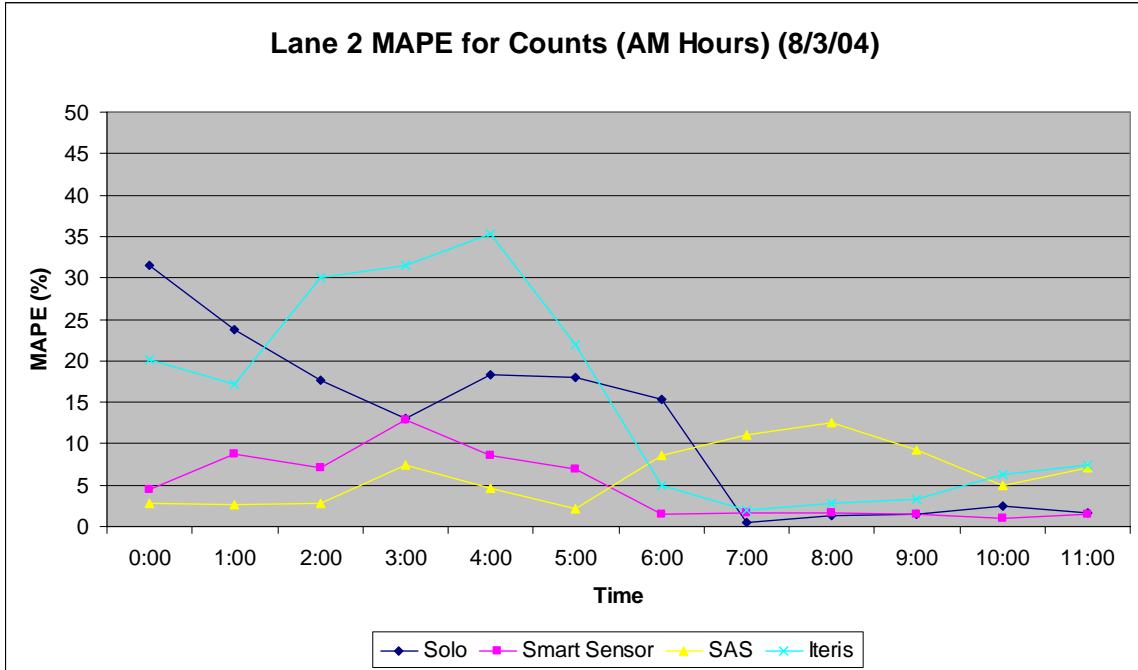


Figure 23. MAPE for Counts during AM Hours August 3, 2004.

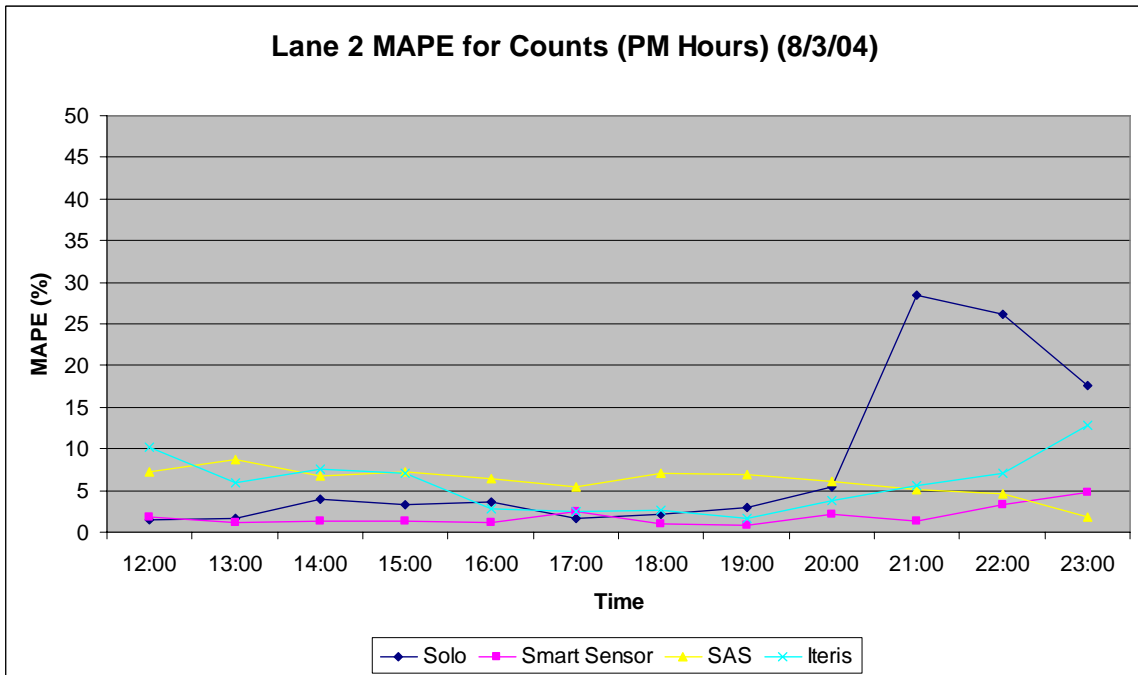


Figure 24. MAPE for Counts during PM Hours August 3, 2004.

4.4.2 Example Count and Occupancy Field Data Results FY 2005

Figures 25 through 34 show graphical count accuracy results for lane 2 on I-35 from the selected dates during the FY 2005 period. The previous section showed speed accuracy as well, but plots indicated much better performance for speeds compared to counts. Therefore, the speed accuracy plots are omitted in this section and the one following. This set of graphics shows only lane 2 as in the previous period. Again, the figures that show the count accuracy also indicate the speed as measured by the baseline system (with a solid orange line) because vehicular speeds affect non-intrusive detector count accuracy.

Figures 32 and 33 are the MAPE graphics corresponding to the FY 2005 count plots. They facilitate easy comparison of detector count accuracy throughout all hours of the selected date for lane 2. Figures 34 and 35 indicate occupancy results for the selected FY 2005 detectors on lanes 2 and 3, respectively, and Figure 36 indicates the effect of rainfall on these same detectors for lane 4 on S.H. 6. The “SS” label in Figures 34 and 35 represents the SmartSensor.

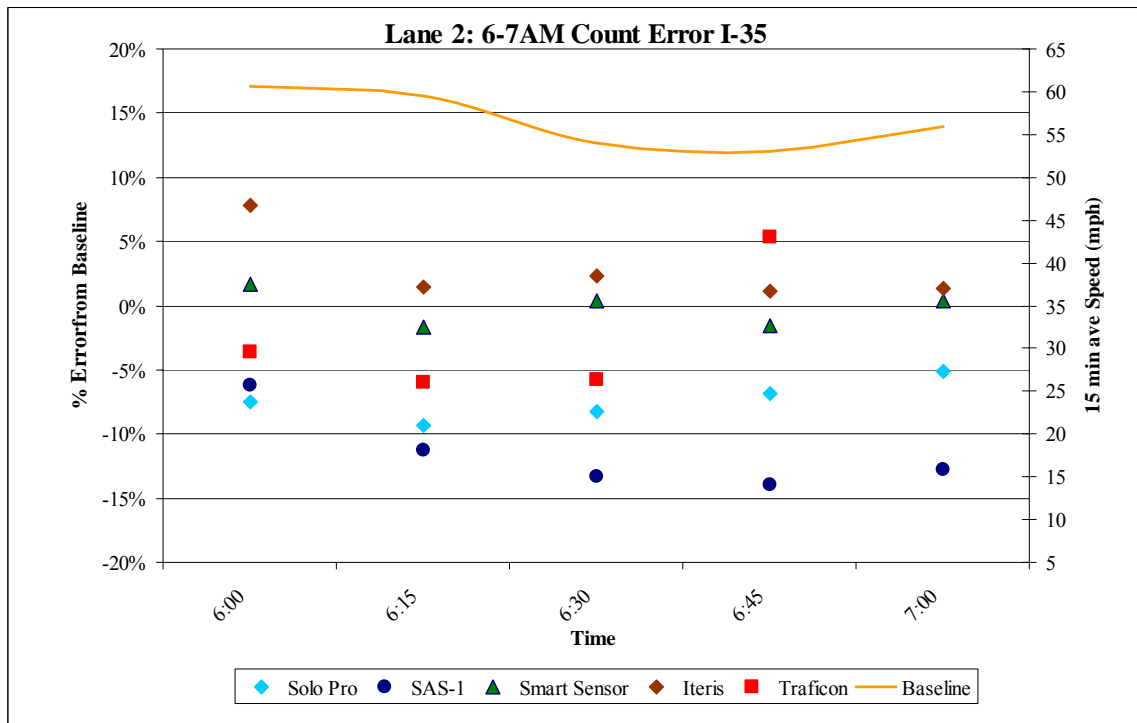


Figure 25. Detector Count Accuracy I-35 6am-7am April 13, 2005.

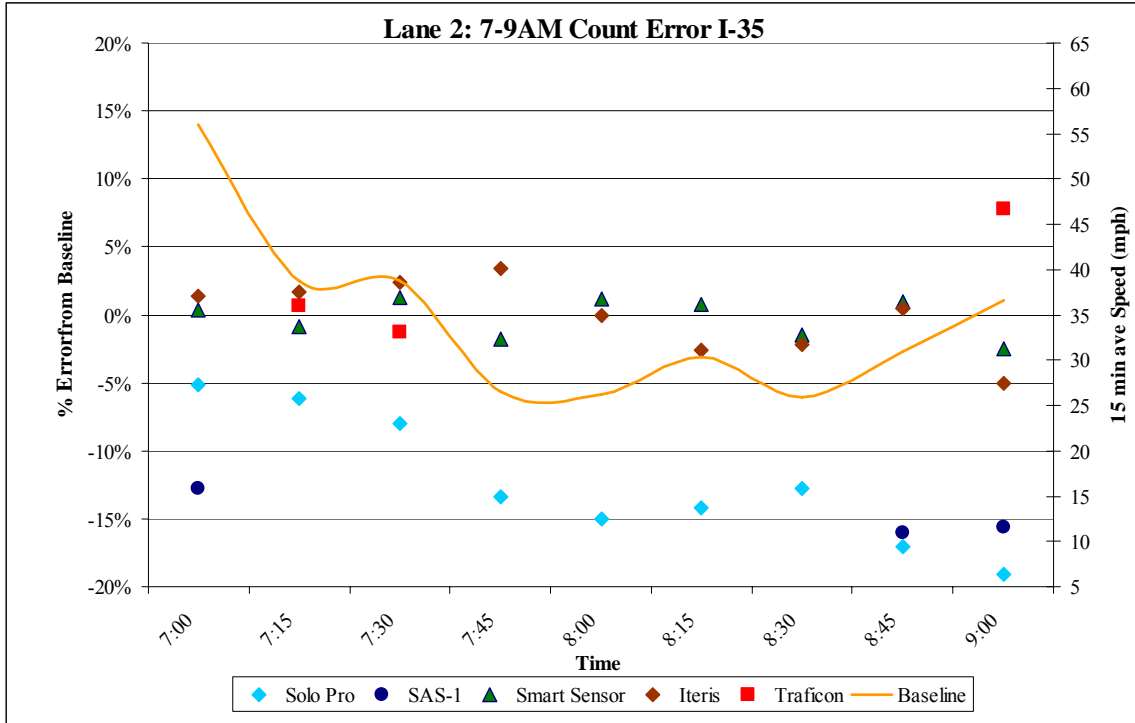


Figure 26. Detector Count Accuracy I-35 7am-9am April 13, 2005.

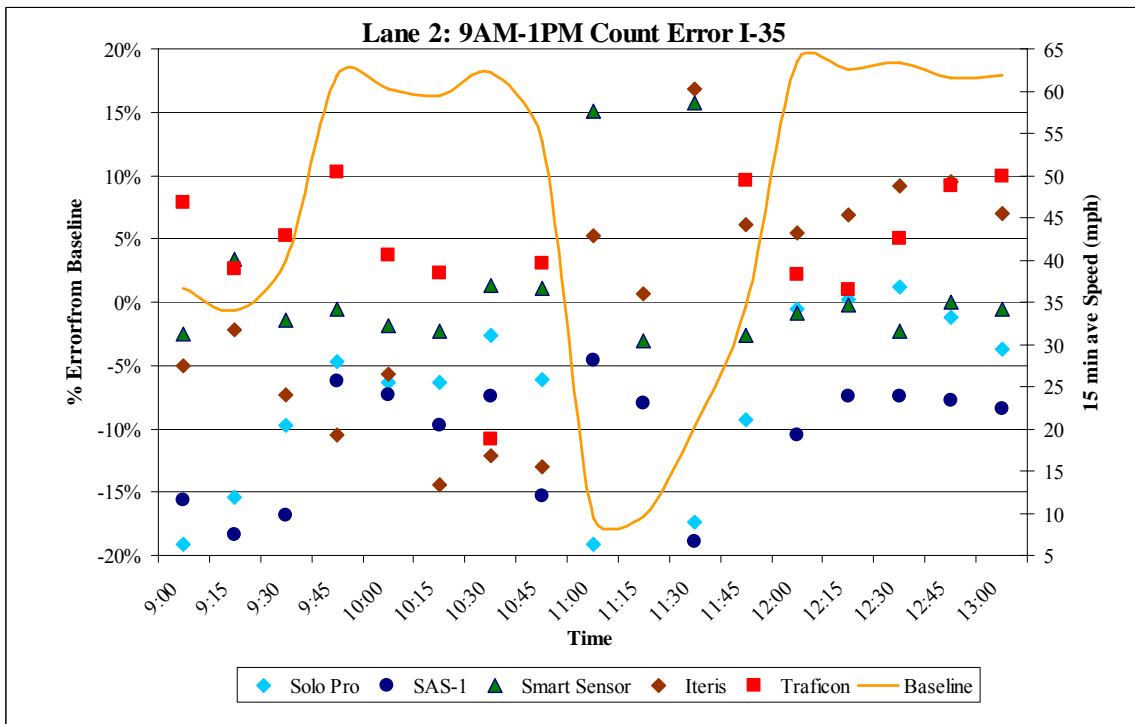


Figure 27. Detector Count Accuracy I-35 9am-1pm April 13, 2005.

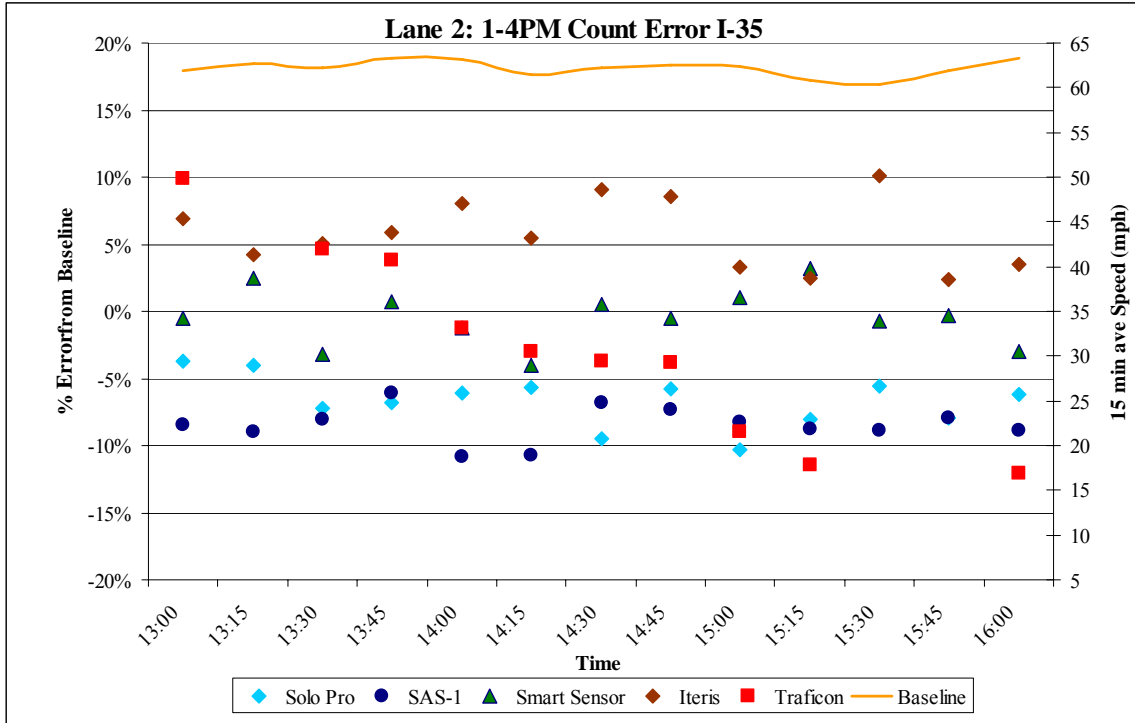


Figure 28. Detector Count Accuracy I-35 1pm-4pm April 13, 2005.

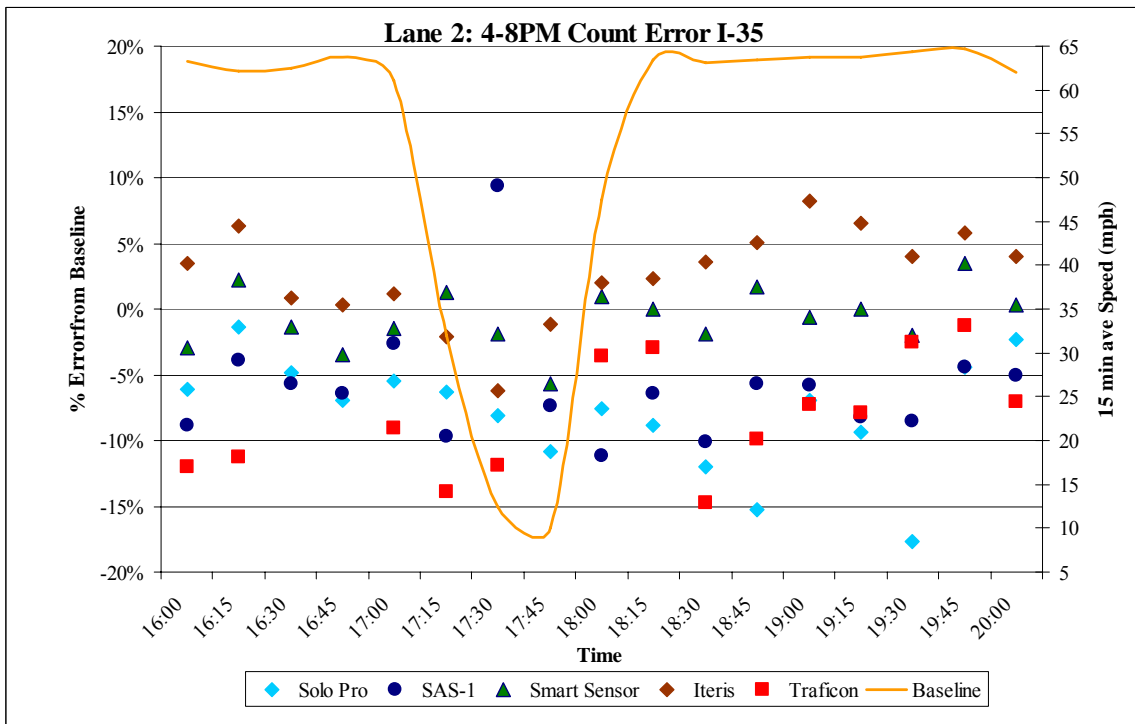


Figure 29. Detector Count Accuracy I-35 4pm-8pm April 13, 2005.

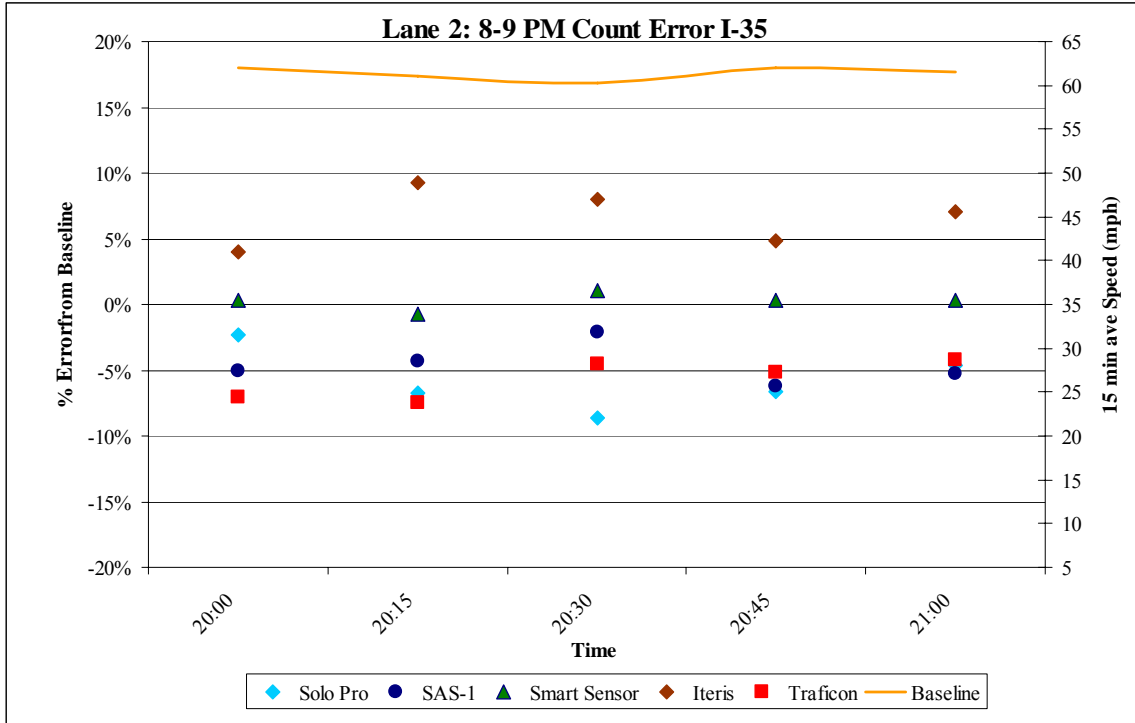


Figure 30. Detector Count Accuracy I-35 8pm-9pm April 13, 2005.

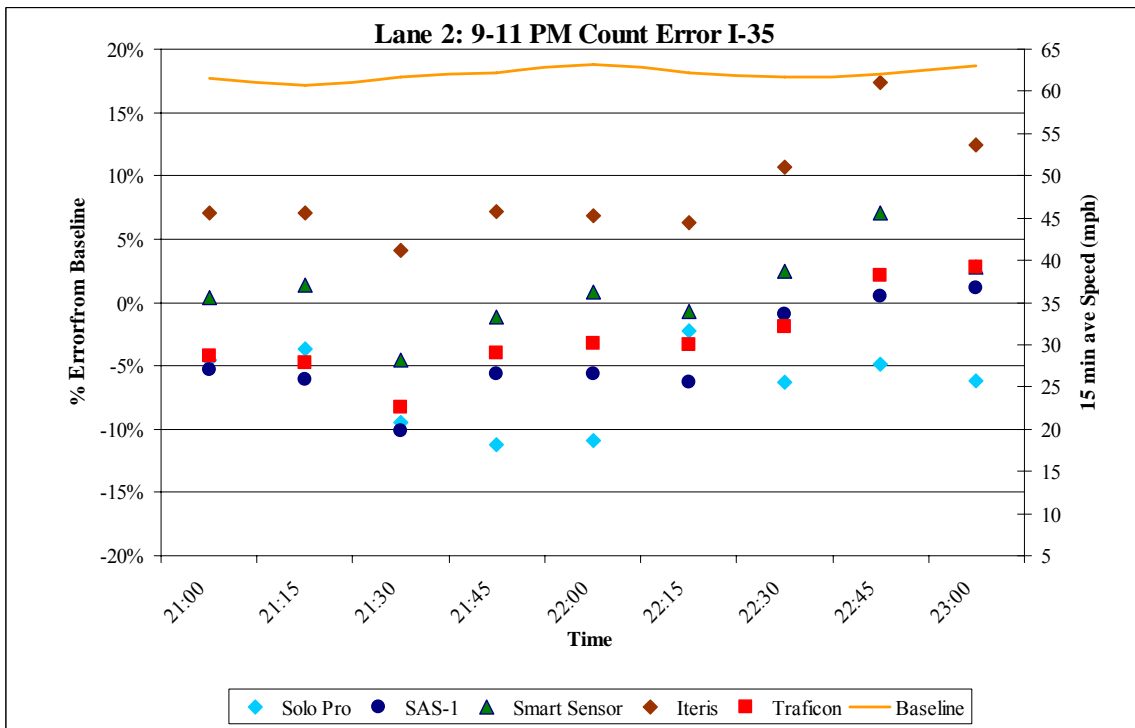


Figure 31. Detector Count Accuracy I-35 9pm-11pm April 13, 2005.

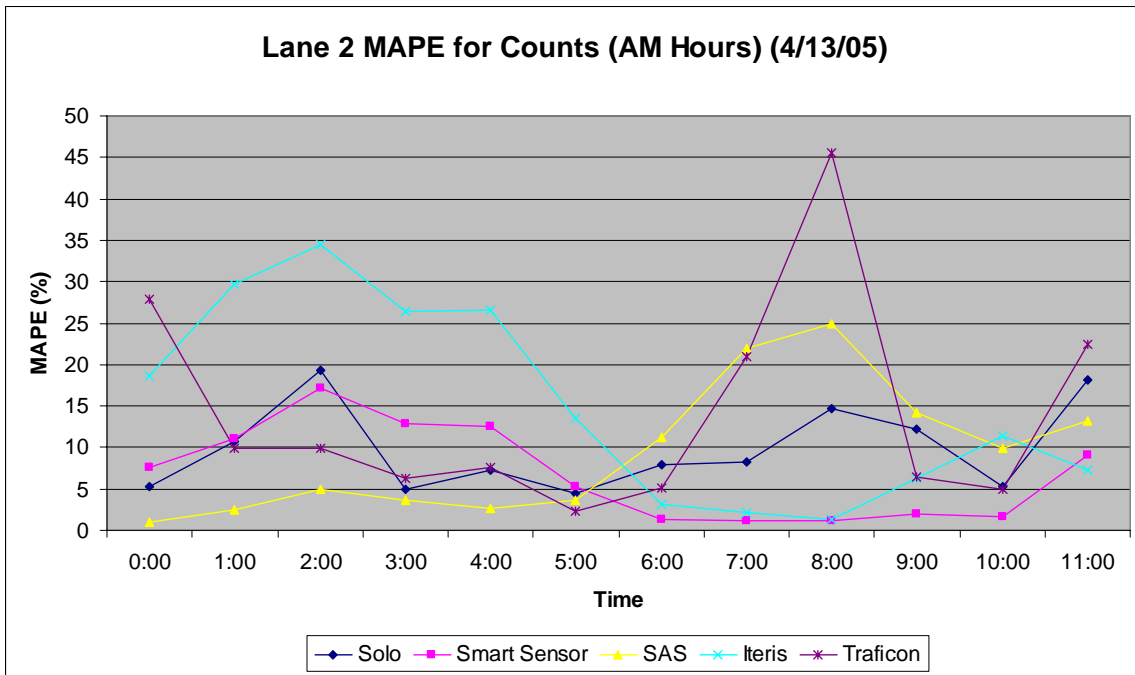


Figure 32. MAPE for I-35 Test Detector Count Data AM Hours April 13, 2005.

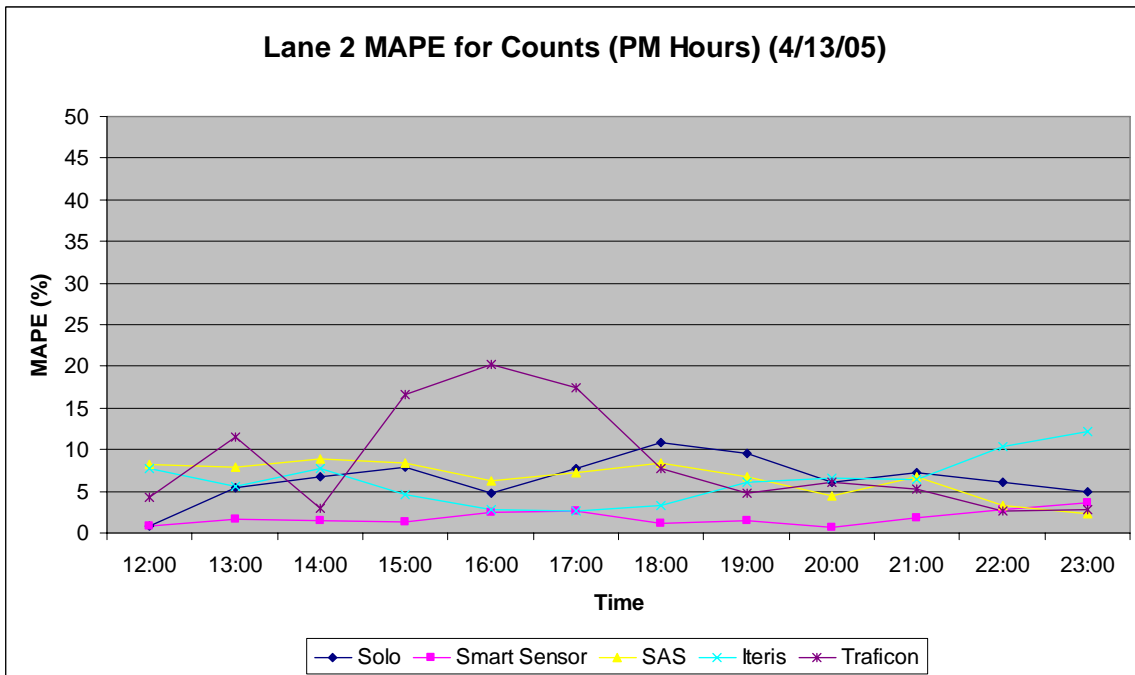


Figure 33. MAPE for I-35 Test Detector Count Data PM Hours April 13, 2005.

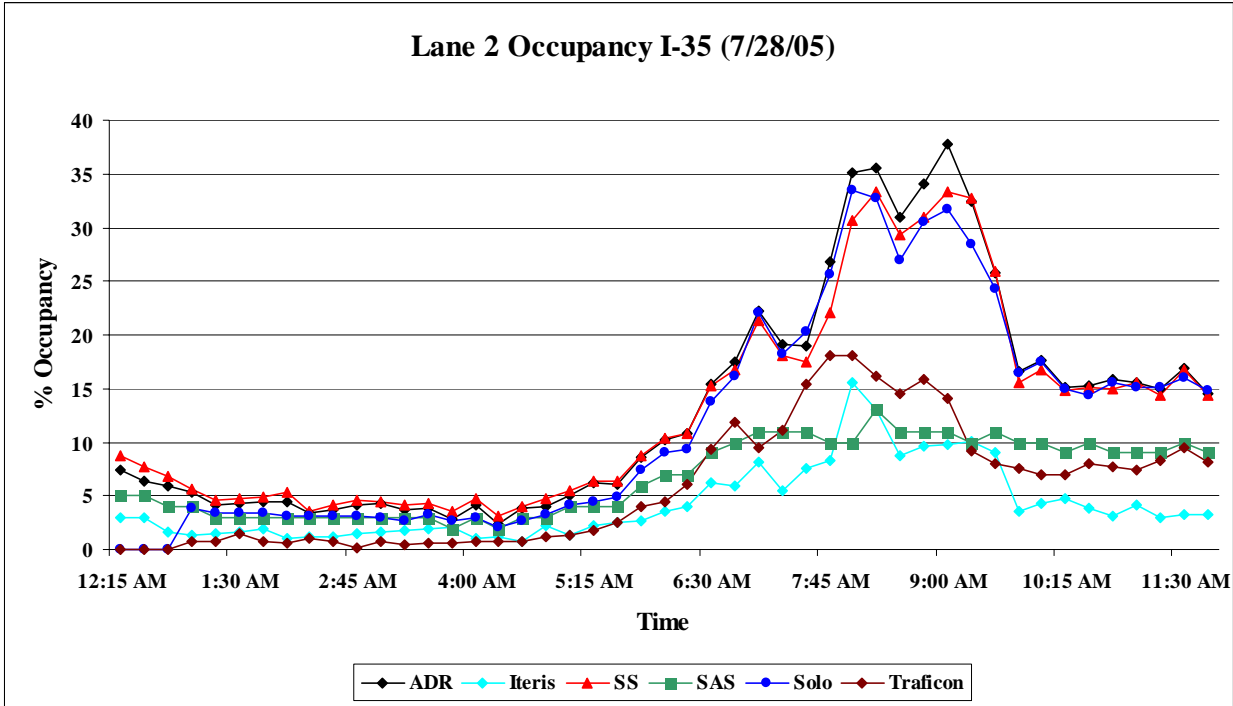


Figure 34. I-35 Lane 2 Occupancy Data.

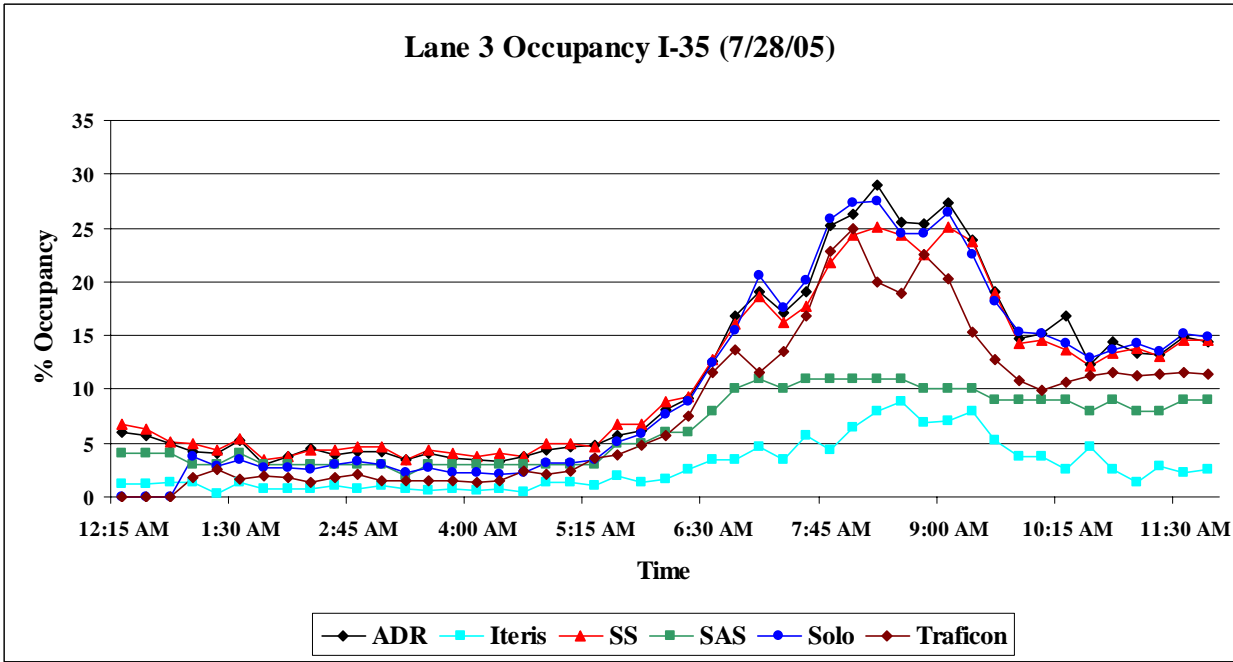


Figure 35. I-35 Lane 3 Occupancy Data.

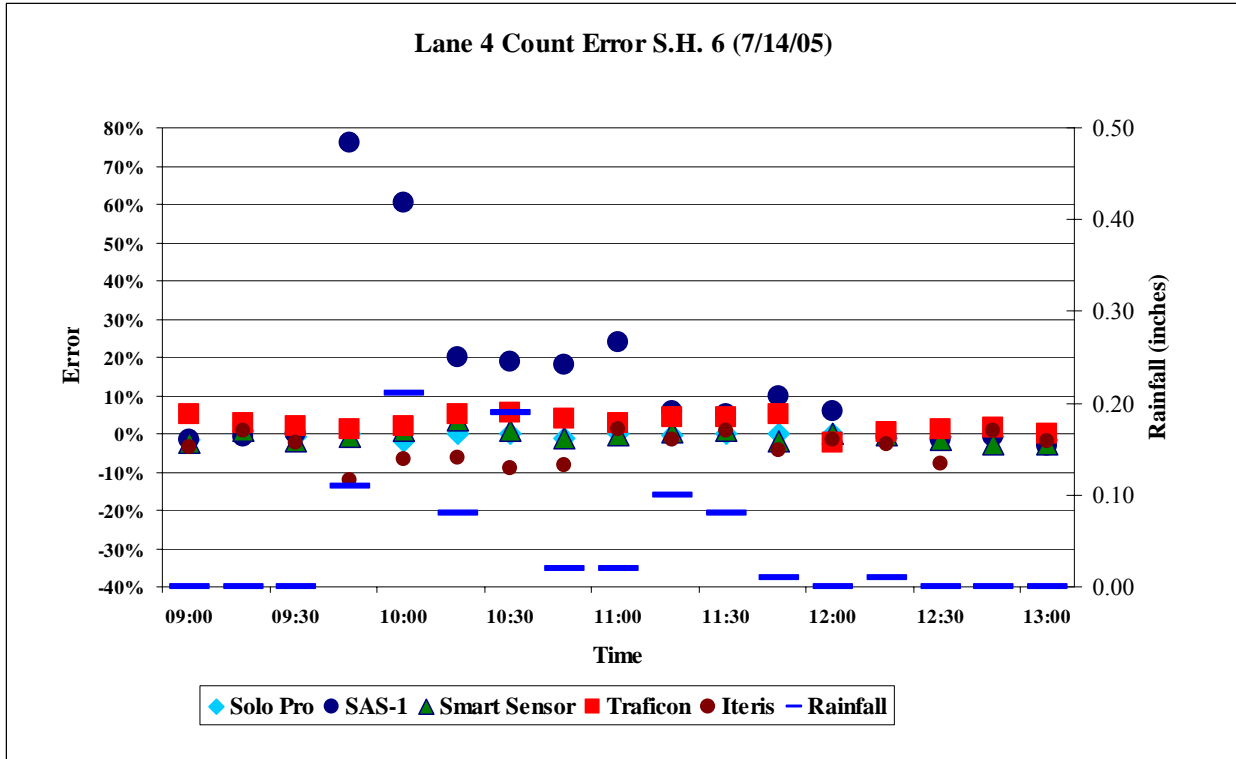


Figure 36. S.H. 6 Lane 4 Rain Data.

4.4.3 Example Count Field Data Results FY 2006

Figures 37 through 43 show graphical count accuracy results for lane 2 from Saturday, July 29, 2006. The previous section for FY 2003-2004 showed speed accuracy as well, but plots indicated much better performance for speeds compared to counts. Therefore, the speed accuracy plots are omitted in this section. This set of graphics shows only lane 2 as in the previous years' periods. Again, the figures that show the count accuracy also indicate the speed as measured by the baseline system (with a solid orange line) because non-intrusive detector count accuracy is affected by vehicular speeds.

Figures 44 and 45 are the MAPE graphics corresponding to the FY 2006 count plots. They facilitate easy comparison of detector count accuracy throughout all hours of the selected date for lane 2.

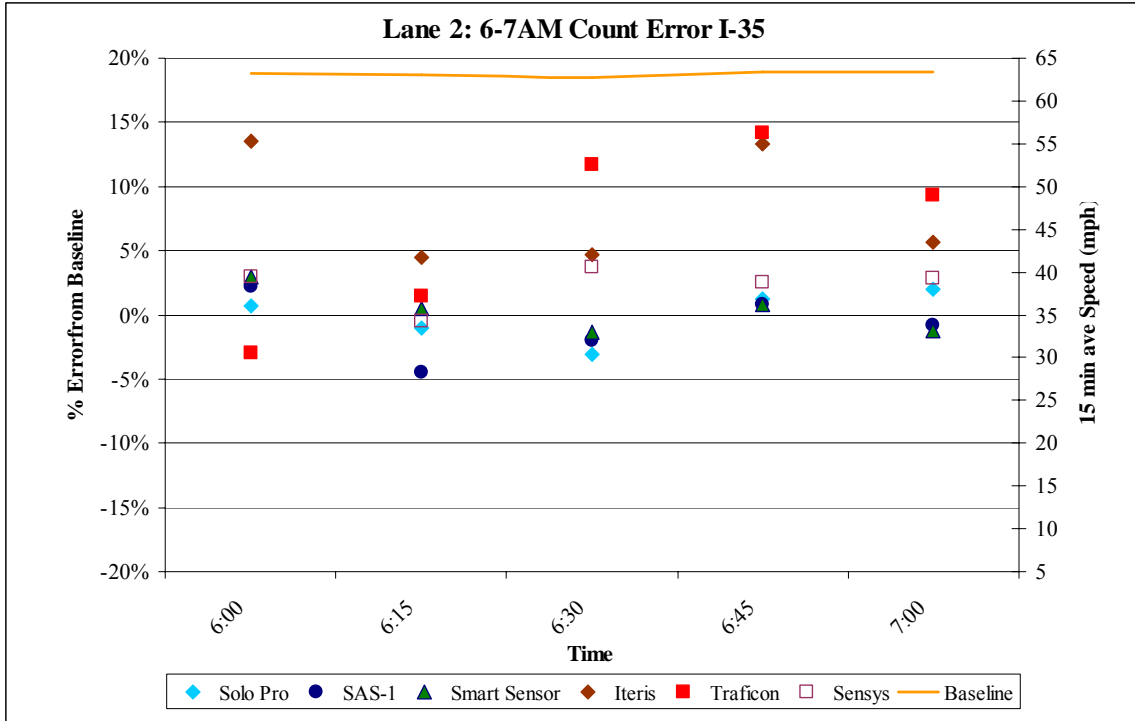


Figure 37. Detector Count Accuracy I-35 6am-7am July 29, 2006.

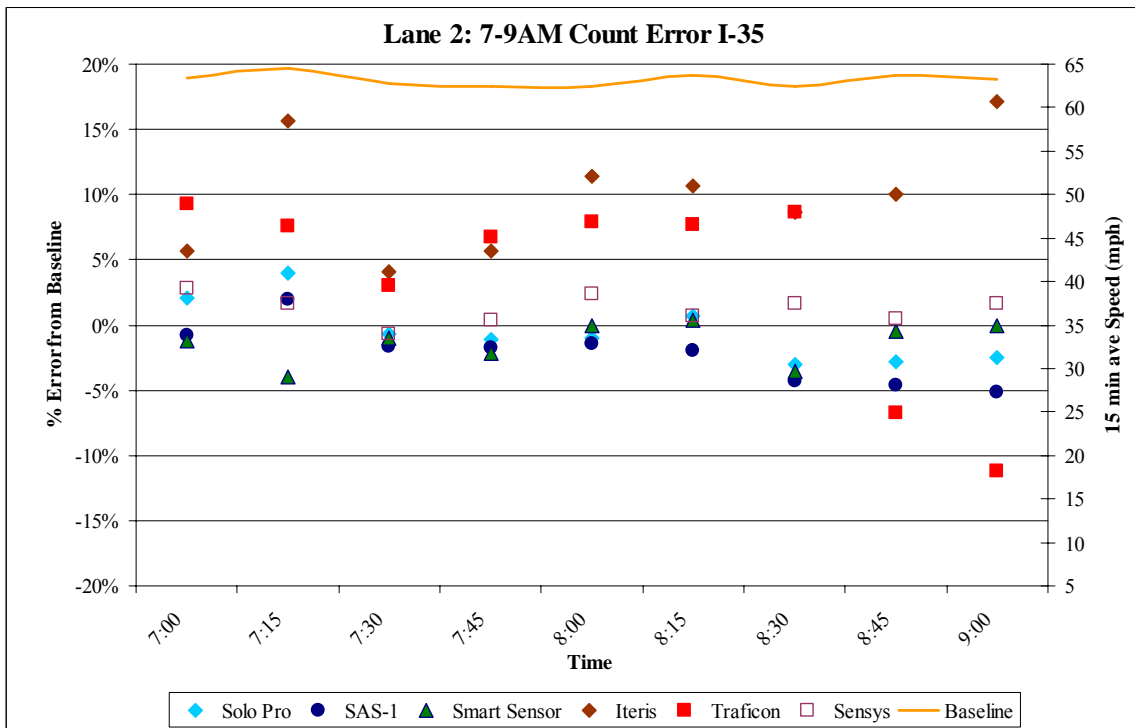


Figure 38. Detector Count Accuracy I-35 7am-9am July 29, 2006.

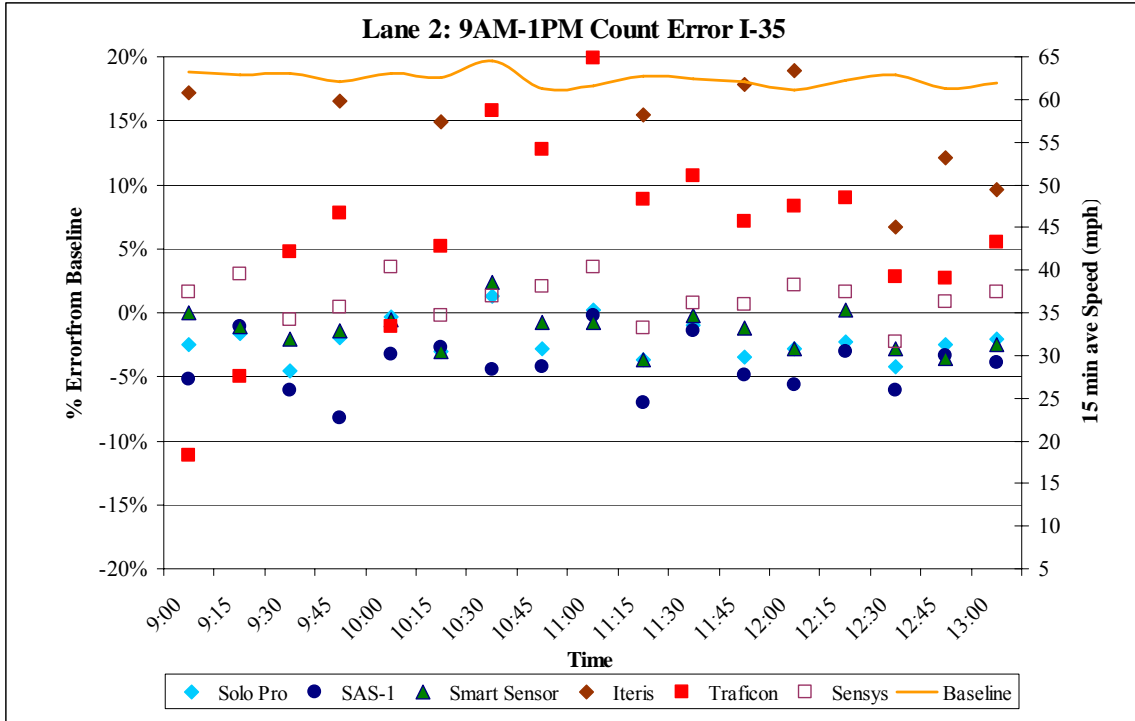


Figure 39. Detector Count Accuracy I-35 9am-1pm July 29, 2006.

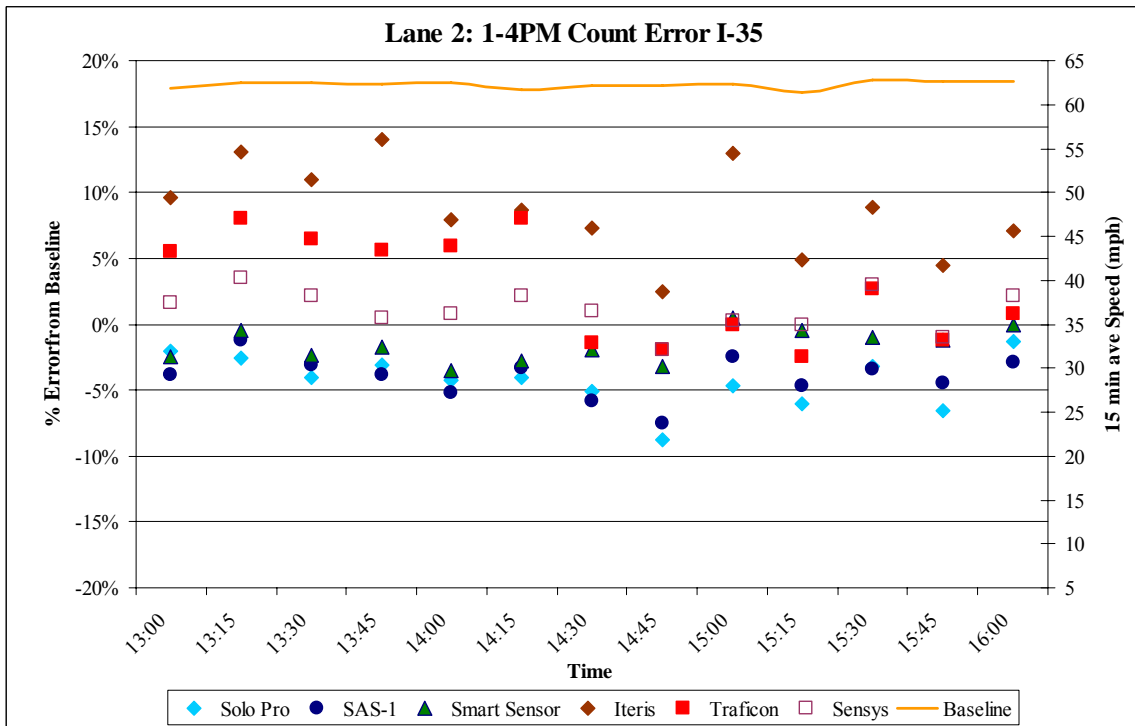


Figure 40. Detector Count Accuracy I-35 1pm-4pm July 29, 2006.

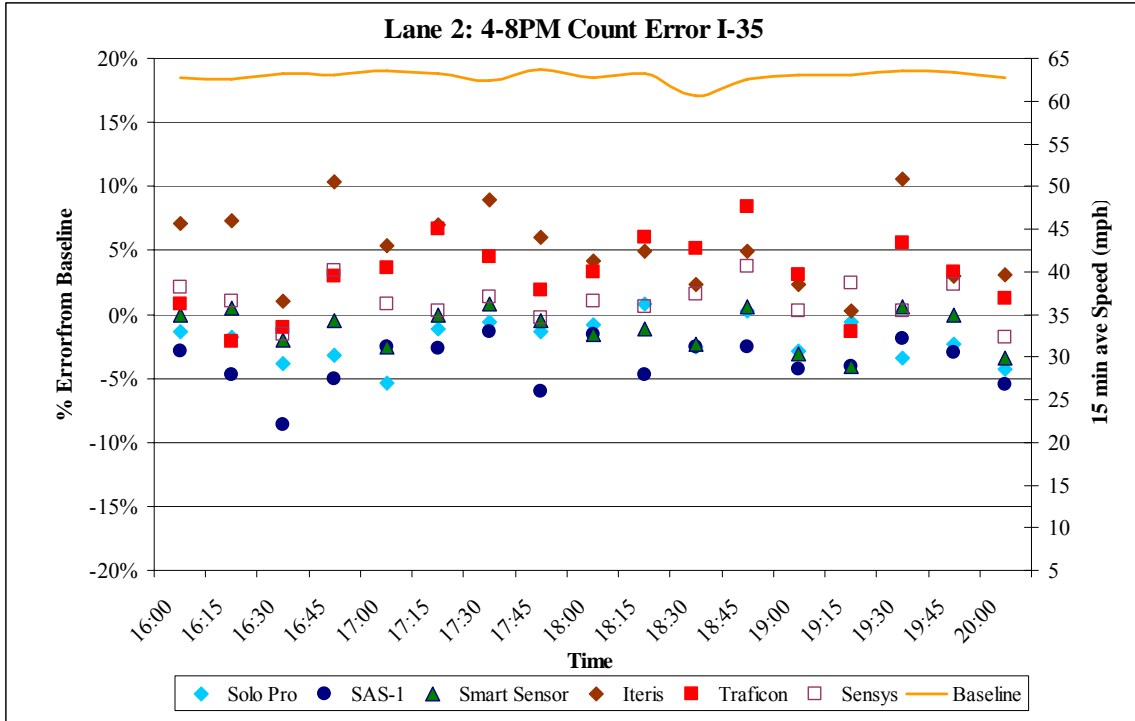


Figure 41. Detector Count Accuracy I-35 4pm-8pm July 29, 2006.

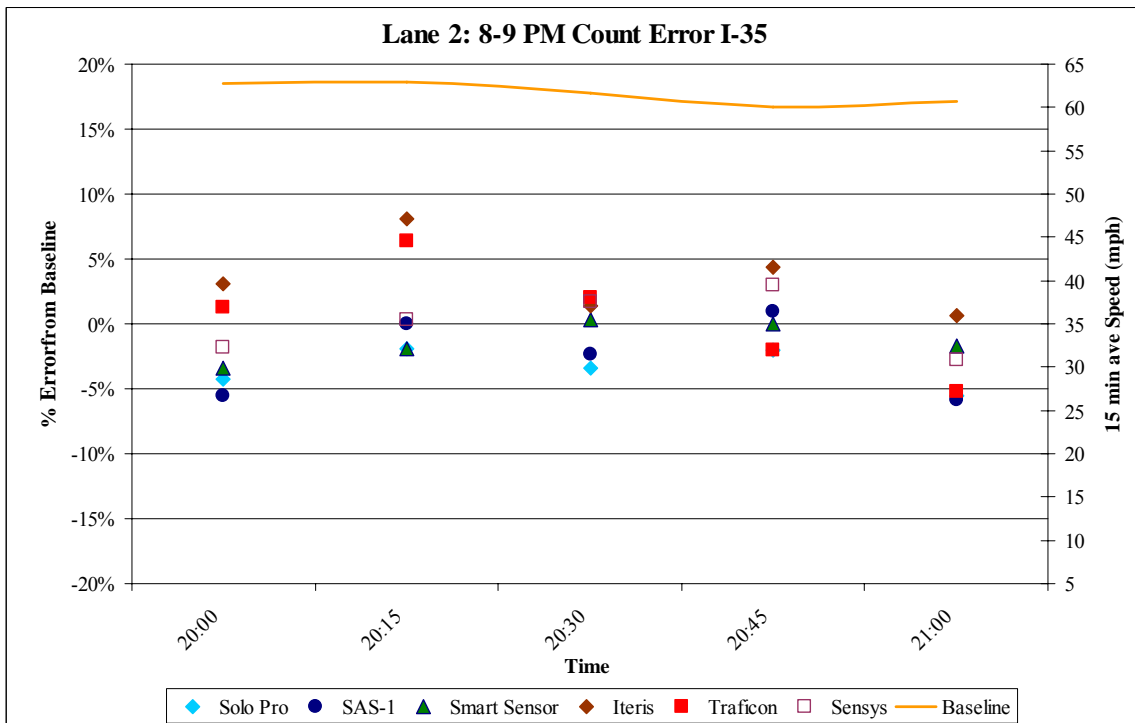


Figure 42. Detector Count Accuracy I-35 8pm-9pm July 29, 2006.

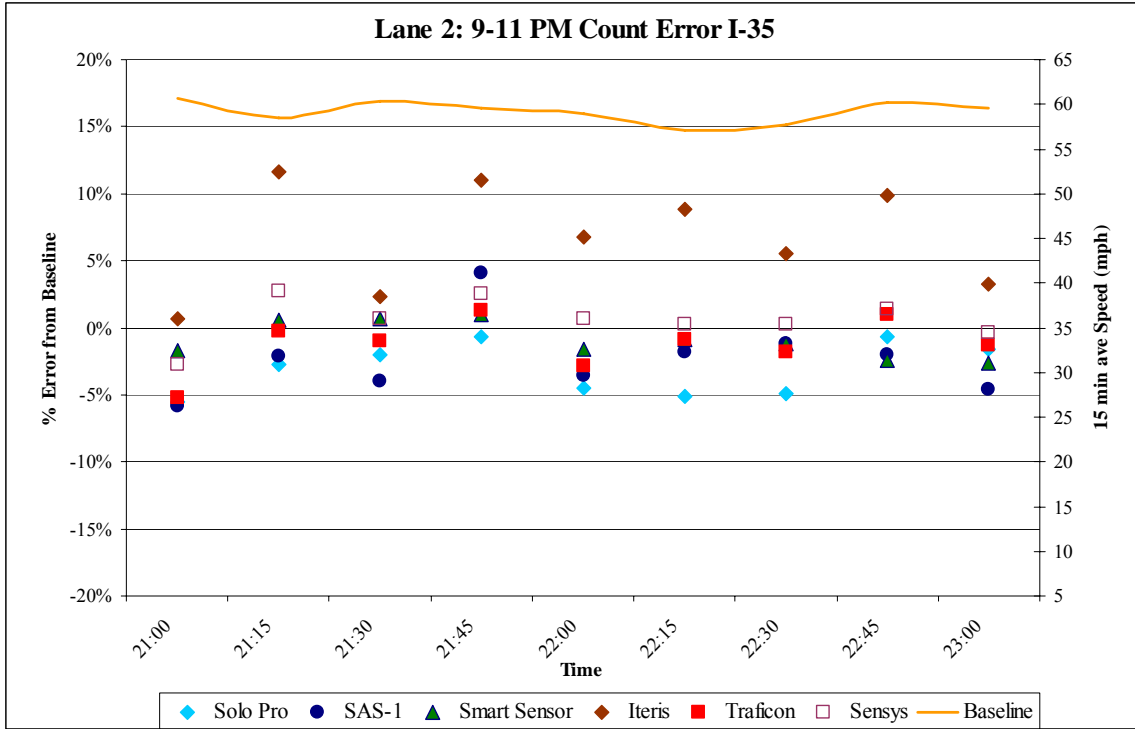


Figure 43. Detector Count Accuracy I-35 9pm-11pm July 29, 2006.

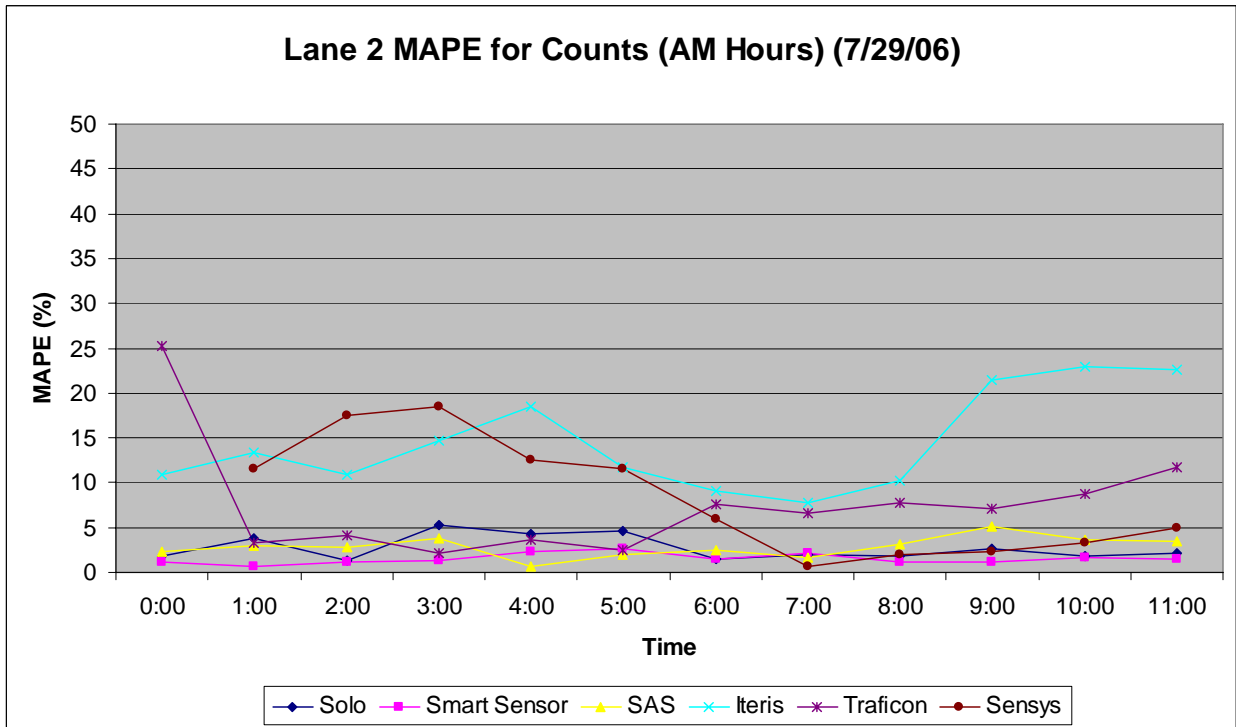


Figure 44. MAPE for I-35 Test Detector Count Data AM Hours July 29, 2006.

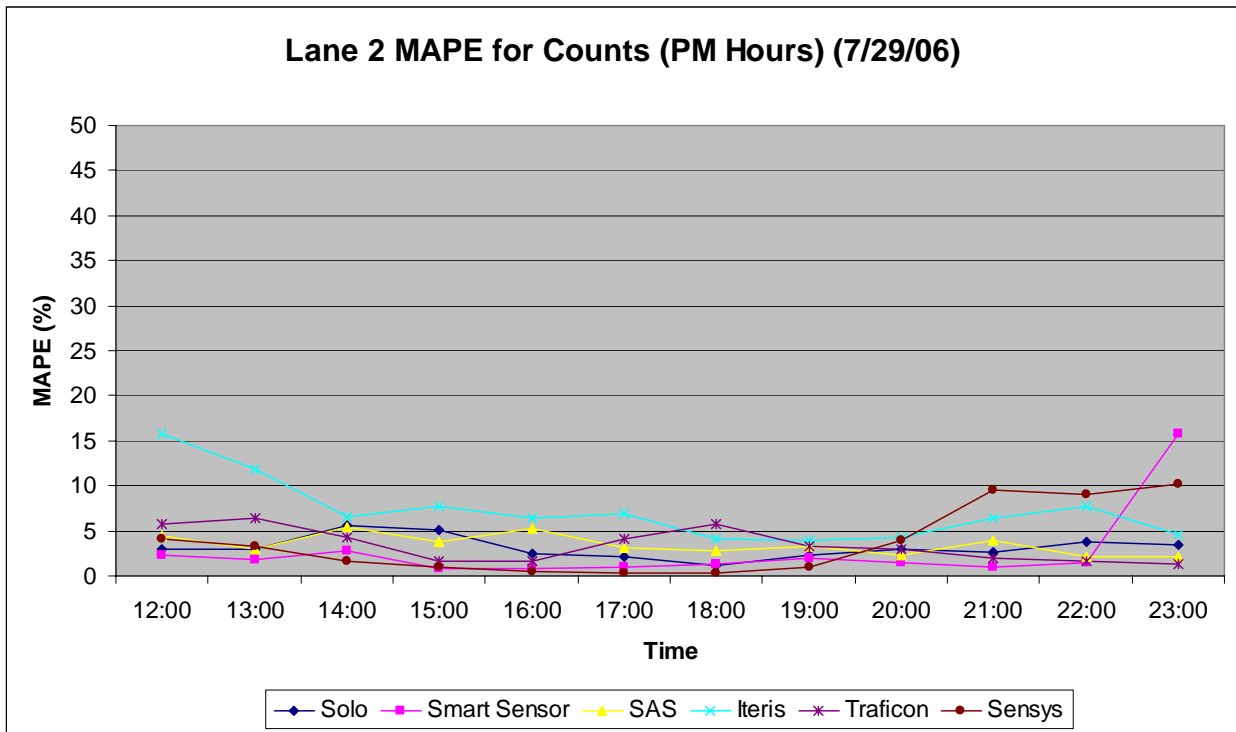


Figure 45. MAPE for I-35 Test Detector Count Data PM Hours July 29, 2006.

4.4.4 Example Vehicle Length Measurement Field Data Results FY 2006

Figures 46 and 47 are histograms indicating the difference in length as measured by the Autoscope Solo Pro and the SmartSensor SS105, respectively, compared to the baseline ADR-6000 for August 17, 2006. The resulting distribution resembles a bell-shaped curve, as expected, with a mean value near the zero point; again, as expected. Figures 48 and 49 are histograms indicating the difference in length as measured by the Autoscope Solo Pro and the Traficon, respectively, compared to the baseline ADR-6000 for August 24, 2006. Results indicate that at least the Traficon could improve with calibration.

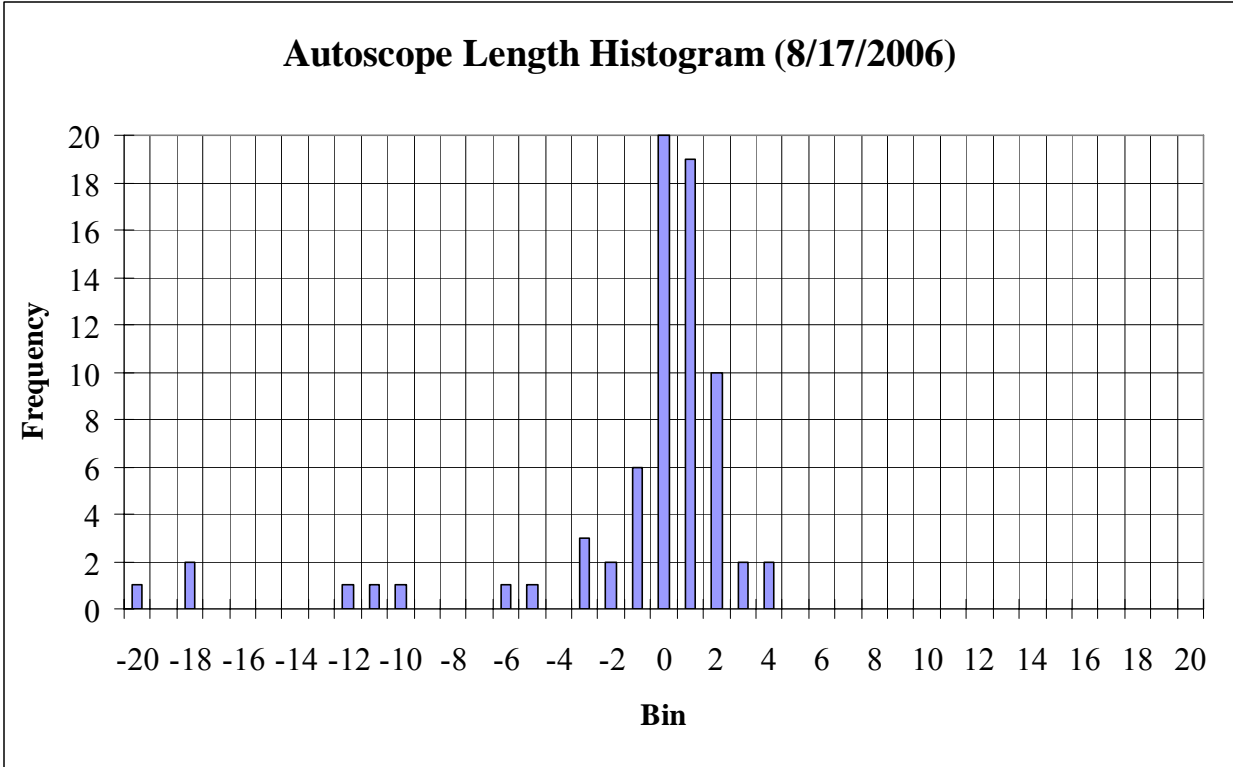


Figure 46. Autoscope Solo Pro Vehicle Length Histogram for August 17, 2006.

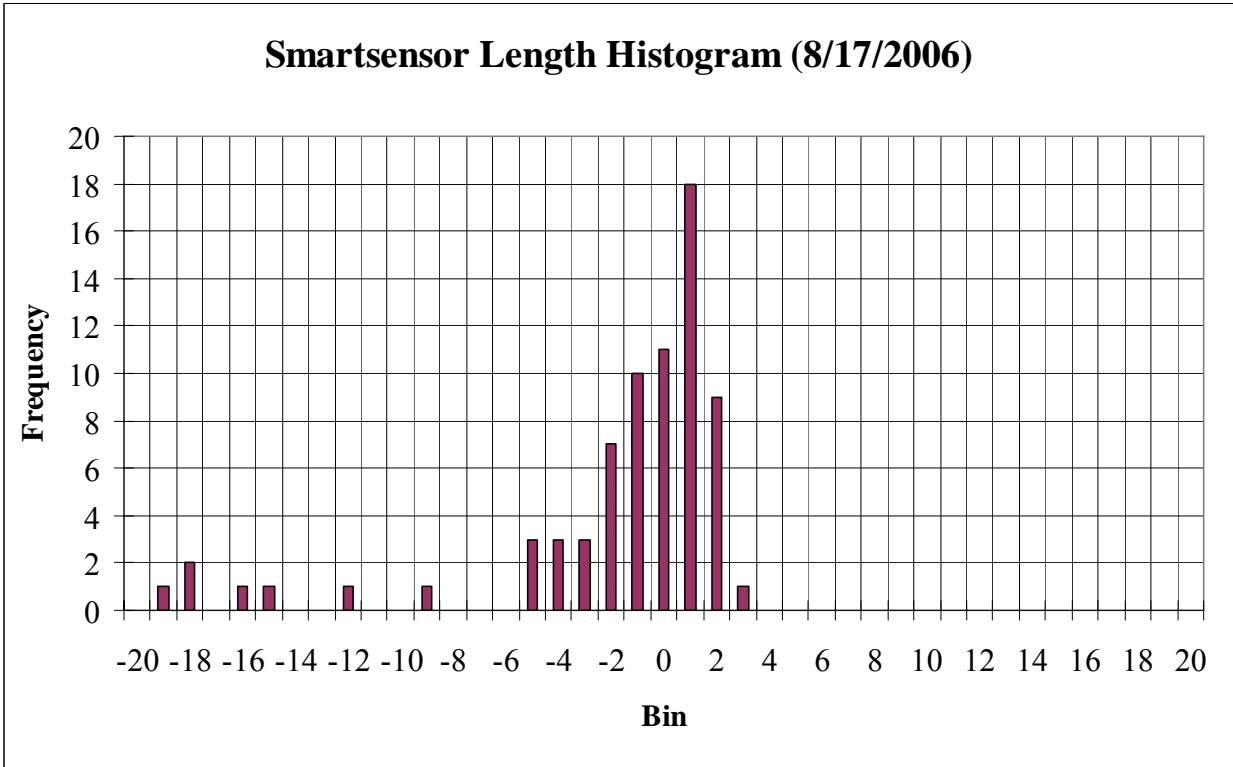


Figure 47. SmartSensor Vehicle Length Histogram for August 17, 2006.

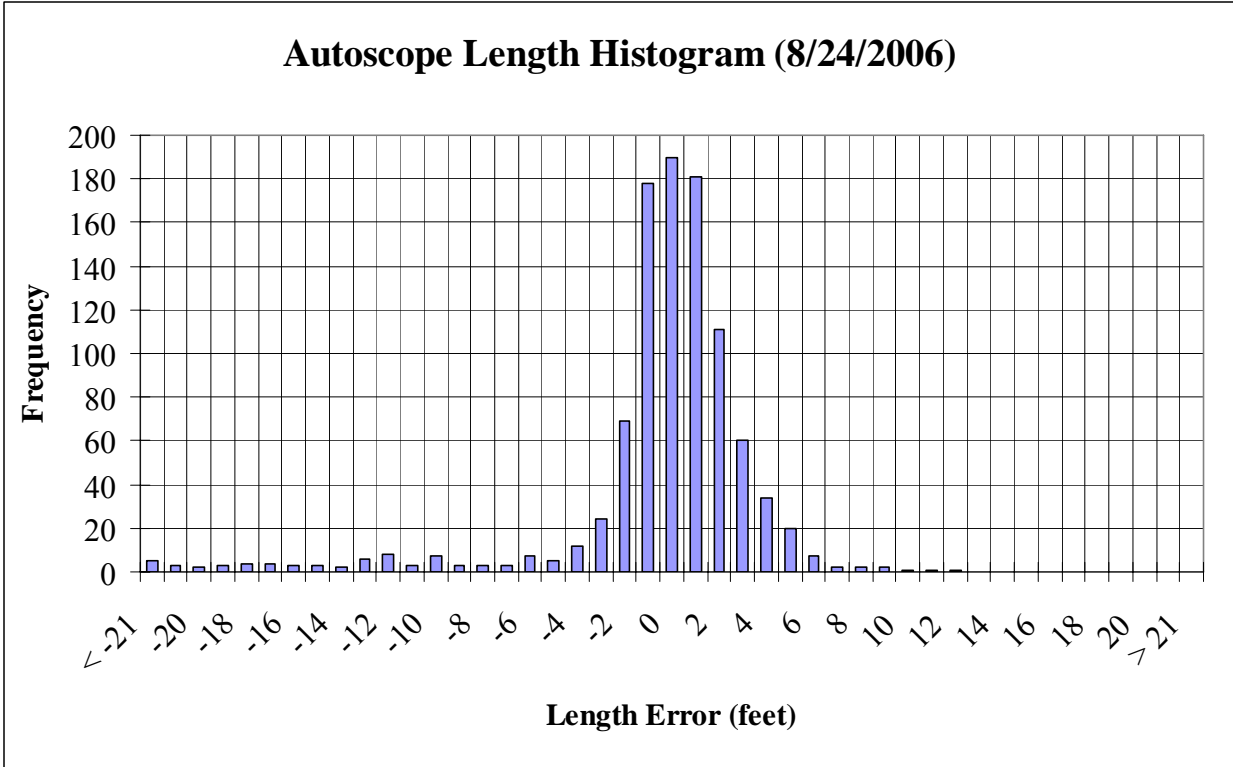


Figure 48. Autoscope Solo Pro Vehicle Length Histogram for August 24, 2006.

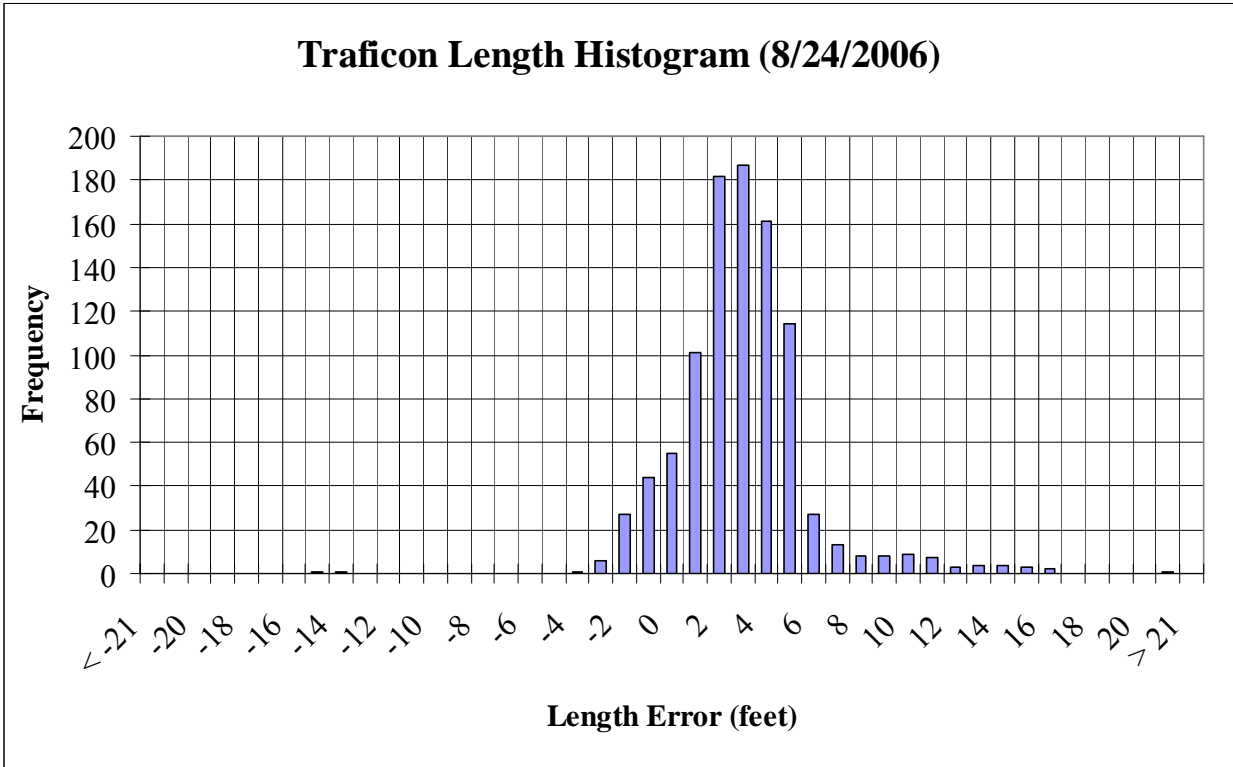


Figure 49. Traficon Vehicle Length Histogram for August 24, 2006.

4.4.5 Example Incident Detection Field Data Results FY 2006

Two of the detection systems (both VIVDS) included in this research claim to be able to detect incidents—the Autoscope Solo Pro and the Traficon. The two systems detect incidents in different ways as described below.

4.4.5.1 Autoscope Solo Pro

The Autoscope Solo Pro generates alarms based on certain user-specified criteria. The detector only generates an alarm if all criteria have been met. The first criterion must be satisfied before moving on to the second, and finally the third. The three parameters used to determine incidents are flow, severity, and persistence. The definitions of these parameters follow.

- 1 Flow (vehicles per hour) – Defines the minimum vehicle flow required before the severity parameter is considered.
- 2 Severity – Defines the minimum drop in speed (%) before the persistence parameter is considered.
- 3 Persistence (seconds) – Defines the minimum duration of the drop in speed before the alarm status is changed to ON.

This approach allows the user to “define” an incident by adjusting these traffic parameter thresholds. The Autoscope actually detects the effects of an incident; that is, the drastic move from free-flow to non-free-flow conditions. A properly configured system can differentiate between congestion due to an incident and congestion during peak periods.

TTI configured the Autoscope located at I-35 in Austin to test the unit’s incident detection capabilities. For testing purposes, researchers set the detection parameters to create alarms for incidents as well as the typical congestion during the morning and evening peak periods. Figures 50 and 51 show the incident alarms generated by the Autoscope on August 25 and 26, respectively. The incident alarm is indicated by an Alarm Status of 1. The half-height indications are warning indicators.

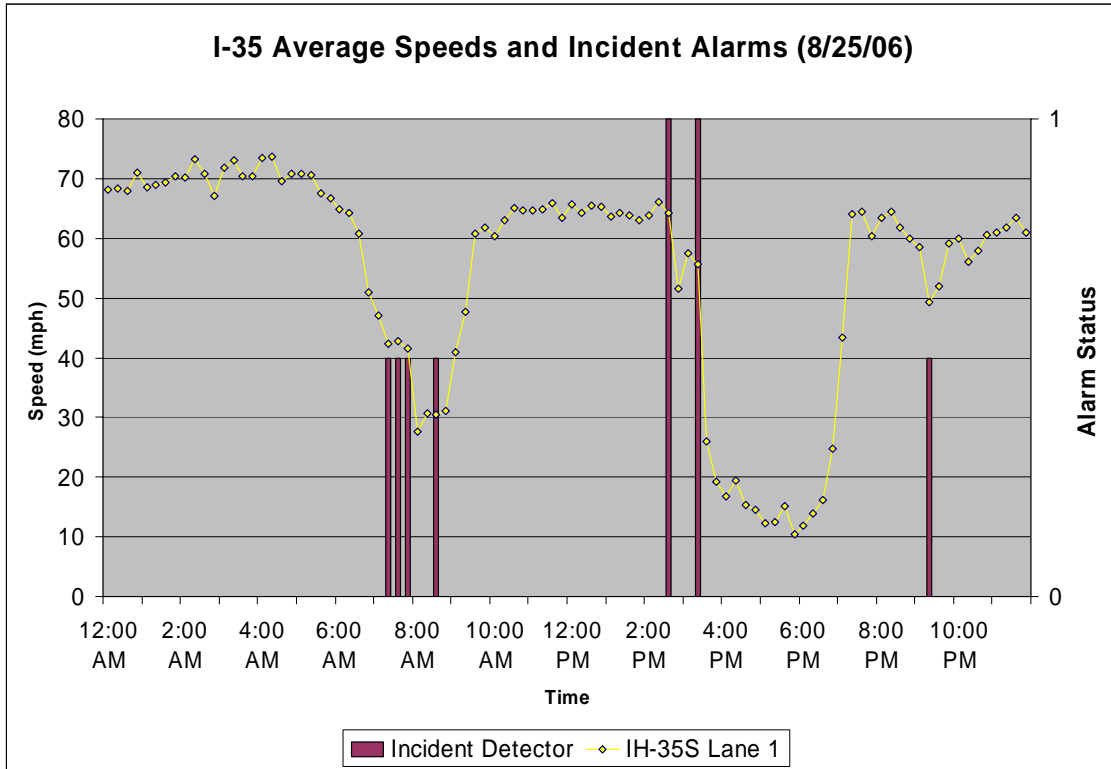


Figure 50. Autoscope Solo Pro Incident Detection August 25, 2006.

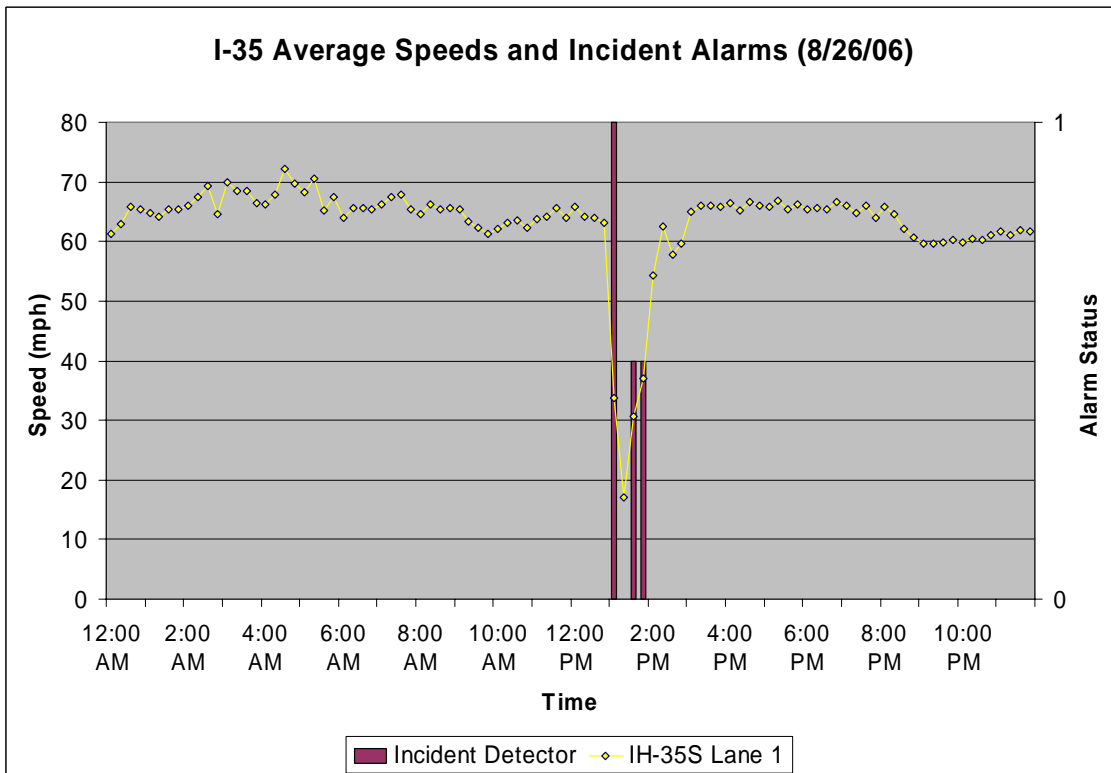


Figure 51. Autoscope Solo Pro Incident Detection August 26, 2006.

4.4.5.2 Traficon

The Traficon VIP-I detector card can be configured to detect many types of incidents. The VIP-I monitors a user-defined area of roadway for specific incidents such as stopped vehicles, speed variations, reverse travel direction, or pedestrians in the roadway.

Technicians configured the VIP-I located at I-35 in Austin to detect stopped vehicles, speed variations, and reverse travel directions. Traficon defined multiple detection zones to separate the main lanes from the access road. The VIP-I generates unique alarms that detail the location and type of incident. [Figure 52](#) shows the Traficon VIP-I display with detected stopped vehicles in the main lanes of I-35. The unit highlights the stopped vehicles by a white box near the top of the viewing area. The VIP-I detector captures and stores video when an incident alarm is triggered.



Figure 52. Traficon Screen Capture of Stopped Vehicles.

4.5 SUMMARY OF FIELD TEST RESULTS

The data samples from each of the three data collection periods show some of the strengths and weaknesses of the detectors tested during the study. More results are available in [Appendix C](#). The SmartSensor was too close to lane 5 in Austin to cover that lane, so its results

are only for lanes 2 through 4 and for lanes 1 through 4 after the lane 1 inductive loop was repaired. Table 22 provides a summary of the graphics presented earlier in this chapter.

Table 22. Summary of Detector Performance.

Count Error Summary (% difference)						
Detector	FY03-04		FY05		FY06	
	Peak^a	Off-Peak^b	Peak	Off-Peak	Peak	Off-Peak
Autoscope Solo Pro (VIVDS)	1.3%	2.7%	11.1%	9.3%	1.8%	3.8%
Iteris Vantage (VIVDS)	2.4%	5.5%	2.1%	6.5%	7.8%	15.1%
SAS-1 (Acoustic)	9.1%	7.5%	16.9%	10.8%	2.8%	4.8%
Sensys (Magnetometer)	-	-	-	-	0.9%	1.5%
SmartSensor (Microwave Radar)	1.9%	1.3%	1.7%	1.7%	1.2%	1.7%
Traficon (VIVDS)	-	-	30.7%	5.0%	5.8%	4.7%
Speed Error Summary (difference, mph)						
Detector	FY03-04		FY05		FY06	
	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak
Autoscope Solo Pro (VIVDS)	0.5	0.8	1.7	0.6	1.6	1.6
Iteris Vantage (VIVDS)	3.9	1.4	4.4	3.1	1.8	0.9
SAS-1 (Acoustic)	11.2	7.9	3.4	3.1	7.7	8.2
Sensys (Magnetometer)	-	-	-	-	0.3	0.3
SmartSensor (Microwave Radar)	1.1	1.0	1.1	0.6	5.7	5.4
Traficon (VIVDS)	-	-	2.5	1.3	0.8	1.3
Occupancy Error Summary (% error)						
Detector	FY03-04		FY05		FY06	
	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak
Autoscope Solo Pro (VIVDS)	-	-	7%	4%	-	-
Iteris Vantage (VIVDS)	-	-	81%	90%	-	-
SAS-1 (Acoustic)	-	-	57%	40%	-	-
Sensys (Magnetometer)	-	-	-	-	-	-
SmartSensor (Microwave Radar)	-	-	10%	3%	-	-
Traficon (VIVDS)	-	-	19%	31%	-	-

^a Peak: 7 – 8 a.m. and 5 – 6 p.m.

^b Off-peak: 9 – 10 a.m. and 2 – 3 p.m.

CHAPTER 5.0 INTERFACING WITH THE TXDOT ATMS

5.1 INTRODUCTION

As TxDOT transitions from its current Local Control Unit/System Control Unit/Advanced Traffic Management System (LCU/SCU/ATMS) architecture, it will need a mechanism to smoothly move to increased use of smart sensors. For this task, TTI originally proposed three stages in the process of developing a Smart Sensor Interface (SSI) with the TxDOT ATMS. In stage 1, TTI planned to continue testing the contact-closure interface provided by smart sensors to communicate with the ATMS system through the existing TxDOT LCU/SCU/ATMS architecture. In the second stage, TTI planned to assist willing traffic detector manufacturers to develop an SSI that provided traffic data generated by smart sensors to the ATMS system using the current SCU architecture. The SSI would have, on one side, interfaced with smart sensors to receive the data generated by the sensor and on the other side it was to interface with the ATMS system by emulating the LCU/SCU architecture. In the third stage, TTI planned to adapt the SSI developed in stage two to comply with the National Transportation Communications for Intelligent Transportation Systems Protocol (NTCIP) standards pertaining to “smart sensors” and Advanced Traffic Management Systems. In a parallel activity the Southwest Research Institute (SwRI) was working to determine the statewide needs of TxDOT in terms of interfacing smart sensors with a variety of platforms at traffic management centers. It was anticipated that the SwRI activity would probably reduce the need for TTI to explore similar ends.

5.2 METHODOLOGY

Due to the development of a new system by Wavetronix to accomplish what TTI had originally planned to do in the three stages noted above, TTI requested a project modification to discontinue the original plan and focus on testing the new Wavetronix system. Then TTI proceeded to request a DataCollector™ and the DataTranslator™ from Wavetronix. After receiving the system, TTI, TxDOT, and Wavetronix engineers established a system of multiple vehicle detectors communicating with the Wavetronix system in the TransLink® laboratory in the Gibb Gilchrist Building on the campus of Texas A&M University. The entire test used the Wavetronix servers provided by Dell, although TxDOT would have preferred to do some of the testing using a more generic hardware platform. Wavetronix would have provided a software-only solution, but generic servers were not available during the test.

5.3 WAVETRONIX DATA APPLIANCES

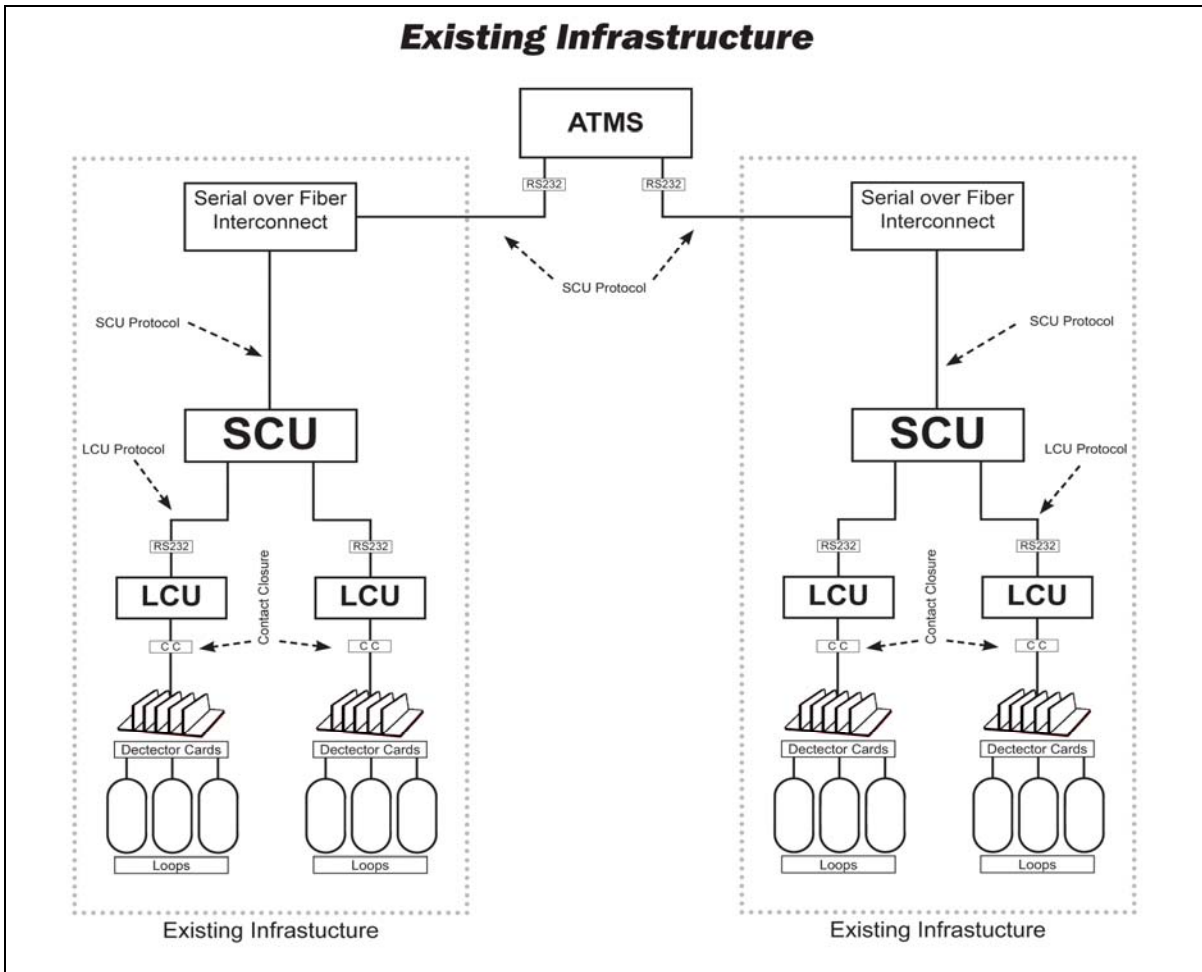
The Wavetronix data appliances allow real-time data collection from TxDOT district sensor network components (LCUs, SmartSensors, RTMS, and others) and provide an interface with the current TxDOT ATMS. TxDOT districts can use the DataTranslator to integrate multiple subsystems such as sensor data collection, data archiving, speed maps, and dynamic message signs into existing traffic management environments. The DataCollector can provide an interface to TxDOT’s LCUs today, but it can also accommodate future needs

by interfacing with newer sensor technologies without compromising data integrity or the advanced functionality that these smarter sensors offer.

The Wavetronix system also provides the necessary transition to the next generation TxDOT ATMS system. It operates in a TCP/IP environment and can communicate data in eXtensible Markup Language (XML) format, the interface medium and protocol of the next generation system from TxDOT. In addition, the Wavetronix solution offers the ability to replace the legacy LCU/SCU subsystems in the current TxDOT ATMS environment by emulating the SCU and providing the ATMS with its data requirements directly. In addition, the Wavetronix solution offers the ability to perform real-time data translation into the proprietary SCU protocols of the current TxDOT environment.

5.3.1 Existing Infrastructure

Existing TxDOT district systems largely utilize inductive loops communicating contact closure data to a locally installed LCU. These LCUs receive input from a system of individual and trap loops. The LCUs are polled constantly by an SCU via RS-232 serial connection using a TxDOT proprietary communication protocol. The SCUs, located in either a Traffic Management Center (TMC) or in a satellite building, aggregate the data from multiple LCUs for delivery to the central ATMS controller. The networks for these communication links are often RS-232-over-fiber. [Figure 53](#) depicts a typical architecture for this existing infrastructure.

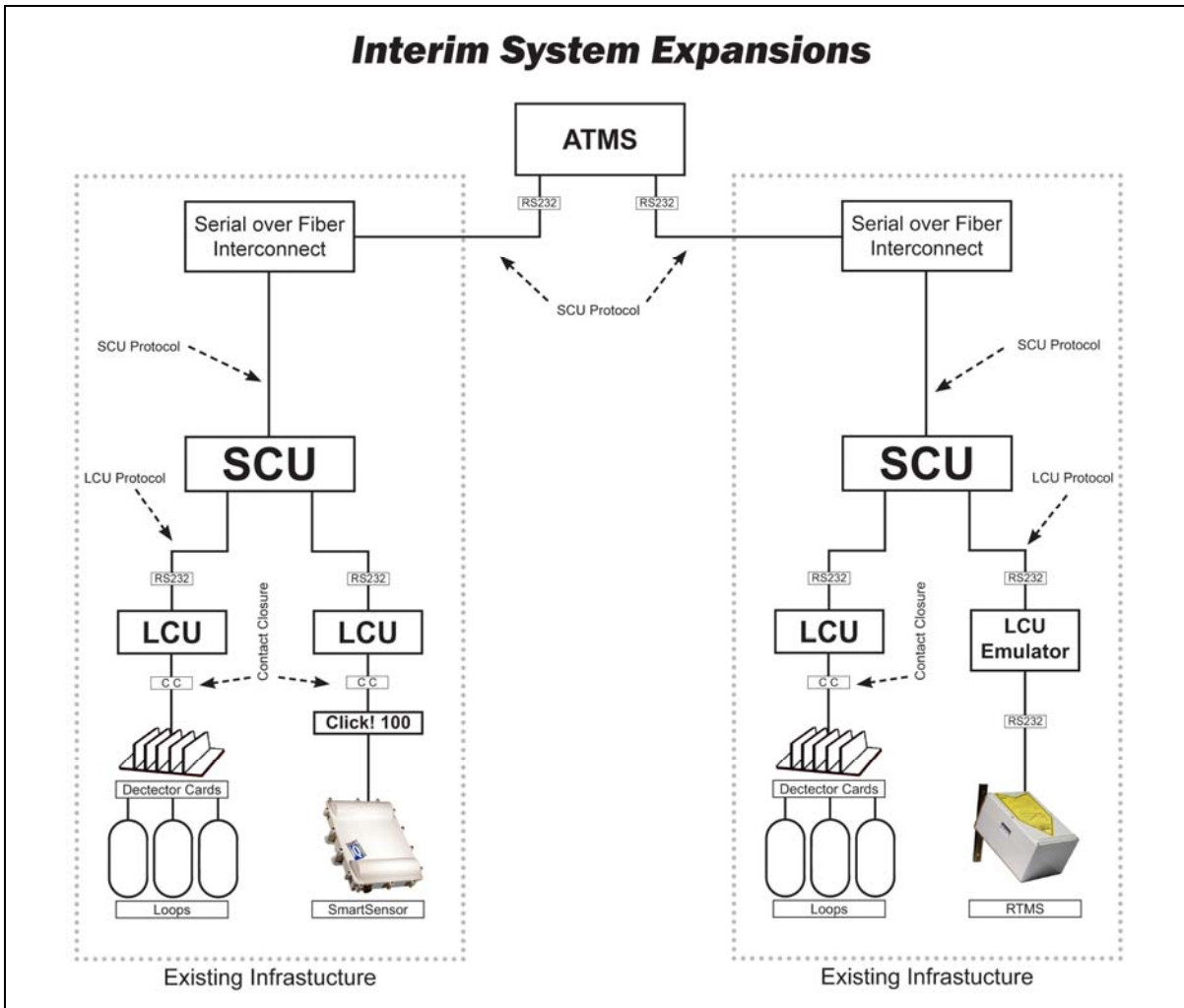


Source: Wavetronix.

Figure 53. Existing Infrastructure.

5.3.2 Interim System Expansions

When TxDOT expands its current system or when it replaces failed loops, it may choose to deploy newer generation traffic sensors such as microwave radar detectors. As [Figure 54](#) indicates, TxDOT might convert the output from the newer detectors to contact closures that are sent to an LCU. The other way it might be done involves an LCU emulator. In both cases, much of the functionality of the newer detectors is lost. The illustrated solution has the advantage of rapid deployment, but the loss of functionality reduces the viability of this solution.

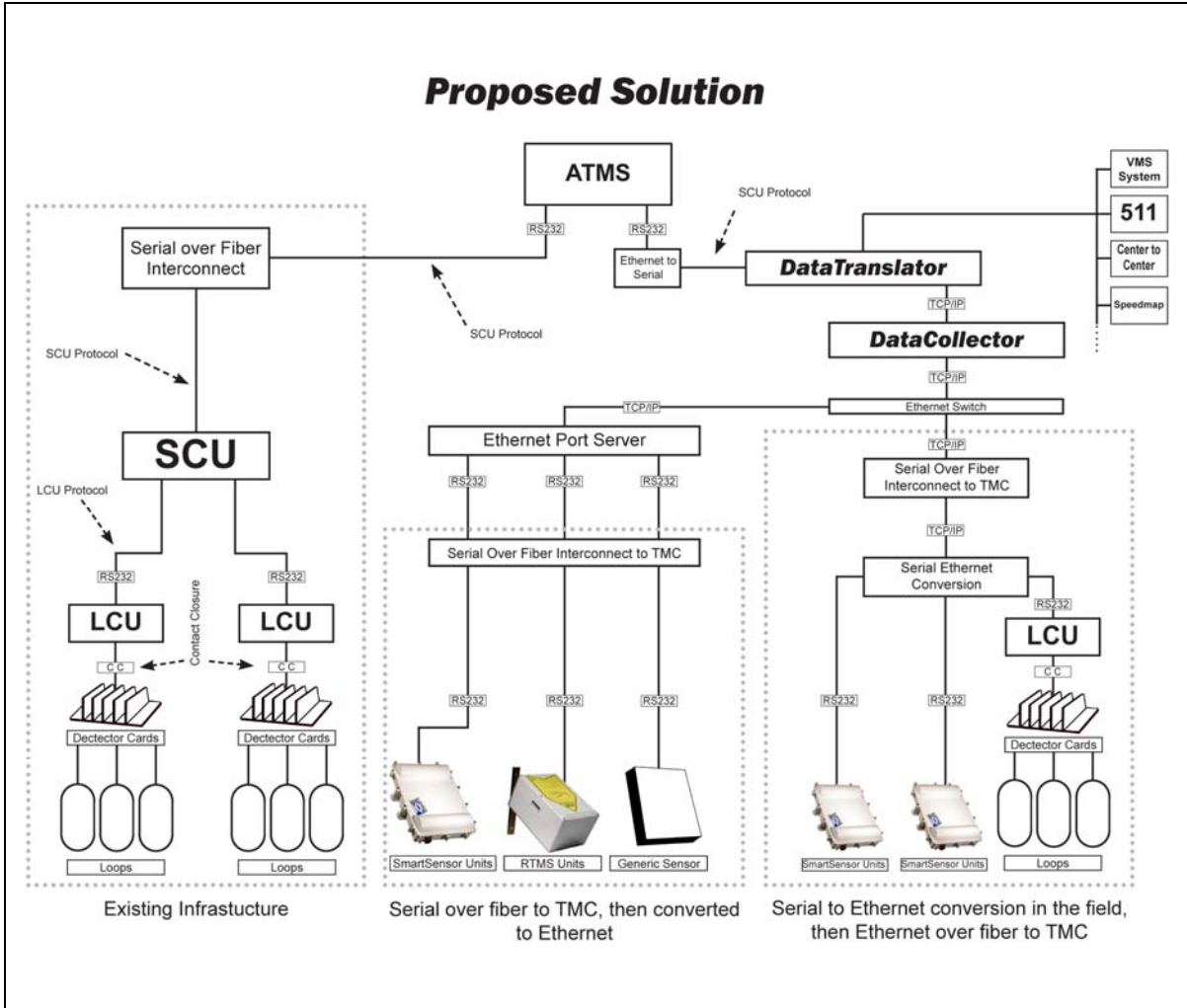


Source: Wavetronix.

Figure 54. Interim System Expansions.

5.3.3 Proposed Solution

The proposed solution provides a transition between the existing TxDOT infrastructure and the next generation of TCP/IP communication over Ethernet, which could be wired or wireless. Figure 55 shows an architecture that allows for a managed growth process that expands traffic sensor networks without compromising the functionality of the newer detectors. The middle and right side of the drawing indicates that communication could be either “home run” serial-over-fiber to the TMC or serial-to-Ethernet conversion in the field, then Ethernet-over-fiber to the TMC. The Wavetronix DataCollector system would interface with the sensor devices and collect data via the Ethernet network. The output would be translated to SCU protocol and data format in the DataTranslator. In this configuration, the ATMS will receive data from the Wavetronix system as if it came from multiple SCUs.



Source: Wavetronix.

Figure 55. Proposed Solution.

5.3.4 TTI Research Application

With support from the TxDOT Traffic Operations Division, TTI developed an operational LCU/SCU/ATMS system operating in the Translink® laboratory. Researchers installed the latest TxDOT ATMS software on research hardware and configured two SCUs with DIGI cards. Following is a brief narrative of key activities related to this endeavor.

During the week of September 13, 2005, researchers installed Wavetronix DataCollector and DataTranslator servers in the TransLink Lab and worked with this system for several weeks. Wavetronix sent a factory representative to set up the DataCollector to collect data from the two test beds (S.H. 6 and I-35) using TCP/IP. The DataCollector polls the two SmartSensor radar detectors every 20 seconds and stores the data temporarily in a

Microsoft SQL Server database. A Wavetronix factory representative created a service in the DataTranslator to retrieve data from the DataCollector database and package it in the same message format the ATMS expects from an SCU.

During the week of November 7, 2005, TTI researchers blanked out the detector database on the ATMS in the TransLink Lab to make a fresh start. The TTI ATMS was connected to a TxDOT SCU using DIGI port one on the SCU, and the Wavetronix DataTranslator was connected to serial port one of the ATMS computer using a terminal server. Researchers configured the ATMS detector database for a virtual LCU connected to the TxDOT SCU having eight lanes of trap detectors. The ATMS was then configured for four lanes of trap detectors on the hardware LCU connected to the same TxDOT SCU in the lab. Researchers connected the hardware LCU to relays simulating inductive loop contact closures generated by VISSIM running on another computer.

TTI then configured a roadway in ATMS to monitor level of service. Once researchers confirmed that simulated data displayed correctly in ATMS, they configured a detector database for the Wavetronix SCU. By using the serial port analyzer, TTI determined that the Wavetronix SCU was not responding properly to 20-second data polls. Wavetronix modified its SCU DLL to respond correctly to the ATMS 20-second data request.

Figures 56 and 57 show the Monitor Detectors screen from the ATMS system and the Configuration Display from the Wavetronix DataCollector, respectively, which provide a snapshot of 20-second data that was collected by the Wavetronix DataCollector and sent to the ATMS system through the Wavetronix DataTranslator. The difference in values between the Wavetronix DataCollector's "Spd" column and the ATMS's "Avg. Speed" column is due to the difference in the unit of speed measurement between the DataCollector (mph) and the ATMS (ft/sec).

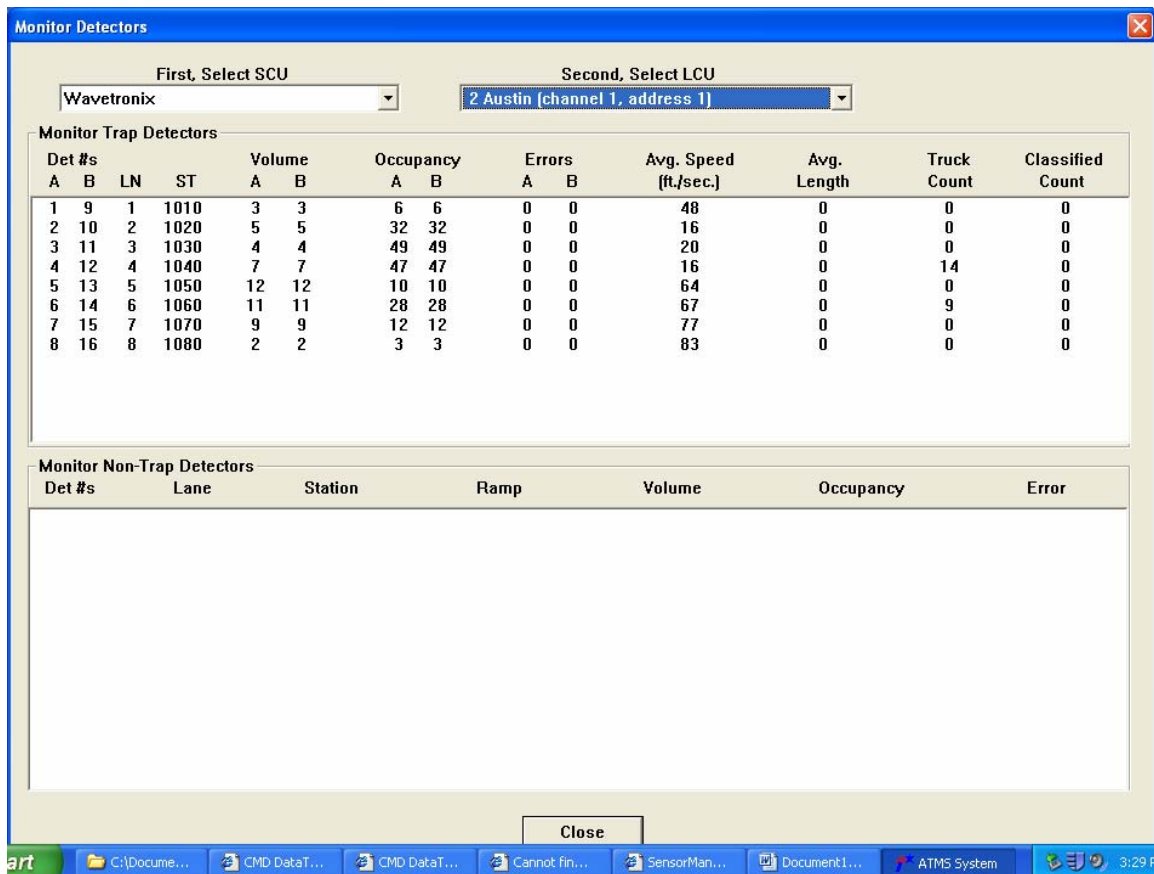


Figure 56. Monitor Detectors Display from the TxDOT ATMS.

5.3.5 Ft. Worth Application

Before TTI requested the two data appliances from Wavetronix for tests, project personnel traveled to the Ft. Worth District (FTW) to learn about the installation of the system at the TransVision Traffic Management Center. One of the unique applications that the district was doing was using the Task Builder (a component of the Wavetronix system) to develop travel time algorithms. [Figure 58](#) shows the architecture of this system.

At the time of this visit, FTW had not verified the reliability of the data, but the district had experienced some relatively minor problems—perhaps related to the communication system. FTW was using a wireless system to communicate from detectors in the field to the DataCollector units in satellite locations, which could be a source of error. FTW was focused on generating speeds at that time and not on counts or other variables. The only detectors being used for this system were the Wavetronix SS105 and EIS RTMS—both radar detectors.

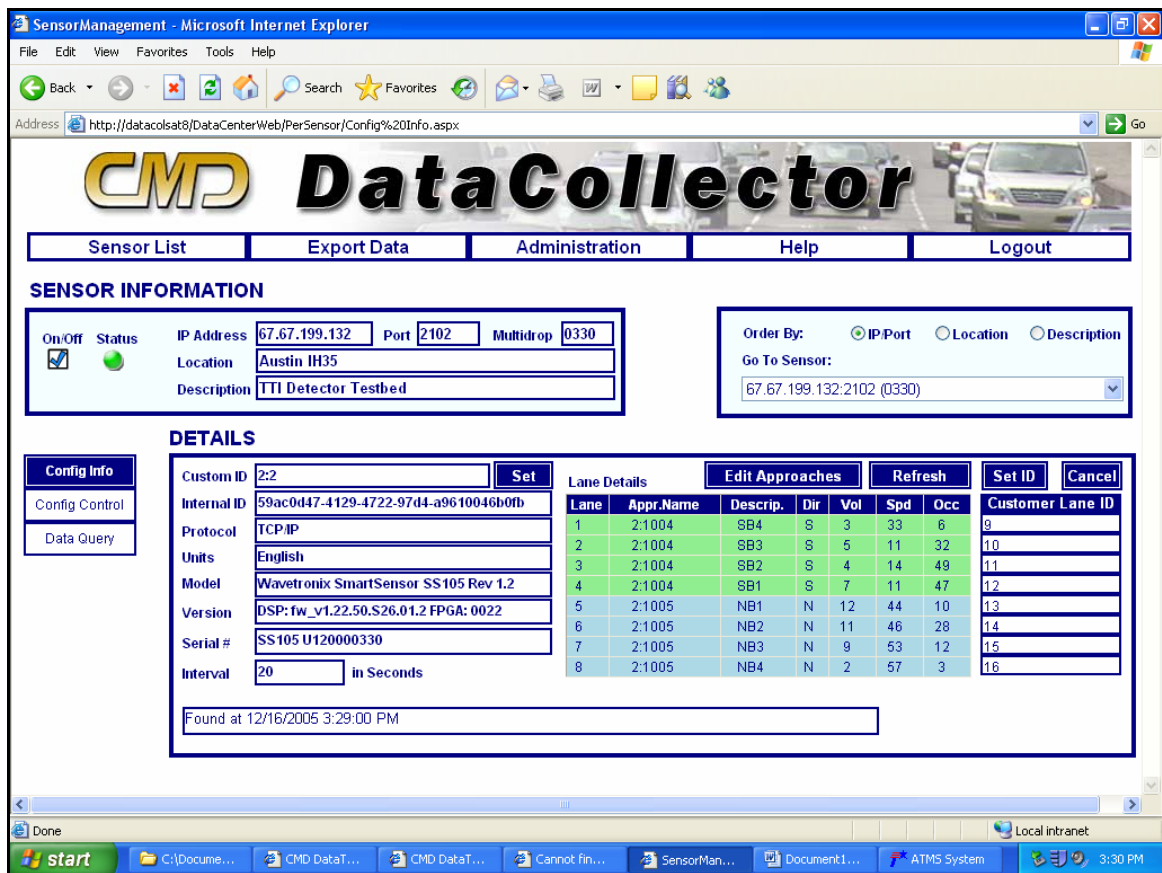
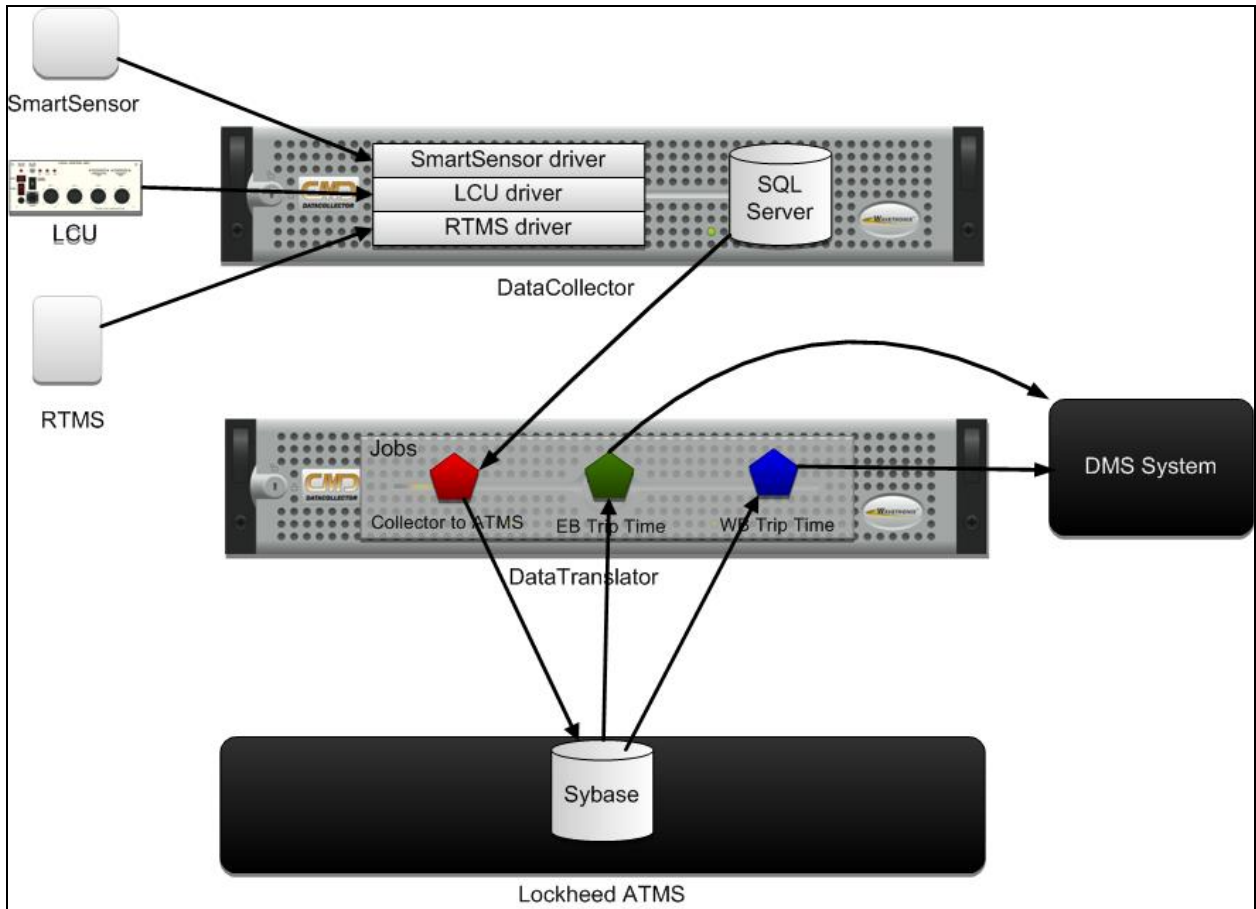


Figure 57. Configuration Display for the Wavetronix DataCollector.

TransVision currently has seven DataCollectors on-line and one DataTranslator. The district plan included two more DataCollectors for a total of nine by the time the system was scheduled for completion around the end of September 2006. The number of detectors connected to each DataCollector varies, but there could be as many as 100, and the total number of detectors currently on-line with this Wavetronix system is 170. The district is in the process of discontinuing all use of inductive loops. The price paid by FTW for both the DataCollector and the DataTranslator was about \$57,500 each (licensed for 50 detectors per DataCollector). Since April 15, 2005, the price for a 100-sensor capacity DataCollector is \$70,000 and a DataTranslator is \$70,000.

The Wavetronix DataCollector and DataTranslator system has been very stable for TransVision overall. The only problems that have been experienced have been induced by other activities and are not the fault of the Wavetronix system. On one occasion, the contractor did not backup the data tables before making a change, resulting in data loss. There have been minor glitches in software, but Wavetronix immediately addressed each problem. There have been some problems with the wireless communication components. High winds have caused movement in antennas resulting in loss of communication until the antennas could be re-oriented.



Source: Wavetronix.

Figure 58. Ft. Worth District DataCollector and DataTranslator Architecture.

The flexibility of the Wavetronix appliances is a tremendous asset and is advanced well beyond comparison with TxDOT's older ATMS system. One example of its flexibility is the local council of governments' request for data on a decision pertaining to truck lane restrictions. Since each DataCollector stores data in a database format, the data can be retrieved for a variety of purposes and almost in real time. For the truck study, the SmartSensor has three vehicle length bins. The default settings are zero to 18 ft, 18 to 35 ft, and over 35 ft. FTW modified these settings because there was a desire for higher threshold for larger trucks. Another example of its flexibility was the need by FTW to link legacy station IDs in their proprietary Sybase database to data in the Wavetronix DataCollector Microsoft SQL database tables, requiring another column in the database beyond what was originally intended. Wavetronix was able to make the change in a timely manner.

There are other attributes that FTW needs or that may become available. For example, FTW wants this system to report its health and status in real time. There has been talk of a third unit from Wavetronix called DataMonitor that would accomplish this task,

although FTW is currently using the Wavetronix DataTranslator to build a task that provides alerts about detector health and status.

The DataTranslator serves a data transfer function by pulling data from the DataCollector which receives data from field detectors. Then, secondary tasks are built in the DataTranslator to provide services such as determining travel times. The DataCollector resolution is 30 seconds with a 60-second bucket, so FTW polls the data from the DataCollector twice each minute. This interval has resulted in no loss of data, so the district considers this to be an effective approach. The standard data aggregation level for data collection is by station (multiple lanes) and in one-minute bins. FTW does not currently archive data. The minimum block desired for future use is 15 minutes.

5.4 FUTURE OF THE WAVETRONIX SYSTEM

Based on installation in the TransLink lab, it seemed as if any major changes in the number and types of detectors might require a company representative to re-configure the Wavetronix system. The problem arises from the fact that the detector stations are configured on the ATMS side independent of the configuration of the sensors in the DataCollector. However, when the DataTranslator emulates the SCU to provide the ATMS system with detector station data, it has to provide the data in the order that the ATMS system is expecting. To bridge this gap between the two configurations, FTW has devised a solution that can be employed to resolve this problem in a system where the DataCollector and DataTranslator are used to provide the ATMS system with its detector data needs. The solution requires adding a field to the DataCollector Microsoft SQL database tables that includes the ATMS detector station IDs. At the same time, the SCU emulation task running on the Wavetronix DataTranslator must listen to the configuration messages sent by the ATMS server to the SCU that specify the order in which it is expecting the data to be reported.

The future of the Wavetronix system appears to be bright based on this research. TTI demonstrated that the system successfully communicates with multiple brands of detectors and provides the data in the proper format and sequence needed by the ATMS. It is viable as a state-of-the-art, flexible, scalable, off-the-shelf, and immediate solution to TxDOT's need where a combination of its legacy components and contemporary detectors are being implemented side-by-side. Perceived negative factors include the cost of this system, which may appear to be high, and the fact that there is practically no competition at the present time. These factors may be short-term deterrents for some TxDOT decision-makers but they should not be for long. The Wavetronix system is an enterprise-quality hardware/software solution, currently marketed using Dell enterprise server hardware. Some TxDOT district needs would be better suited by Wavetronix providing a software-only solution that would run on a generic enterprise hardware platform. Wavetronix representatives have stated that they can provide a software-only option, but they request that Wavetronix be allowed to review the selected server for compliance with Wavetronix performance specifications. Based on this review, Wavetronix might ask TxDOT to ship the selected server to Wavetronix for testing and configuration before installation in a TxDOT facility.

CHAPTER 6.0 IMPLEMENTATION OF FINDINGS

6.1 INTRODUCTION

Vehicle detection for freeways continues to evolve with existing detectors being modified on a regular basis and an occasional new detector being introduced. During this 3 ½ year project, each manufacturer of selected detectors made changes to hardware and/or software. There was one new detector, the Sensys Networks magnetometer, introduced during the course of this research. Other detectors that became available were deemed not as suitable for TxDOT's needs and were not included in field-testing.

[Appendix A](#) contains a generic detector specification for the procurement of detectors for the following technologies: VIVDS, acoustic, microwave radar, and magnetic. [Appendix B](#) has the Detector Selection Guide for assisting TxDOT and others in selecting the most appropriate detector. [Appendix C](#) has additional data plots shown as [Figures 62](#) through [68](#) based on data collection from S.H. 6 not included in the main body of the report.

6.2 SUMMARY OF FINDINGS

The organization of the findings begins with the literature, followed by field tests, and then interfacing with the TxDOT ATMS. This summary encapsulates the main points from Chapters [2](#), [4](#), and [5](#), respectively. For more details on these sources, the reader should go to the respective chapters.

6.2.1 Literature Findings

6.2.1.1 Acoustic Detectors

MnDOT research on the SAS-1 indicated that, for the 24-hour data, the absolute percent differences for lanes 2 and 3 were under 8 percent at all mounting heights, and between 12 percent and 16 percent for lane 1 with heights less than 30 ft. At the first base (15 ft from the nearest lane [lane 1]), the detector provided better results for lanes 2 and 3 than for lane 1. Overall test results show that the detector performs best when mounted with equal height and horizontal offset between the detector and the centerline of multiple lanes (45-degree angle) ([15](#)).

For TTI tests at I-35, the SAS-1 height above the freeway was 35 ft and its offset from the nearest lane (lane 5) was 6 ft. Its count accuracy for lane 1 (farthest) dropped during congested flow compared to free flow, but on lane 3 the accuracy was similar for the two conditions. The SAS-1 generally undercounted almost all intervals. In lane 1 during the a.m. peak and while speeds were over 40 mph its count range was 0 to -10 percent. During slower speeds, its range was -12 to -32 percent.

The SAS-1 consistently overestimated speeds in lane 1 during the morning peak by 5 to 10 mph. During the afternoon peak, it overestimated speed by as much as 20 to 25 mph

during very slow speeds then improved to within 5 mph as speeds reached free-flow conditions. On lane 2 during both the morning and afternoon peaks, the SAS-1 was almost always over the baseline system by 0 to 5 mph with a maximum of 10 mph. On lane 3 this detector was consistently within 2 to 5 mph of the baseline system. On lane 4, its morning peak speed estimates were consistently within 5 mph and its afternoon peak speed estimates were less consistent but still within ± 5 mph (3).

6.2.1.2 Inductive Loop Detectors

The inductive loops used by MnDOT were only approximately four years old when testing occurred on I-394. Initial loop accuracy tests showed that the loops in lanes 1 and 2 on the freeway undercounted by 0.1 percent, while the HOV lane loops undercounted by 0.9 percent. Speed tests indicated that lane 1 loops underestimated true speed by 6.1 percent, and the lane 2 loops underestimated speed by 1.9 percent.

TTI found that the Peek ADR-6000, which uses four inductive loops per lane, was extremely accurate for count, speed, and occupancy measurement at both of its freeway test beds. The classification results for a dataset of 1923 vehicles indicated only 21 errors, resulting in a classification accuracy of 99 percent (ignoring Class 2 and 3 discrepancies). This data sample occurred during the morning peak and included some stop-and-go traffic, which makes the result even more impressive. For count accuracy, the Peek in this same dataset only missed one vehicle (it accurately accounts for vehicles changing lanes). It only exhibited speed discrepancies at slow speeds (below about 15 mph) when compared with Doppler radar results. The future of the ADR-6000 in Texas and elsewhere in similar applications is expected to be a function of its cost, willingness of agencies to continue installing inductive loops, and multiple agencies being willing to develop agreements to share maintenance responsibilities (e.g., shared data).

6.2.1.3 Magnetic Detectors

MnDOT tests showed that the absolute percent volume difference between the 3M microloop sensor and the baseline was under 2.5 percent, which is within the accuracy capability of the baseline loop system. For speeds, the test system generated 24-hour test data with absolute percent difference of average speed between the baseline and the test system from 1.4 to 4.8 percent for all three lanes (15). TTI tests at its S.H. 6 test bed showed that microloop counts were within 5 percent of baseline counts 99.4 percent of the time in the right lane (dual probes). In the left lane (single probes), 94.5 percent of the 15-minute intervals were within 5 percent, 4.5 percent were between 5 and 10 percent, and for 1.0 percent there was a more than 10-percent difference from the baseline (2).

6.2.1.4 Microwave Radar Detectors

California tests indicated that with proper installation and calibration either the RTMS or the Wavetronix SS105 detector can deliver better than 95 percent overall vehicle count accuracy at 5-minute and 30-second intervals and 95 percent speed accuracy at 5-minute intervals. The Wavetronix unit only required 15 to 20 minutes total to set up,

whereas a factory representative took about one hour per lane for the RTMS. Also, the technology can be very accurate in the center of a roadway but the presence of trucks and heavy traffic can cause the detectors to miss vehicles as well as to create false readings in side lanes (18).

Coifman found that the RTMS count and on-time are typically noisier than loops, although pluses and minuses tend to cancel each other. In the flow measurements, the RTMS was within 10 percent of values generated by the loops with the loops being within 3 percent of each other. Occupancies were not as accurate, ranging from 13 percent to 40 percent, again compared to inductive loops (24).

ORITE test results indicate that the Wavetronix SS105 misses some vehicles due to occlusion and it sometimes registers phantom vehicles from extraneous radar echoes (e.g., from a truck in an adjacent lane). On one of the test days, the number of phantoms was 7.03 percent, but on other days, the number of phantoms and misses was always less than 5 percent, and often under 1 percent. Speeds measured by the Wavetronix system (based on the moving average technique) usually correlated well with true speeds. The standard deviations in data measured by the trailer were always higher than those from the hand-held radar unit, generally by a factor of 2 to 3. The smallest difference was 0.1 mph (2.0 mph Wavetronix vs. 1.9 mph for radar), and the largest difference was 3.8 mph (4.2 mph Wavetronix vs. 1.1 mph radar) (26).

6.2.1.5 VIVDS

MnDOT tests of the Autoscope Solo 30 ft over the center of the lanes indicated excellent performance. The absolute percent volume difference between the sensor data and loop data were under 5 percent for all three lanes. The detector also performed well for speed detection with an absolute average percent difference of 7 percent in lane one, 3.1 percent in lane two, and 2.5 percent in lane three. For other mounting locations beside the roadway, the detector performed best when mounted high and closest to the roadway (15). TTI tests showed that the Autoscope Solo Pro count accuracy was within 5 to 10 percent of the baseline counts during free-flow conditions, but it generally diminished in all lanes when 5-minute interval speeds dropped below 40 mph and especially during stop-and-go conditions. Speed and occupancy of the Solo Pro were the best of any non-intrusive devices tested by TTI in Project 0-2119. Speeds were almost always within 0 to 3 mph of the baseline system. Its 15-minute cumulative occupancy values differed from loops by as much as 3.9 percent, but during most intervals its difference was less than 1 percent (3).

Of the three non-intrusive systems tested, the Iteris Vantage was the second most accurate device for measuring occupancy. Its 15-minute cumulative occupancy values differed from loops by as much as 8.1 percent, but during most intervals its difference was less than 6 percent.

MnDOT Phase II tests mounted the Traficon video image detector directly over the lanes at heights of 21 ft and 30 ft facing downstream. The preferred orientation was facing oncoming vehicles, but site features precluded this orientation. At the 21-ft height, the

absolute percent difference between the sensor data and loop volume data was under 5 percent for all three lanes. At the 30-ft height, its off-peak performance was similar but it undercounted during congested flow showing an absolute percent difference of some 15-minute intervals from 10 percent to as high as 50 percent. Reasons suspected for the reduced accuracy were snow flurries and sub-optimal calibration. Its speed accuracy at 21 ft indicated good performance. Its 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 snowfall, its speed accuracy declined to a range of 8.9 percent to 13 percent (15).

MnDOT research found that mounting video detection devices is a more complex procedure than that required for other types of devices. Camera placement is crucial to the success and optimal performance of this detection device.

6.2.2 Field Test Findings

The following field test results are based on the representative graphics shown in Chapter 4. These graphics only show speeds for FY 2003-2004 since speed compliance by these detectors was better than count compliance. Since lane 2 had baseline data for all years, this comparison uses lane 2 exclusively for all years represented in order to investigate trends that might show up from one year to the next. Most of the detectors demonstrated better results for closer lanes (lanes 3, 4, and 5).

6.2.2.1 Acoustic Detectors

The only acoustic detector included in this research was the SmarTek SAS-1 and it was included during the full research period. During FY 2003-2004, its speed accuracy always showed a bias of about 10 mph faster than the baseline speed, but it tracked the baseline almost perfectly. Count errors are worse during slow speeds. About one-fourth of its counts were within ± 5 percent and over half were in the -5 percent to -10 percent range. About 15 percent were in the -10 to -15 percent range.

During FY 2005, the count errors for the SAS-1 were worse during congested periods compared to its accuracy during free-flow conditions. It almost always undercounted whether in free-flow or not. Many of the free-flow periods were within 5 to 10 percent of the baseline, but congested periods reached as high as 20 percent or greater.

During FY 2006, there were no periods of highly congested flow on I-35. The SAS-1 was usually within 5 percent of baseline counts but never more than 10 percent worse than the baseline.

6.2.2.2 Inductive Loop Detectors

The Peek ADR-6000 was the only “test” of inductive loops, given that it uses loops for both speed detections and axle detections. For all tests conducted on speeds, its speeds were almost always exactly the same as lidar speeds and rarely 1 to 2 mph different from lidar speeds. There was no change detected throughout the course of the research project.

Both counts and classifications (ignoring class 2 and 3 differences) were always within 99 percent of truth.

6.2.2.3 Magnetic Detectors

This research only included the Sensys Networks magnetometer during FY 2006 due to its recent availability. The test plan included the 3M microloops but there was not a suitable high-volume site for its tests. This detector was always within 5 percent of the baseline loops.

6.2.2.4 Microwave Radar Detectors

During FY 2003-2004, the Wavetronix SS105 was near-perfect on speeds. It showed no bias and tracked the baseline speeds best of all detectors included during this time period. Its count accuracy during this period for lane 2 was within ± 5 percent of baseline counts with only one exception in 70 time intervals. During the FY 2005 period, the SS105 almost always counted within 5 percent of the baseline counts. There were two periods during very congested conditions when it overcounted by 15 percent. In FY 2006, the SmartSensor consistently demonstrated better than 5 percent count accuracy for all intervals.

6.2.2.5 VIVDS

Autoscope Solo Pro speeds during FY 2003-2004 were always within 5 mph of the baseline speeds and usually within 1 to 2 mph. Counts were within 5 percent until 8:45 p.m. through 10:45 p.m., perhaps due to changing light conditions. During FY 2005, the Solo Pro counts were generally worse but perhaps due to more congestion during that day compared to the day selected to represent the previous year. During free flow, its counts were typically within 10 percent of the baseline system, but during congested conditions its counts were as high as 15 percent and occasionally 20 percent different from the baseline. During FY 2006, the Solo Pro was consistently within 5 percent of the baseline counts with only three intervals slightly worse. This improvement compared to other years was perhaps because of the lack of highly congested conditions.

During free flow in FY 2003-2004, the Iteris speeds tracked the baseline speeds well except during periods of mild to heavy congestion. These errors were between 5 and 10 mph different from the ADR-6000. The Iteris count accuracy was almost always within 10 percent of the baseline with a few midday intervals as high as 10 to 15 percent. In FY 2005, the Iteris usually counted within 10 percent of the baseline system but errors were as high as 15 percent higher and lower than the baseline.

The Traficon was not available in FY 2003-2004. In FY 2005, the Traficon counts were usually within 10 percent of the baseline counts but some count periods during congested flow differed from the baseline by more than 20 percent. In FY 2006, its counts were more high than low, but in the range of 5 to 20 percent on overcounts and usually within 5 percent on undercounts.

6.2.3 Interfacing with the TxDOT ATMS

As TxDOT transitions from its current LCU/SCU/ATMS architecture, it will need a mechanism to smoothly move to increased use of smart sensors. The solution investigated by this research involved two data appliances from Wavetronix called the DataCollector and the DataTranslator. After receiving this system, TTI, TxDOT, and Wavetronix engineers established a system of multiple vehicle detectors communicating with the Wavetronix system in the TransLink® Lab in the Gibb Gilchrist Building on the campus of Texas A&M University. The entire test used the Wavetronix servers provided by Dell, although TxDOT would have preferred to do some of the testing using a more generic hardware platform. Wavetronix would have provided a software-only solution, but generic servers were not available during the test.

The tests by TTI indicated that the Wavetronix system does what it is designed to do, although the early version provided to TTI still needed additional development resources. TTI demonstrated that the system successfully communicates with multiple brands of detectors and provides the data in the proper format and sequence needed by the ATMS. One remaining activity would be for Wavetronix to provide a software-only option, which should be evaluated by an independent party on servers provided by TxDOT.

6.3 RECOMMENDATIONS

Findings of this research indicate that the new detectors do not always operate as well as inductive loops. The ADR-6000 used inductive loops but its signal processing and, therefore, its accuracy are superior to a typical loop installation. The comparison being made here is with the more typical inductive loops. Presence detection (count) accuracies of standard inductive loops are typically in the 95 to 99 percent range if they have been installed properly and are well maintained. Loop speed accuracies are typically within 2 to 5 mph of true speeds, but again, proper installation and maintenance are critical. Sidefired microwave radar detectors in this research exhibited consistent speed accuracy, although limited tests of an overhead-mounted SmartSensor SS105 in its Doppler mode was even better (it can only cover one lane in Doppler mode). Therefore, the SmartSensor SS105 should be considered as an accurate speed detector for replacing loops with its orientation depending on site-specific accuracy needs. For a three-color urban speed map display, most of the detectors tested in this research have the needed speed accuracy.

The research findings indicate differences in accuracy of non-intrusive devices according to levels of congestion. When congestion reaches a point where the prevailing speed begins to drop, accuracy of most non-intrusive detectors will probably decline significantly. Even for freeways that do not currently reach those congestion levels on a recurring basis, TxDOT decision-makers must consider that incidents can happen anywhere and at any time. Minimizing the variety in types and brands of detectors is important from an inventory and training standpoint.

Findings of this research indicate that, from a performance standpoint, microwave radar, magnetometers, and video image vehicle detection systems are probably all suitable

for freeway applications. VIVDS is more complex, requires periodic lens cleaning, and is usually more expensive, but a positive attribute is that it offers a view of the traffic stream. However, some limited weather and lighting conditions may affect the latest VIVDS although the manufacturers have reduced those impacts in recent models. The magnetometer that was included in this research is by Sensys Networks and warrants continued evaluation over a longer period of time. Its accuracy levels are noteworthy and, of course, it is not affected by weather, but its battery life needs to be verified in high-volume traffic. One negative attribute is that it is an intrusive device, requiring interference with traffic for installation. It is a promising replacement for loops since installation is faster. Finally, the SmartSensor SS105 (and its newer version, the HD) is a rugged device that:

- does not interfere with traffic,
- can be mounted on an existing pole,
- automatically calibrates speed and configures lane positions for each lane monitored,
- can cover up to eight lanes (10 lanes for the HD) in sidefire orientation, and
- is apparently not affected by any weather or lighting conditions.

The Wavetronix DataCollector/DataTranslator system appears to be very appropriate for interfacing with the TxDOT ATMS. It is viable as a state-of-the-art, flexible, scalable, off-the-shelf, and immediate solution to TxDOT's need where a combination of its legacy components and contemporary detectors are being implemented side-by-side. Negative factors include the perception that the system is expensive, but decision-makers should be careful not to dismiss this solution before carefully costing out the alternatives. There is little competition at the present time, but products from all other competitors only collect data from their brand of sensors and cannot export data to other databases. These factors may be short-term deterrents for some TxDOT decision-makers but they should not be for long.

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APPENDIX A:
DETECTOR SPECIFICATION

SPECIAL SPECIFICATION

XXXX

Vehicle Sensing Device for Freeways (Generic Technology)

- 1. Description.** Furnish and install vehicle detection system as shown in the plans, as detailed in the special specifications, and as directed. A “detection system” or “detector” in this special specification will conform to the following technologies: video image vehicle detection system (VIVDS), microwave radar, passive acoustic, or magnetic. The Detector Selection Guide (See [Appendix B](#)), which is a product of this research, provides information for decision-makers on selecting the appropriate detector. Ensure that each detector will be able to distinguish and monitor individual lanes as opposed to monitoring an area with no distinction to travel lanes. Provide all equipment required to interface with an existing/proposed infrastructure as subsidiary.

Ensure after the setup there are no external tuning controls of any kind, which will require an operator.

Furnish all new equipment and component parts of the latest proven design and manufacture, and in an operable condition at the time of delivery and installation. Provide all parts that are of high quality workmanship.

Provide design to prevent reversed assembly or improper installation of connectors, fasteners, etc. Design each item of equipment to protect personnel from exposure to high voltage during equipment operation, adjustments, and maintenance.

Include licenses for all equipment, where required, for any software or hardware in the detection system.

Provide all detectors within a specified technology from the same manufacturer.

Provide detector firmware that is upgradeable by external local or remote download.

- 2. Materials.** Ensure the detector is easy to install and will automatically or with a human operator configure a minimum of five lanes (acoustic and VIVDS) or eight lanes (microwave radar), or the maximum number of lanes shown on the plans (whichever is less) by determining lane boundaries, concrete barriers, and detection thresholds. Ensure the detector system detects vehicle volume, speed and occupancy in all weather conditions without performance degradation (performance defined later). Ensure that microwave radar operates in both sidefire and forward fire orientations. Ensure the detector is remotely accessible, provides multiple connectivity options for easy integration into the existing system, and supports the communications protocols identified in Section 2.D “Communication.” Ensure the detector is manufactured to the

strictest industry standards to ensure product quality and minimizes the risk of unit failure.

Provide a detector that requires less than 10 of the largest vehicles expected on the roadway to pass the detector and that is able to tune out stationary objects such as traffic barriers and retaining walls prior to completing the configuration.

Provide documentation on the auto-configuration process (if applicable).

Provide a detector that does not cause interference or alter the performance of any known equipment.

A. Sensor Performance. Ensure the detector provides accurate, real-time volume, average speed, and occupancy data. Ensure the detector provides user-configurable settings for a collection interval from 20 seconds to 15 minutes and polling intervals from 20 seconds to 1 hour. Ensure the detections are correctly categorized into a minimum of three user definable length-based classifications. Ensure that siderefired microwave radar detectors monitor vehicle detections at a range of 9 ft to 200 ft from the detector. Ensure that magnetic detectors mounted in horizontal conduit under the pavement can accurately monitor vehicle passage from 36 inches below the surface. Ensure that magnetic detectors mounted flush with the surface (core-drilled) are wireless and are self-powered with battery life of 10 years in any traffic conditions. Ensure the detector unit (any technology) or accompanying field equipment provides a minimum of three hours of local storage for detection interval settings of 20 seconds to 15 minutes in local storage to reduce data loss during communication outages. Ensure the detector or accompanying field equipment transfers locally stored data to the Traffic Management Center's Transportation Sensor System (TSS) when communication is restored.

Ensure microwave radar detectors provide two modes of operation: siderefired and forward fire. When operating in siderefired mode, a single detector must simultaneously detect traffic in a maximum of eight lanes or the maximum number of lanes shown on the plans (whichever is less). In forward-fire mode, the detector must provide data for a minimum of one lane.

Ensure the detector (any technology) maintains accurate performance in all weather conditions, including rain, freezing rain, snow, wind, dust, fog, and changes in temperature and light. Ensure detector operation continues in rain or snow up to 4 inches per hour, and the device will not experience degraded performance when encased in 1/2 inch of ice.

Ensure microwave radar siderefired and forward-fire (acoustic siderefired) volume data are accurate within 5 percent of actual for any direction of travel in nominal conditions. Ensure individual lane accuracy (any technology) is within 10 percent of actual during nominal conditions. Nominal conditions exist when traffic is flowing at average 5-minute speeds greater than 15 miles per hour, with less than

10 percent truck traffic per lane, and at least 30 percent of each vehicle visible above roadway barriers for true sensor detection.

Ensure VIVDS, magnetic, microwave radar (sidefire), and acoustic (sidefire) average speed data are accurate within 5 mph for any direction of traffic for all conditions involving more than 16 vehicles in an averaging interval. Ensure speed accuracy for individual lanes is within 10 mph of actual for all traffic conditions and similar intervals. Provide true speed detection without the requirement to enter average vehicle lengths for the speed calculation.

For microwave radar, ensure forward-fire speed data are accurate for individual vehicle measurements. Ensure 50 percent of all measurements are within 1 mph of actual, and 85 percent are within 5 mph.

Ensure occupancy data are accurate within 10 percent of actual for any direction of travel when actual occupancy is less than 30 percent. For example, if the true occupancy in a lane is 20 percent, the measured occupancy must be between 18 percent and 22 percent. Ensure lane occupancy is accurate within 20 percent in similar conditions.

Ensure classification data based on vehicle length are accurately determined for 90 percent of detected vehicles. Ensure detector measures at least three length intervals, one for small vehicles, one for mid-size vehicles, and one for large trucks and buses.

Provide test data, using methods required in Section 3.F.3, demonstrating or proving performance.

- B. Maintaining Performance.** Provide detector that requires minimum cleaning or adjustment to maintain performance. For microwave radar, acoustic, and magnetic ensure that the detector requires no maintenance. For VIVDS, ensure that the only maintenance is lens cleaning at a rate of no more than twice per year. Ensure it does not rely on battery backup to store configuration information. Ensure the detector, once calibrated, does not need recalibration to maintain performance unless the roadway configuration changes. Provide remote connectivity to the detector to allow operators to change the unit's configuration, update the unit's firmware programming, and recalibrate the unit automatically from a centralized facility.
- C. Cabling.** Supply the detector with a connector cable of the appropriate length for each installation site.

Ensure the connector meets the MIL-C-26482 specification. Provide an environmentally sealed backshell that offers excellent immersion capability, and is designed to interface with the appropriate MIL-C-26482 connector. Encase all conductors that interface with the connector in a single jacket and ensure the outer diameter of this jacket is within the backshell's cable outside diameter range to ensure proper sealing. Ensure the backshell has a clampbar style strain relief with

enough strength to support the cable slack under extreme weather conditions. Provide the MIL-C-26482 connector that provides contacts for all data and power connection.

If communication is conducted over the RS-485 or RS-232 bus, the communication cable must be Belden 9331 or an equivalent cable with the following specifications:

- shielded, twisted pairs with a drain wire;
- nominal Capacitance Conductor to Conductor @ 1Khz \leq 26pF/Ft;
- nominal Conductor DC Resistance @ 68°F \leq 15 ohms/1000Ft;
- single continuous run with no splices allowed; and
- terminated only on the two farthest ends of the cable.

- D. Communication.** Ensure that the detector provides communication options that include RS-232, RS-485, or TCP/IP. Provide a detector that has the ability to support a variety of baud rates from 9600 to 115200.

Ensure the detector provides RS-232, RS-485, and an internal serial communication port. Each communication port must support all of the following baud rates: 9600, 19200, 38400, 57600, and 115200. Additionally, the RS-232 port must be full-duplex and must support true Request to Send/Clear to Send (RTS/CTS) hardware handshaking for interfacing to various communication devices.

Data Packets. The detector must produce data packets containing, at a minimum:

- one or more detection zones;
- collection interval durations;
- sensor ID;
- 32-bit time stamps indicating end of collection interval;
- total volume by detection zone;
- average speed in each detection zone during the collection interval. Speed value units must be selectable as either miles per hour or kilometers per hour;
- occupancy in each detection zone during the collection interval, reported in 0.1 percent increments; and
- a minimum of three vehicle classifications reported as number of vehicles of each classification identified in each detection zone during the collection interval.

- E. Operating System Software.** Provide the detector to also include graphical user interface software that displays all configured lanes and provides visual representation of all detected vehicles. The graphical interface must operate on current department core operating system software. The software must automatically select the correct baud rate and serial communication port from up to

15 serial communication ports. The software must also operate over a TCP/IP connection and support a dial-up modem connection.

The software must give the operator complete control over the configuration process.

The operator must have the ability to save the configuration information to a file or reload the detector configuration from a file using the graphical user interface software.

Using the installation software the operator must be able to:

- easily change the baud rate on the sensor by selecting baud rates from a drop-down list,
- add response delays for the communication ports,
- switch between data pushing and data polling, and
- change the detector's settings for Flow Control from none to RTS/CTS and vice versa.

The operator must be able to upload new firmware into non-volatile memory of the detector over any supported communication channel including TCP/IP networks.

- F. Software.** Provide all configuration and remote communication software required to support the detector system. Install the configuration and remote communication software in the appropriate equipment at the time of acceptance testing. Complete and pass acceptance testing using a stable release of the configuration and software provided.

Provide software update(s) free of charge during the warranty period.

- G. Manufacturing Requirements.** Ensure the assembly of the units adheres to industrial electronic assembly practices for handling and placement of components.

The detector must undergo a rigorous sequence of operational testing to ensure product functionality and reliability. Include the following tests:

- functionality testing of all internal subassemblies,
- unit level burn-in testing of 24 hours duration or greater, and
- final unit functionality testing prior to shipment.

Provide test results and all associated data for the above testing, for each purchased detector by serial number. Additionally, maintain and make available manufacturing quality data for each purchased detector by serial number.

Externally, the detector must be modular in design to facilitate easy replacement in the field. Ensure the total weight of the detector does not exceed 15 lb.

Provide all external parts made of corrosion resistant material, and protect all materials from fungus growth and moisture deterioration.

- H. FCC.** Ensure the microwave radar detector has Federal Communications Commission (FCC) certification. Display the FCC-ID number on an external label. Ensure each detector is FCC certified under CFR 47, Part 15, Section 15.245 as a field disturbance sensor. Display this certification on an external label on each device according to the rules set out by the FCC.

Provide the microwave radar detector system that is FCC certified under Part 15, Subpart C, Section 15.250 for low-power, unlicensed, continuous radio transmitter operation. Assure that the detector system (any technology) will not cause harmful interference to radio communication in the area of installation. If the operation of the detector system causes harmful interference, correct the interference at the Contractor's expense.

Provide the microwave radar detector that transmits in the 10.50 to 10.55 GHz or 24.00 to 24.25 GHz frequency band and meets the power transmission requirements specified under Sections 15.245 and 15.249 of CFR 47.

Provide documentation proving compliance to all FCC specifications.

- I. Support.** Ensure installers and operators of the detector (any technology) are fully trained in the installation, auto-configuration, and use of the device.

The manufacturer must thoroughly train installers and operators to correctly perform the tasks required to ensure accurate detector performance. The amount of training necessary for each project will be determined by the manufacturer (not less than 4 hours) and must be included, along with training costs, in the manufacturer's quote. In addition, provide technical support to provide ongoing operator assistance.

- J. Power Requirements.** Provide the detector that operates either at 12 VDC to 28 VDC or at 12 VAC to 24 VAC from a separate power supply to be provided as part of the bid item and ensure it does not draw more than 10 watts (VIVDS can be up to 25 watts) of power each.

Provide the separate power supply or transformer that operates from 115 VAC ± 10 percent, 60 Hz ± 3 Hz.

Provide equipment operations that are not affected by the transient voltages, surges, and sags normally experienced on commercial power lines. Check the local power service to determine if any special design is needed for the equipment. The extra cost, if required, must be included in the bid of this item.

Provide equipment that is designed such that failures of the equipment will not cause the failure of any other unit of equipment. Ensure automatic recovery from power failure will be within 15 seconds after resumption of power.

- K. Wiring.** Provide wiring that meets the requirements of the National Electric Code. Provide wires that are cut to proper length before assembly. Provide cable slacks to facilitate removal and replacement of assemblies, panels, and modules. Do not double-back wire to take up slack. Lace wires neatly into cable with nylon lacing or plastic straps. Secure cables with clamps. Provide service loops at connections.
- L. Transient Suppression.** Provide DC relays, solenoids, and holding coils that have diodes or other protective devices across the coils for transient suppression.
- M. Power Service Protection.** Provide equipment that contains readily accessible, manually re-settable or replaceable circuit protection devices (such as circuit breakers or fuses) for equipment and power source protection.

Provide and size circuit breakers or fuses such that no wire, component, connector, PC board, or assembly must be subjected to sustained current in excess of their respective design limits upon the failure of any single circuit element or wiring.

- N. Fail Safe Provision.** Provide equipment that is designed such that failures of the equipment must not cause the failure of any other unit of equipment. Ensure automatic recovery from power failure will be within 15 sec. after resumption of power.
- O. Mechanical Requirements.** For microwave radar and acoustic, enclose the detector in a Lexan polycarbonate, ultraviolet resistant material. Ensure that magnetometers in horizontal conduit are waterproof and that surface bored magnetometers are completely encased in waterproof epoxy. The unit (any technology) must be classified as watertight according to the NEMA 250 Standard.

Ensure the enclosure is classified “f1” outdoor weatherability in accordance with UL 746C.

The detector should withstand a drop of up to 5 ft without compromising its functional and structural integrity.

Do not use silicone gels or any other material for enclosure sealing that will deteriorate under prolonged exposure to ultraviolet rays. Ensure the overall dimensions of the box (microwave radar and acoustic), including fittings, do not exceed 13 in. by 11 in. by 9 in. Ensure VIVDS camera dimensions do not exceed 16 in. by 12 in. by 6 in. Ensure the overall weight of the box (microwave radar and acoustic) or the VIVDS camera, including fittings, does not exceed 15 lb.

Coat printed circuit boards with a clear-coat moisture and fungus resistant material (conformal coating).

Ensure external connection for telecommunications and power be made by means of a single military style multi-pin connector, keyed to preclude improper connection.

- **Modular Design.** For any technology, provide equipment that is modular in design to allow major portions to be readily replaced in the field. Ensure

modules of unlike functions are mechanically keyed to prevent insertion into the wrong socket or connector.

Identify modules and assemblies clearly with name, model number, serial number, and any other pertinent information required to facilitate equipment maintenance.

- **Connectors and Harnesses.** For any technology, provide external connections made by means of connectors. Provide connectors that are keyed to preclude improper hookups. Color code and appropriately mark wires to and from the connectors.

Provide connecting harnesses of appropriate length and terminated with matching connectors for interconnection with the communications system equipment.

Provide pins and mating connectors that are plated to improve conductivity and resist corrosion. Cover connectors utilizing solder type connections by a piece of heat shrink tubing securely shrunk to ensure that it protects the connection.

- **Environmental Requirements.** For any technology, the detector must be capable of continuous operation over a temperature range of -35°F to +165°F and a humidity range of 5 percent to 95 percent (non-condensing).

3. Construction.

- A. **General.** For any technology, provide equipment that utilizes the latest available techniques for design and construction with a minimum number of parts, subassemblies, circuits, cards, and modules to maximize standardization and commonality.

Design the equipment for ease of maintenance. Provide component parts that are readily accessible for inspection and maintenance. Provide test points that are for checking essential voltages and waveforms.

- B. **Mounting and Installation.** For any technology, install the detector according to manufacturer's recommendations to achieve the specified accuracy and reliability.

Verify, with manufacturer assistance, the final detector placement if the detector is to be mounted near large planar surfaces (sound barrier, building, parked vehicles, etc.) that run parallel to the monitored roadway.

Include, at a minimum, detector unit, enclosures, connectors, cables, junction box, mounting equipment and hardware, controller interface boards and assemblies, local and remote software, firmware, power supply units, and all other support, calibration, and test equipment for the detector system.

Furnish the detector (microwave radar, acoustic, or VIVDS camera) with bracket or band designed to mount directly to a pole or overhead mast-arm or other structure.

Ensure the mounting assembly has all stainless steel, or aluminum construction, and supports the load of the detector. Incorporate for the mounting assembly a mechanism that can be tilted in both axes then locked into place, to provide the optimum area of coverage. Ensure the mounting bracket is designed and installed to prevent sensor re-positioning during 80 mph wind conditions.

Proper placement, mounting height, and orientation of the detector systems are critical to the overall performance and accuracy of the systems and must conform to the manufacturer's published requirements for the system provided. Install the detector units as shown on the plans. Analyze each proposed pole or other location to assure that the detector installation will comply with the manufacturer's published installation instructions. Advise the Engineer, before any trenching or pole installation has taken place, of any need to move the pole from the location indicated in the plans in order to achieve the specified detector performance. Confirm equipment placement with the manufacturer before installing any equipment. Ensure magnetic detectors remain vertical, symmetrically arranged, and centered in each lane.

Ensure alignment, configuration, and any calibration of the detector takes less than 60 minutes per lane once mounting hardware and other installation hardware are in place. Install detector units such that each unit operates independently and that detectors do not interfere with other detector units or other equipment in the vicinity.

- C. Electronic Components.** Provide electronic components in accordance with Special Specification, "Electronic Components."
- D. Mechanical Components.** Provide external screws, nuts, and locking washers that are stainless steel; no self-tapping screws will be used. Provide parts made of corrosion-resistant material, such as plastic, stainless steel, anodized aluminum, or brass. Protect materials from fungus growth and moisture deterioration. Separate dissimilar metals by an inert dielectric material.
- E. Documentation Requirements.** Provide documentation in accordance with Article 4, Special Specification, "Testing, Training, Documentation, Final Acceptance, and Warranty."
- F. Testing.** Perform testing in accordance with Article 2, Special Specification, "Testing, Training, Documentation, Final Acceptance, and Warranty." Test all detectors to ensure compliance to all FCC and Department specifications.

Supply a medical statement as to the safety of the unit to the general public (example: Pacemakers, etc.).

Additional testing requirement is as follows:

1. **NEMA 4X Testing.** The detector enclosure must conform to test criteria set forth in the NEMA 250 Standard for Type 4X enclosures. Provide third party enclosure test results for each of the following specific Type 4X criteria:
 - External Icing (NEMA 250 Clause 5.6),
 - Hose-down (NEMA 250 Clause 5.7),
 - 4X Corrosion Protection (NEMA 250 Clause 5.10), and
 - Gasket (NEMA 250 Clause 5.14).

2. **NEMA TS2-1998 Testing.** The detector (any technology) must comply with the applicable standards stated in the NEMA TS2-1998 Standard. Provide third party test results for each of the following specific tests:
 - shock pulses of 10g, 11 ms half sine wave;
 - vibration of 0.5 Grms up to 30 Hz;
 - 300 V positive/negative pulses applied at 1 pulse per second at minimum and maximum DC supply voltage;
 - cold temperature storage at -49°F for 24 hours;
 - high temperature storage at +185°F for 24 hours;
 - low temp, low DC supply voltage at -30°F and 10.8 VDC;
 - low temp, high DC supply voltage at -30°F and 26.5 VDC;
 - high temp, high DC supply voltage at 165°F and 26.5 VDC; and
 - high temp, low DC supply voltage at 165°F and 10.8 VDC.

3. **Performance Testing.** Ensure the detector (any technology) meets functional performance requirements of Section 2.A by the following methods:

Verify volume accuracy by comparing recorded video to the detections. Record the number of missed vehicles and false detections. Calculate errors by dividing the difference between missed and false detections, obtained over a minimum of 24 hours, by the total number of vehicles. To ensure low variability in performance, missed and false detections must not exceed 10 percent. Provide such performance analysis for the following environments:

 - free flowing traffic (speeds greater than 45 mph);
 - congested traffic (speeds from 15 to 40 mph);
 - traffic in lanes adjacent to a concrete barrier;
 - 20 ft and 200 ft lateral offset simultaneous performance (microwave radar); and
 - occluded vehicle error must not exceed 15 percent on roadways where the proportion of tall vehicles (e.g., large trucks) is 15 percent or less.

Failure to meet these thresholds will result in the product being disqualified. Verify speed accuracy with laser speed gun or by video speed trap using the frame rate as a time reference.

G. Experience Requirements. The contractor or subcontractor involved in the installation and testing of the detector must, as a minimum, meet the following experience requirements:

- Two years continuous existence offering services in the installation of the specific detector systems being installed.
- Two installed detectors where systems have been in continuously satisfactory operation for at least 1 year. Submit as proof, photographs or other supporting documents, and the names, addresses, and telephone numbers of the operating personnel of the business or agency owning the system who can be contacted by the Department regarding the system.
- Necessary documentation of contractor or subcontractor qualifications pursuant to contract award.

H. Technical Assistance. Ensure that a manufacturer's technical representative is available on site to assist the Contractor's technical personnel at each installation site and with equipment installation and communication system configuration.

Do not execute the initial powering up of the detector without the permission of the manufacturer's representative.

I. Training. Provide training in accordance with Article 3, Special Specification, "Testing, Training, Documentation, Final Acceptance, and Warranty."

J. Warranty. Provide a warranty in accordance with Article 6, Special Specification, "Testing, Training, Documentation, Final Acceptance, and Warranty."

K. Maintenance. Ensure that the manufacturer's technical representative and product documentation clearly specify the required maintenance and the required intervals. This will include a troubleshooting guide to overcome problems specific to the technology.

4. Measurement. This Item will be measured as each unit is complete in place.

5. Payment. The work performed and material furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "VIVDS Sensing Device," "Acoustic Vehicle Sensing Device," "Magnetic Vehicle Sensing Device (Surface Mounted)," "Magnetic Vehicle Sensing Device (Horizontal Bore)," or "Radar Vehicle Sensing Device." This price is full compensation for furnishing all equipment described under this Item with all cables, connectors, and mounting assemblies; all documentation and testing; and all labor, materials, tools training, warranty, equipment, and incidentals.

APPENDIX B:
DETECTOR SELECTION GUIDE

INTRODUCTION

Accuracy, failure rate, ease of setup and maintenance, compatibility with existing detection systems, and life-cycle cost are important considerations to decision-makers in choosing the most appropriate detection system. Inductive loops are more mature than the newer detectors investigated in this research, but the newer mostly non-intrusive detectors have features that encourage their use and their accuracy has improved. The primary bases of the detector selection will be accuracy, ease of setup, and cost. Figure 59 lists several considerations for selecting the most appropriate detector technology and device to deploy.

- | |
|--|
| <p>Step 1: Decide general detector environment</p> <ul style="list-style-type: none">• Directly over or beside the road<ul style="list-style-type: none">○ Camera image of traffic (VIVDS only)<ul style="list-style-type: none">▪ Communication bandwidth▪ Surveillance cameras already available▪ VIVDS cameras generally fixed and have minimal coverage• In the pavement• Below the pavement<ul style="list-style-type: none">○ Horizontal bore○ Under bridge <p>Step 2: Consider power and communication requirements</p> <ul style="list-style-type: none">• Portable• Stationary <p>Step 3: Consider data needs (type and accuracy)</p> <ul style="list-style-type: none">• Data Types<ul style="list-style-type: none">○ Speed○ Count○ Occupancy○ Classification<ul style="list-style-type: none">▪ Axle-based (FHWA Scheme F)▪ Length-based• Data Accuracy: a) stop-and-go and b) free-flow<ul style="list-style-type: none">○ Speed○ Count○ Occupancy○ Classification<ul style="list-style-type: none">▪ Axle-based (FHWA Scheme F)▪ Length-based <p>Step 4: Consider user-friendliness</p> <ul style="list-style-type: none">• User interface• Maintenance requirements• Complexity<ul style="list-style-type: none">○ Number of settings to learn and amount of calibration○ Amount affected by lighting and weather○ How much of the setup is automatic○ Health monitoring and status output <p>Step 5: Consider life-cycle cost</p> <ul style="list-style-type: none">• Initial cost• Mean-time-between-failures (MTBF)• Complexity usually adds cost |
|--|

Figure 59. Freeway Detector Selection Considerations.

DETECTOR SELECTION

The following text amplifies the major steps or considerations in determining the best detection system for a particular freeway application.

Step 1: Decide general detector environment

Consider the best location for the detector(s) for the likely design period of several years. The options are:

- directly over or beside the roadway,
- in the pavement, or
- below the pavement.

VIVDS cameras mounted above and centered over the lanes they monitor perform better than cameras mounted beside the roadway. VIVDS systems also provide a view of the traffic stream and serve as a verification mechanism. However, decision-makers should realize that cameras perform best if aimed downward at about 30 to 45 degrees from horizontal and do not cover a long length of roadway. Also, they typically do not serve both surveillance and monitoring functions because changing from a monitoring to surveillance mode requires movement by pan-tilt-zoom control. The change from surveillance back to monitoring requires returning to the exact orientation and focal length so as not to disturb detector placement, which is typically not practical without significant additional expense. If surveillance cameras are already available, then installers might consider a less expensive alternative than VIVDS. Also, consider the higher bandwidth needs of video as opposed to the lower bandwidth data sent by other detector systems.

If VIVDS is the technology of choice for monitoring freeway traffic, it is important that the installer know some critical information pertaining to placement of cameras. For TxDOT, the desired location is beside the roadway since placement over the roadway would require proper structures and, perhaps more importantly, would also require closing lanes for installation and maintenance. Proper positioning of the camera involves the right height and offset to minimize side-to-side occlusion. For measuring speed, this research project found that cameras mounted 30 to 35 ft above the roadway perform reasonably well throughout the range of speeds observed. However, vehicle counts and lane occupancies require higher cameras (or less offset) for achieving the desired accuracy. Finding an existing pole that is in the correct position and is tall enough for more than about three or four lanes is challenging. Installing a special pole for mounting cameras is costly, so the use of existing poles is desirable, at least to a point.

To investigate the camera placement needs, research personnel utilized three-dimensional visualization software and a two-dimensional occlusion calculator using Microsoft Excel to develop the results shown in [Table 23](#). These results allow the camera to see half of the lane width plus 1 ft on the far side of each vehicle. For camera heights ranging

from 15 ft to 50 ft and offsets from zero to 35 ft, the tabulated values indicate the number of lanes that a camera could see and avoid practically all side-to-side occlusion. The zero offset position is the edge of the outside traffic lane, so increasing values of offset indicate movement away from the monitored lanes. These values used only passenger cars on lanes that are 12 ft wide. Some jurisdictions are using special 40-, 45-, or 50-ft poles along with, in some cases, camera lowering devices for camera maintenance especially in cases in which the jurisdiction does not have a large bucket truck.

Table 23. Maximum Number of Detectable Lanes with Only Cars. ^a

Camera Height (ft)	Offset (ft)										
	0	2	4	6	8	10	15	20	25	30	35
50	7	6	6	6	6	6	5	5	5	4	4
45	6	6	6	6	5	5	5	4	4	4	3
40	6	5	5	5	5	5	4	4	3	3	3
35	5	5	5	4	4	4	4	3	3	2	2
30	4	4	4	4	4	4	3	3	2	2	1
25	4	4	4	3	3	3	3	2	2	1	1
20	3	3	3	3	3	2	2	1	1	1	1
15	3	3	2	2	1	1	1	1	1	1	1

^a A lane is detectable if the camera view shows half or more of its width plus 1 ft with a passenger vehicle in the near adjacent lane.

Typical heights for existing poles are in the 30 to 35 ft range, but they may not be located close enough to the lanes or equipped with a mast arm (e.g., luminaire poles) to get cameras to the zero offset position laterally. Therefore, the designer must sometimes either accept lower performance or install a taller pole. Figures 60 and 61 provide a visual comparison of the view from a 35-ft pole with the view from a 45-ft pole, clearly indicating the advantages of the taller pole. Both views position cameras at zero offset and hold the focal length and orientation constant. The large vehicle shown in both views replicates the size of a large truck (8.5 ft wide by 13.5 ft tall by 65 ft long) to indicate the amount of occlusion it might cause. It represents a “worst case” since not all large trucks are 13.5 ft tall for their entire length. For side-to-side occlusion with cars only, one guideline used by the industry is to provide at least half a lane width over the top of each vehicle (on the far side of each passenger vehicle). This appendix uses half the lane width plus 1 ft for cars. To illustrate, the nearest five lanes for a camera mounted at 35 ft as in Table 23 provide the required visible lane width but the lanes farther from the camera do not.

Of course, avoiding or minimizing occlusion due to trucks is not as easy and, in fact, may not be practical. This analysis differed by allowing the full lane beyond the truck to be occluded instead of about half the lane as before using cars only. The designer must decide based on the number of trucks in the traffic stream whether to accept the occlusion error or opt for a taller, more expensive pole. Table 24 summarizes the results indicating the

maximum number of detectable lanes where trucks are present given the same range of camera heights and offsets as before.

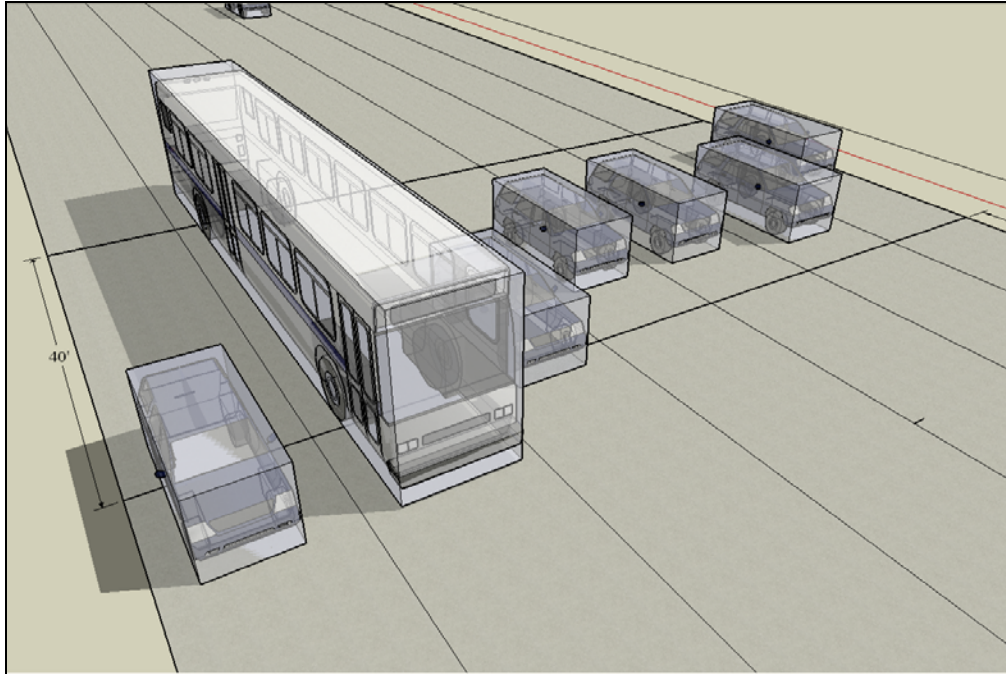


Figure 60. View from Camera Height of 35 ft and Offset of 0 ft.

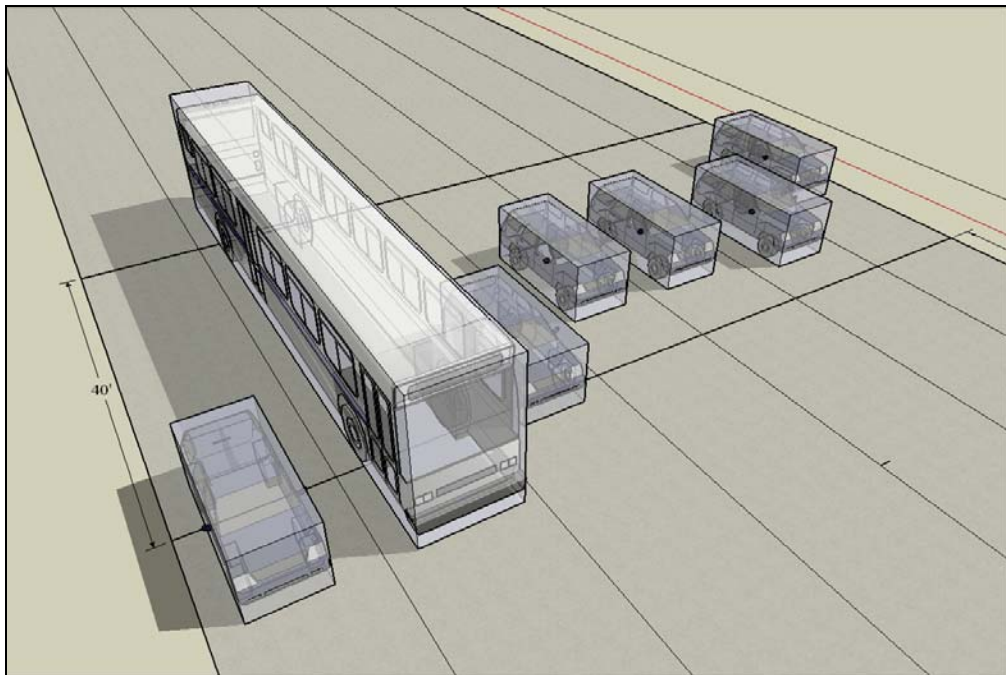


Figure 61. View from Camera Height of 45 ft and Offset of 0 ft.

Table 24. Maximum Number of Detectable Lanes with Trucks Present. ^a

Camera Height (ft)	Offset (ft)										
	0	2	4	6	8	10	15	20	25	30	35
50	4	3	3	3	3	3	2	2	2	1	1
45	3	3	3	3	3	2	2	2	1	1	1
40	3	3	2	2	2	2	2	1	1	1	1
35	2	2	2	2	2	2	1	1	1	1	1
30	2	2	2	1	1	1	1	1	1	1	1
25	2	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1

^a Allows the truck to obscure the full lane width adjacent to and beyond the truck but limits occlusion to no more than one lane.

Similar information for microwave radar and acoustic detectors is not necessary since at least one design mode for each technology relies on being mounted in a sidefire orientation. Mounting heights for microwave radar units typically range from 12 to 50 ft, whereas the desirable mounting height for the SAS-1 acoustic detector is 35 ft.

Installing detectors in the pavement has been common practice for the past 40 years, specifically in the form of inductive loops and, for some data needs, in combination with axle sensors. In-pavement sensors weaken pavement, require expensive lane closures, cause traffic delays, and compromise safety by requiring installers to work in traffic.

Installation under the roadway in this report involves magnetometers; the two models that were part of this research were 3M microloops and SenSys Networks magnetometers. The latter is one of the newest detectors and the most recent addition to the research test plan. Installation of this detector requires drilling and extracting a shallow core (about 5 inches in diameter) from the pavement surface and securing the detector in the slot with epoxy. Even though this detector requires lane closures, its installation only takes about 30 minutes per magnetometer. The other magnetometer is the 3M microloop, which is typically installed either under the pavement in a horizontal bore or under a bridge. Placement under a bridge may require fabricating a support system and a survey of the earth’s magnetic flux lines (due to bridge steel) to determine effective placement. Even though efforts to find a high-volume location to test 3M microloops in this research project were unsuccessful, researchers drew from other research findings and previous experience where microloop installation occurred on S.H. 6 in College Station in September 1999. These detectors are still operable and have required almost no maintenance as of 2006.

Step 2: Consider power and communication requirements

Data collection falls in two categories—stationary and portable. This research only tested detectors in a stationary environment, but some of the findings also apply to portable data collection. For power, all of the systems included in this research used grid power for all

major components with the exception of the SenSys Networks magnetometers. The in-road detectors used internal battery power and communicated wirelessly with the roadside. For any detection technology, communication needs are usually a function of the bandwidth requirements of the technology. Again, VIVDS has more stringent requirements than the other technologies tested if it is transmitted at a high frame rate (e.g., 30 frames per second). Portable detectors reduce setup time by using wireless communications and by relying on solar panels combined with batteries for power. The technologies that would work best in a wireless mode from the roadside to a communications hub are microwave radar and acoustic. Some magnetometers also have low power requirements and can transmit wirelessly. They may also be a good choice for portable data collection if a suitable way can be found to install and remove them with little or no disruption to traffic.

Step 3: Consider data needs (type and accuracy)

This research emphasized speed, count, and occupancy data types, but it also considered vehicle classification because the Peek ADR-6000 was part of the research. Excluding the ADR-6000 for the moment, the factors that seemed to affect detector performance most significantly were detector placement, occlusion, and congestion levels (and therefore prevailing speeds).

For non-intrusive detectors, placement of the detection unit is crucial to achieving optimum results. TxDOT normally places freeway VIVDS cameras beside the lanes being monitored so the Project 0-4750 research test plan followed accordingly. While mounting over lanes gives better results, safety requires closing lanes for installation and repairs whereas mounting beside the roadway on an existing pole saves money and interferes minimally with traffic. For sideloaded microwave radar and acoustic detectors, mounting on a pole beside the roadway is the intended option. Recommended mounting heights for radar are 12 to 30 ft, so pole height is not as critical as it is for VIVDS. However, horizontal offset from the nearest lane is critical for radar and must be at least 9 ft (6 ft for the new SmartSensor HD). Its range may extend as far as 200 ft (250 ft for HD). Microwave radar is switchable to a Doppler mode to be used overhead, but then it only covers one lane. It becomes significantly more accurate as a speed monitor in Doppler mode, and it can still monitor the nearest lane from beside the roadway if the angle between the detector line-of-sight and approaching traffic is small. The SAS-1 acoustic detector needs to be about 35 ft above the pavement for optimum performance. Concrete median barriers and other flat surfaces can be a deterrent to optimum performance for both radar and acoustic detectors.

Magnetometer accuracy approaches that of inductive loops, but decision-makers need to consider several factors to ensure good performance. Placement for 3M magnetometers depends primarily on the depth below the surface of the roadway, either in a horizontal bore or under a bridge. Boring contractors are skeptical about boring at depths shallower than 36 inches due to possible pavement damage, but vehicle detection for other than motorcycles is adequate at that depth. Many urban environments are not conducive to horizontal boring due to density of development along the roadway. Finally, there is a practical limit to the number of lanes that can be covered using 3M microloops since the probes are less likely to remain vertical with longer runs. The top of SenSys Networks magnetometers must be flush

or almost flush with the surface to be effective. Both types of magnetometers need to be centered in the lanes. Each type requires two stations placed a known distance apart to accurately determine speeds and vehicle lengths.

Occlusion is a factor for all detectors investigated in this research except magnetometers and inductive loops. For VIVDS cameras mounted beside the roadway, side-to-side occlusion occurs, and for VIVDS cameras mounted overhead front-to-back occlusion is more likely. In more congested conditions, occlusion seems to play an even larger role for any technology in reducing detector accuracy. None of the technologies included in this research project maintained their best detection accuracy (i.e., presence detection) during periods of highest congestion as characterized by stop-and-go conditions. However, even the standard TxDOT methods of counting and classifying vehicles using inductive loops (usually supplemented by axle sensors) are not accurate in these conditions.

The Peek ADR-6000 uses more sophisticated methods to count and classify vehicles compared to standard classifiers and performed well in congested conditions. The ADR-6000 accounts for lane changing and even for vehicles stopping over its pavement sensors. In multiple datasets using human observers and stop-action video, its count error was no worse than 1 in 2000 vehicles and its classification error was less than 1 percent in all congestion levels (ignoring Class 2 and 3 vehicles). Its occupancy measures were extremely accurate as well but required setting the unit to record “PVR” (per-vehicle record) data. This setting filled the memory buffers within a day or two (depending on traffic volume), causing the system to discontinue collecting data. Unless Peek modifies this feature, an agency could not leave the unit running continuously in the PVR mode. It is the best vehicle classifier tested thus far in TTI research and the only one known to adequately address highly congested conditions. Negative factors include its high cost, the PVR issue, and the intrusive nature of its detectors. The smaller axle loops require shallow depths, so pavement overlays require re-cutting of loops. Vendors might reduce the cost per unit if an agency purchases multiples. Another consideration for reducing the effective cost of this system is to use one unit to serve the needs of both operations and planners simultaneously at one location, especially along high-volume freeways.

There are special cases where the usual guidelines for detector selection may not apply. One special case is depressed urban freeways, which often have paved side slopes. Both active and passive detectors may be affected by reflections from these flat surfaces. Of the detectors tested in Research Project 0-4750, the microwave radar and acoustic systems would likely experience problems. A better choice might be a VIVDS with one or two cameras per station (depending on the number of traffic lanes).

Step 4: Consider user-friendliness

User-friendliness of detectors pertains to the user interface and the difficulty and time required to set up and calibrate the detector. VIVDS are generally more complex than other options and take more time to set up, especially for new installers. The SmartSensor SS105 is perhaps the fastest and easiest to install due to its auto-configuration routine, which senses the locations of traffic lanes and only requires that the detector be oriented in the general

direction of traffic. Its total setup time for each site should not exceed 30 minutes after pulling the wiring and getting all hardware loosely installed. Its user interface is intuitive and requires no special instructions, and its user manual is adequate. Both the acoustic and the SenSys Networks detectors are relatively easy to install as well, and their user manuals are adequate. VIVDS installation requires more than one person on site—one to orient the camera on the pole and one on the ground to monitor the image and guide the camera orientation. Once the camera is oriented, installers must use vendor-supplied software to draw detectors in the site field of view and then monitor these detectors for some period of time to determine need for adjustment. The VIVDS installation process can easily take a few hours to complete.

Step 5: Consider life-cycle cost

This comparison of detector costs uses a six-lane freeway cross-section. It is based upon annualized life-cycle costs and a 5 percent rate of return on investment. Any such comparison requires several assumptions, especially for detectors that have not established a performance history such as the SenSys Networks magnetometers.

For VIVDS cost, this analysis uses Autoscope because maintenance costs were readily available (although admittedly dated). The initial cost of the Autoscope Solo Pro II is similar to that of some other detectors in this project. Its maintenance costs could be higher, however, depending on how often lens cleaning is required. Lens cleaning frequency is a function of mounting height and nearby mobile and non-mobile air pollutant sources. The minimum frequency is twice per year. Research Project 0-1715 documented VIVDS maintenance costs for a large Autoscope system in Oakland County, Michigan (*1*). That project found that the average monthly cost for cameras and processors together was \$31.76 per month or \$381.12 per year. The initial cost of an Autoscope Solo Pro II system for a six-lane freeway (one unit covering six lanes of traffic) is \$6500. This price includes the detector unit, video output, power supply, surge protector, and serial communication panel for one camera, but excludes installation, system integration, and testing. Using a life of 10 years, the annualized life-cycle cost would be \$1222.

TTI spent \$9900 for installation of a two-lane system of 3M microloops on S.H. 6 in 1999. The installation used two horizontal bores with 3-inch Schedule 80 conduit spaced 20 ft apart with two probes per station in one lane (four total in that lane) and one probe per station in the other lane. Based on a 2006 cost quote from a Texas distributor, the cost of the components for a six-lane freeway system would be \$13,224. Boring would cost an estimated \$22 per foot. This system would consist of three probes per lane at each of two locations in each lane spaced a known distance apart to be able to detect vehicle speeds. Three probes per lane are needed to detect motorcycles. Annual maintenance cost would be about \$50 or less based on the S.H. 6 experience, and the life expectancy would be about 15 years. The annualized life-cycle cost for the microloop system would be \$1945.

The initial cost of a SenSys Networks magnetometer system for a six-lane freeway would be \$12,546. The freeway would require two detectors in each lane spaced a known distance apart and centered in the lane. Besides the 12 flush-mount detectors, the system would also require an “Access Point” communication node with Ethernet, mounting brackets,

a power supply, a battery-operated repeater, battery packs, and epoxy. The assumed average annual maintenance cost was \$210 (assume one failed detector [\$600] and cost of freeway lane closure [\$1500] in 10 years) and the estimated detector life is 10 years. The annualized life-cycle cost would be \$1834. Since this system is newer than others investigated in this research, the maintenance cost is not as well known.

The initial cost of a SmartSensor SS105 microwave radar detector is \$6500. This cost includes one SS105 detector, a pole mounting bracket, a Click 200 surge protector, serial communication, Click 201 1A power supply, and 60 ft of cable. A six-lane freeway would only need one detector in most cases, although two units are sometimes needed for cross-sections with taller median barriers (one per direction). This cost estimate assumes one detector. The annual maintenance cost would be about \$50 per detector and the estimated life of the detector is 10 years. The annualized life-cycle cost for the SS105 would be \$891.

The initial cost of a SmarTek SAS-1 acoustic detector is \$2800 before the contractor’s markup, with a final cost of about \$3500 per site (each side of the freeway). A six-lane freeway would require two detectors—one for each direction of traffic. The components needed in the installation would include the traffic sensor with a 50-ft RS-422 pigtail, a mounting tube and flange, a shelf-mount cabinet termination, and communications cable. Based on historical data from the manufacturer in 2006, the annual maintenance cost would average about \$50 or less and the estimated life of the detector would be 10 years. The annualized life-cycle cost for the SAS-1 would be \$956.

SUMMARY OF RESEARCH FINDINGS

Table 25 summarizes some typical accuracy and cost factors that should be considered for selecting specific detectors or detection technologies for freeway applications. The costs are life-cycle costs based on an assumed life for each detector and 5 percent rate of return. The count and speed accuracies shown reflect general trends.

Table 25. Quantitative Evaluation of Detectors on Freeways.^a

Technology/Product	Annualized Life-Cycle Cost	Overhead Accuracy (%)		Sidefire Accuracy ^b (%)	
		Count	Speed	Count	Speed
Magnetometer – 3M	\$1945	98	95	NA	NA
Magnetometer – SenSys	\$1834	98	98	NA	NA
Microwave Radar – SS105	\$891	98	98	94	92
Passive Acoustic – SAS-1	\$956	NA	NA	90	80
VIVDS – Autoscope Solo Pro	\$1222	NA ^c	NA ^c	90	82

^a Six-lane freeway with median barrier.

^b “Sidefire” means mounted on a structure beside the roadway.

^c Not evaluated in this research project.

APPENDIX C:
S.H. 6 DATA PLOTS

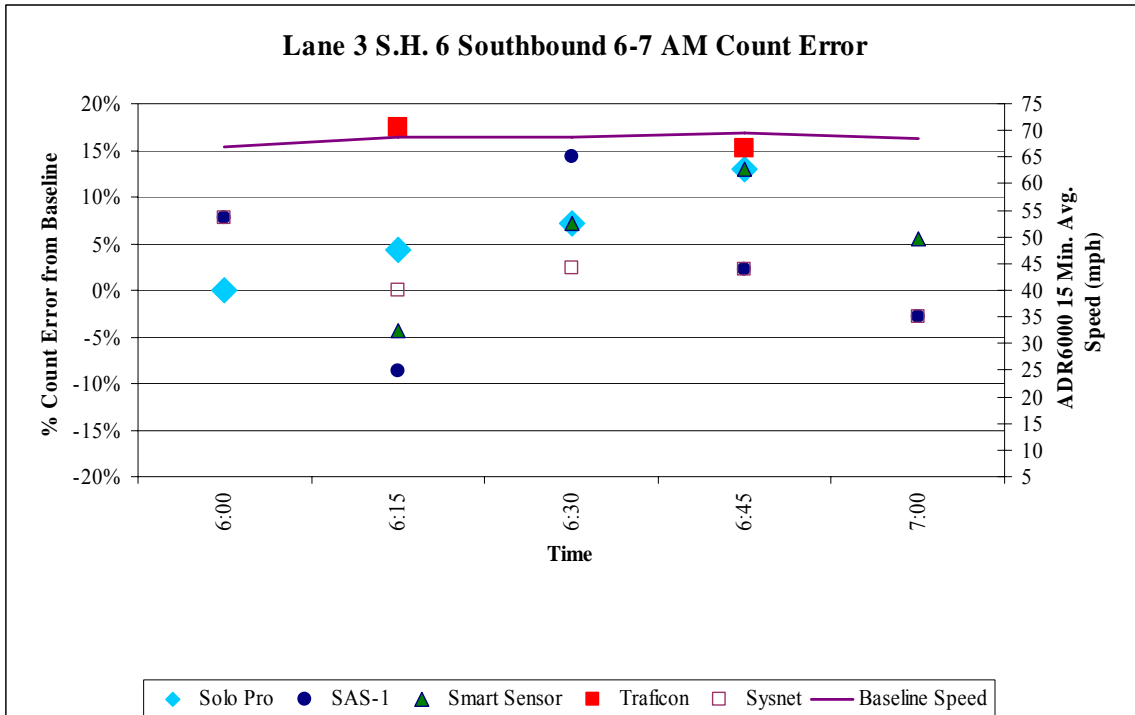


Figure 62. Detector Count Accuracy S.H. 6 6am-7am July 15, 2006.

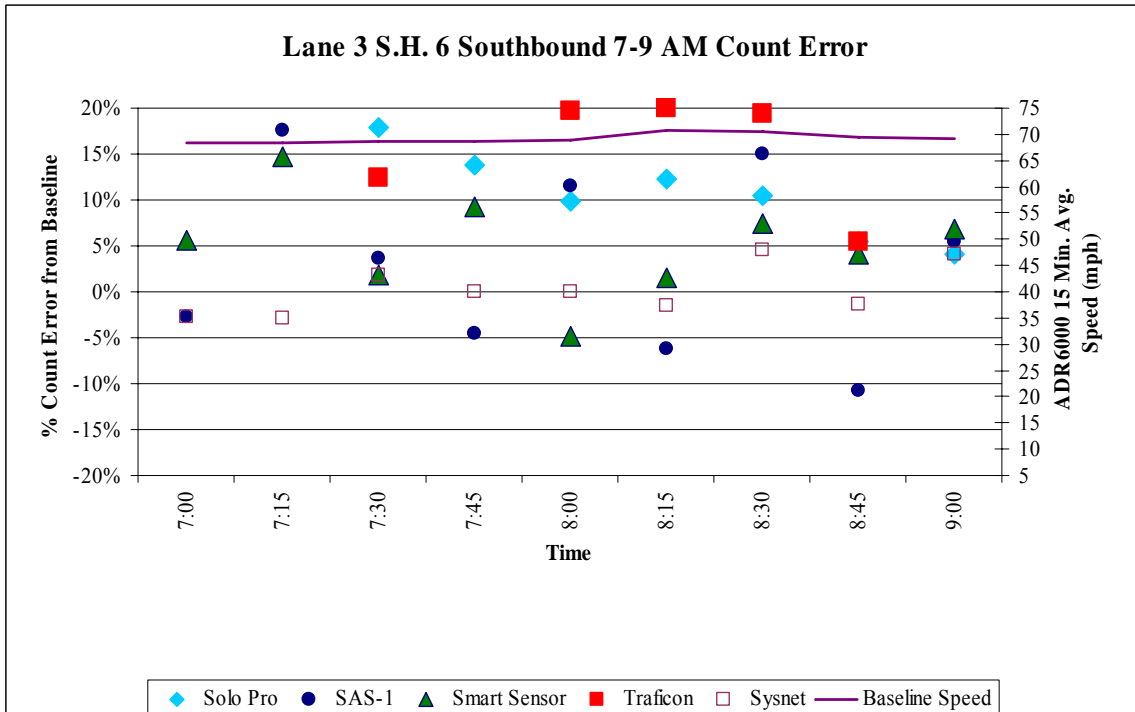


Figure 63. Detector Count Accuracy S.H. 6 7am-9am July 15, 2006.

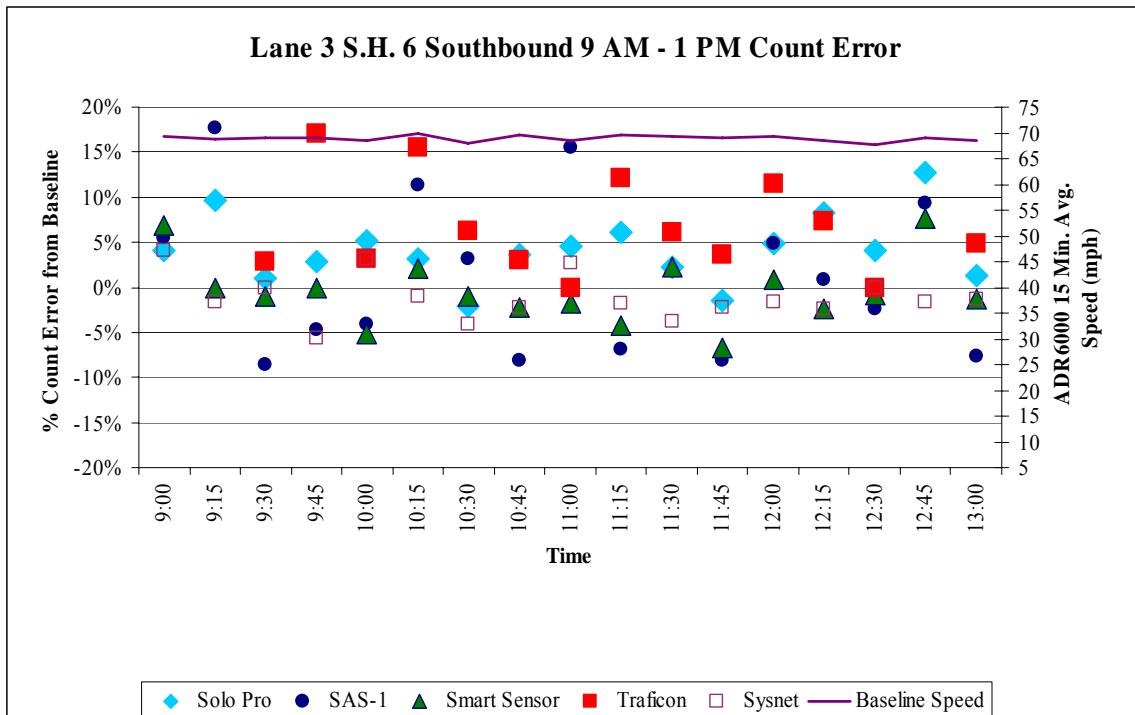


Figure 64. Detector Count Accuracy S.H. 6 9am-1pm July 15, 2006.

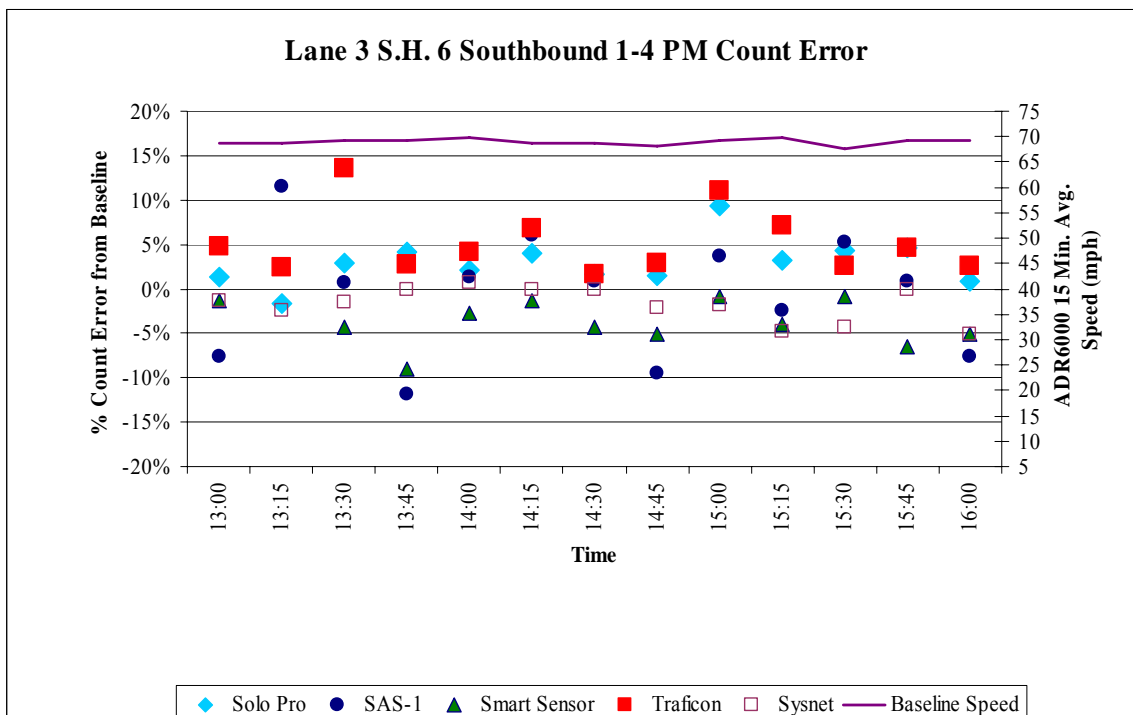


Figure 65. Detector Count Accuracy S.H. 6 1pm-4pm July 15, 2006.

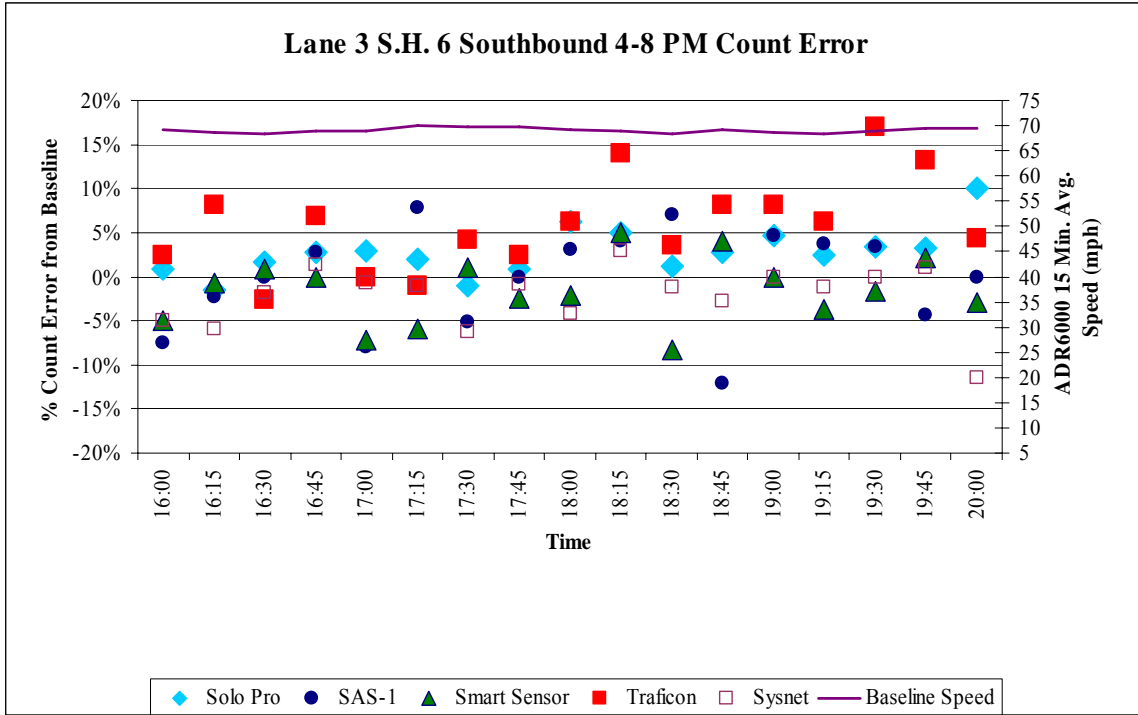


Figure 66. Detector Count Accuracy S.H. 6 4pm-8pm July 15, 2006.

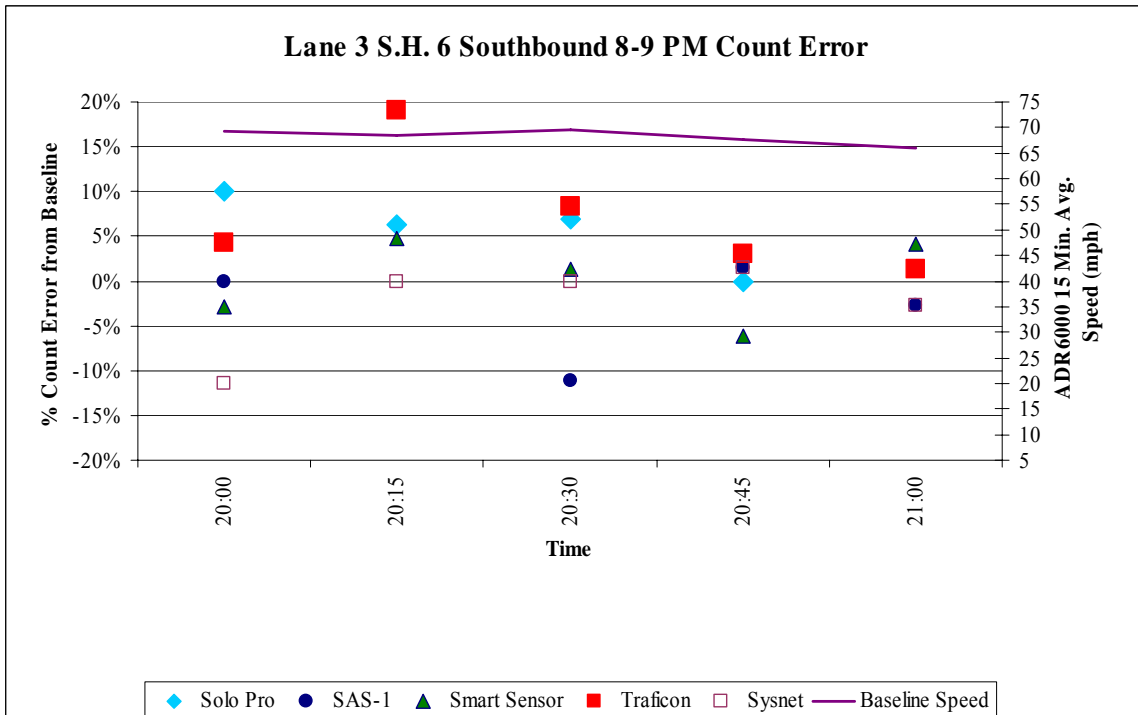


Figure 67. Detector Count Accuracy S.H. 6 8pm-9pm July 15, 2006.

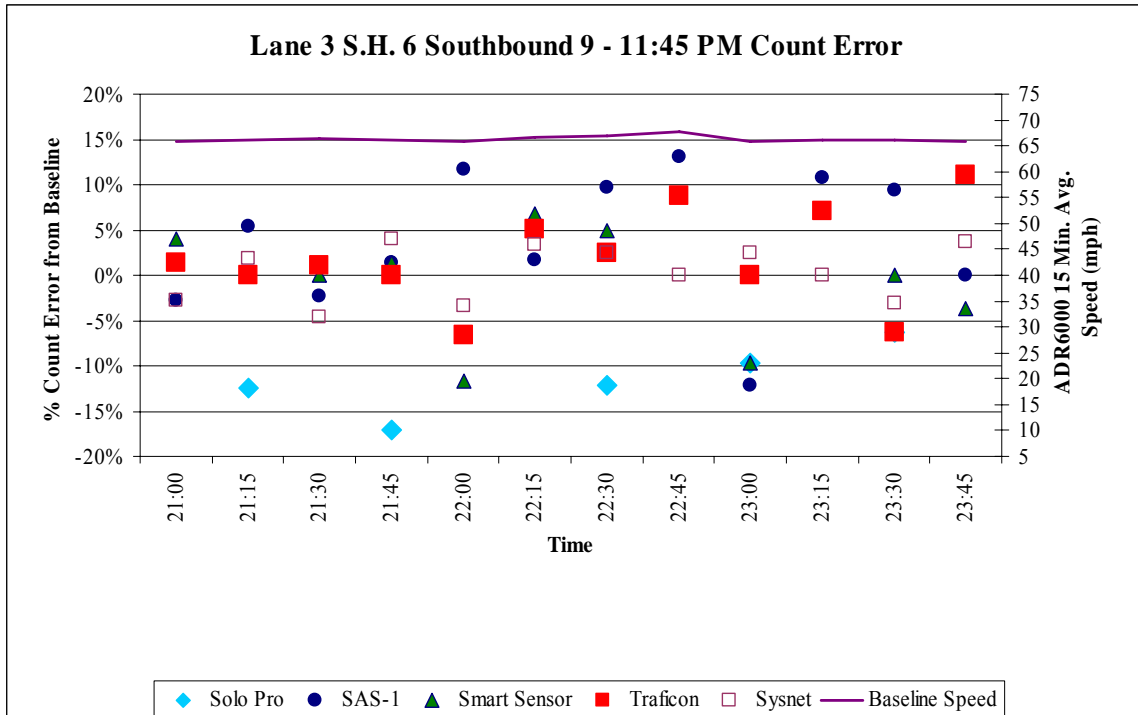


Figure 68. Detector Count Accuracy S.H. 6 9pm-11:45pm July 15, 2006.