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16. Abstract

Problems with installation and maintenance of inductive loop detectors, especially on freeways, have necessitated evaluation of alternative detection systems. The approach used in this research relied on recent evaluations of non-intrusive detectors and knowledge of researchers to identify three detection systems that warranted further evaluation in Texas. These were the Videotrak® 900 by Peek (video image processing), the non-invasive microloop by 3M™ (magnetic), and the SAS-1 by SmarTek (acoustic). Testing of these detectors utilized the Texas Transportation Institute's (TTI) freeway test bed for conducting full-scale field-testing. The parameters measured for accuracy were vehicle presence and speed, but installation cost and ease of setup and calibration were also considered. The 3M microloop was the most consistent detector overall, and performed well both on a freeway as well as under a bridge. The Peek VideoTrak system's presence and speed accuracy both declined to unacceptable levels during nighttime and during rain. It was also the most difficult to set up and the most expensive. The SAS-1 by SmarTek was the least expensive and demonstrated reasonable accuracy. TTI recommends continued evaluation of the SAS-1 and the 3M microloops.

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INITIAL EVALUATION OF SELECTED DETECTORS
TO REPLACE INDUCTIVE LOOPS ON FREEWAYS

by

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. This project was conducted in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation. The Research Supervisor, Dan Middleton, is a registered professional engineer in Texas, number 60764.

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INTRODUCTION

Tomorrow's traffic management and data collection needs will be met by a number of different detectors, including the inductive loop detector (ILD). Two primary problems with ILD systems must be addressed. One is their high failure rate in some jurisdictions, and the other is that they are not the most appropriate detector based on site-specific constraints such as unfavorable pavement conditions or where detection is needed across railroad tracks. Even though a need exists for loop replacements, some agencies are not willing to risk the uncertainty of new detectors that have not been adequately proven. The purpose of this research effort at the Texas Transportation Institute (TTI) related to new detector technology was to screen selected detectors to determine whether they were worthy of further scrutiny in a more demanding environment and to determine long-term performance *(1)*.

Non-intrusive detector systems are increasing in prominence due to congestion on urban freeways and at high-volume signalized intersections, where interference with traffic to install and maintain detectors installed in the pavement has become unfeasible. These newer detectors substantially reduce traffic delays and excess fuel consumption normally associated with inductive loop detector installation and maintenance. They can also be used on bridge decks where installation of ILD systems is generally prohibitive. However, the lack of familiarity of these relatively new systems and the maturity and relative simplicity of inductive loop systems are among the factors that encourage agencies to continue to use inductive loops.

It should be noted that detection needs for intersections and freeways are similar in some ways but different in other ways. One similarity is with respect to the need to determine simple "presence" of vehicles. At the most basic level, detectors must accurately detect the passage of vehicles for comparison with an accurate ground truth system. A difference that currently exists is the need for speed output on freeways but not at signalized intersections. This research dealt with both presence accuracy and speed accuracy.

RECENT DETECTOR EVALUATION EFFORTS

Previous research, researcher experience, and Texas Department of Transportation (TxDOT) needs provided a basis for selection of detectors to evaluate in this research project. Prominent findings based on TTI research and findings by others documented in the literature are provided below.

1. In Minnesota Guidestar tests of vehicle count accuracy, researchers found that the Remote Traffic Microwave Sensor (RTMS) (true presence microwave) mounted easily but required a moderate amount of calibration to achieve optimal performance. At the freeway site, the RTMS undercounted vehicles by 2 percent or less in the overhead position and 5 percent in the sidefire position. It was not tested at the intersection site *(1,2,3)*.

2.   Minnesota tests included two pulse ultrasonic detectors, the Microwave Sensors TC-30 and the Novax Lane King. Both were relatively easy to mount, but the Lane King required more extensive calibration. Weather conditions did not impact the performance of the devices, and either device can mount overhead or sidefire. Both detectors overcounted vehicles stopped at the intersection, counting individual vehicles multiple times. The Lane King was extremely accurate in counting vehicles at the freeway site *(1,2,3)*.

3.   Video image detection system (VIDS) testing in Minnesota included the Peek VideoTrak® 900, the Autoscope 2004, and the Eliop Trafico EVA 2000 (freeway application only). Lighting variations and shadows were the most significant weather-related conditions that affected video devices. The count accuracy of the VideoTrak® 900 was within 5 percent of baseline on the freeway, but periodic failures occurred during intersection tests. The Autoscope performed within 5 percent accuracy at both freeway and intersection test sites, although light transitions resulted in undercounting *(1,2,3)*.

4.   Hughes Aircraft research results favored Doppler microwave detectors, but this technology does not detect stopped vehicles. The Doppler microwave, true presence microwave (Remote Traffic Microwave Sensor (RTMS)), visible VIDS, SPVD magnetometer, and inductive loop technologies performed well for low-volume counts *(4)*.

5.   For high-volume counts, the Doppler microwave, true presence microwave, visible VIDS, and inductive loops performed well. The Doppler microwave was the best performing technology for speed accuracy in both low- and high-volume traffic. The Doppler microwave, true presence microwave (RTMS), SPVD magnetometer, and inductive loop technologies performed best in inclement weather *(4)*.

6.   Duckworth et al. *(5)* tests indicated that VIDS had limitations in poor lighting and certain weather conditions, and was the most expensive sensor tested. Pulsed ultrasound was best for detection and classification when cost, the communications bandwidth requirements, and processing power were considered. Radar was the best speed sensor for vehicles it detected *(5)*.

7.   Field tests at the Texas Transportation Institute freeway test bed included inductive loop detectors for baseline data, Accuwave (microwave), Nestor TrafficVision (VIDS), RTMS, SmartSonic (acoustic), and PIR-1 (passive infrared). Count accuracy of the ILDs was within 1 to 2 percent of manual counts based upon repetitive review of videotapes. With the exception of the RTMS, test detectors exhibited count errors as high as 20 to 50 percent in short one-hour intervals. The worst count error observed with the RTMS was 15 percent for only one hour, with the remainder falling within 10 percent *(6)*.

8.   Field tests on US 290 in Houston, a high-volume urban freeway, provided additional vehicle count performance data to supplement College Station tests. Testing included the Nestor TrafficVision, the Autoscope 2004, and the RTMS. Detector performance was more erratic at higher volumes in which traffic was very congested during parts of the day *(6)*.

9.   Lane 1 Autoscope counts evaluated by TTI in Houston from 6:00 a.m. to midnight were generally within 10 percent of baseline counts. Many of the 15-minute counts were within 5 percent. Counts after darkness were the exception, with the Autoscope overcounting by as much as 30 to 40 percent. Lane 2 counts were more erratic than lane 1 counts. Daylight errors were both positive and negative in the range of plus 20 percent to minus 50 percent. Nighttime errors were even worse. Lane 3 daylight errors were in the plus 20 to minus 30 percent range, and nighttime errors were again worse. A better camera and camera position would probably improve these results *(6)*.

10.   In Houston tests, the Nestor both overcounted and undercounted vehicles in lane 1 by 30 percent during daylight hours. There were many time periods during the daytime when its count error was in the zero to 10 percent range. A better camera and camera position would probably improve these results *(6)*.

11.   RTMS performance was apparently not affected by changing light conditions. Its count performance in Houston during early morning and late afternoon light transition periods was similar to its mid-day performance. It generally undercounted lane 1 traffic by 5 to 10 percent. In lane 2, the RTMS mostly overcounted in the range of up to 10 percent. On two days, it also undercounted traffic in lane 2, but usually by no more than 5 percent. Lane 3 counts showed no bias toward overcounting or undercounting for most time periods, with maximum errors in the range of 10 percent. RTMS performance was unaffected by the distance of the pole from the roadway *(6)*.

12.   The difficulty in finding suitable test sites in Houston and Ft. Worth emphasized the need to identify and instrument urban test beds for future tests. Important factors are: a properly positioned pole, working trap loops in each lane, good alignment, flat profile, minimal weaving and lane changing, and an equipment cabinet *(6)*.

13.   Inductive loop accuracy and durability is directly attributable to rigid specifications and an aggressive inspection and test program. There is an immediate need for TxDOT to improve on these items. Examples in Europe are the Netherlands with a failure rate of one per 1,500 loops and Switzerland with a failure rate of five per 200 *(6)*.

RESEARCH METHODOLOGY

INTRODUCTION

TxDOT preferences, researcher experience, and previous testing provided the necessary criteria to decide what needed to be tested. The three systems selected were: the 3M non-invasive microloop (magnetic), the Peek VideoTrak 900 VIDS, and the Smartek Acoustic Sensor – Version 1 (SAS-1), which utilizes passive acoustic technology. All three devices were either relatively new or had recently undergone modifications that had not been tested on a widespread basis. A fourth detector, selected for baseline speed comparisons, was the RTMS by Electronic Integrated Systems (EIS). It too required initial ground truth testing for speed accuracy using new software.

RTMS Installation and Test

TTI researchers, with assistance from the manufacturer and a local vendor, installed the RTMS Doppler radar detector 22 ft above the center of the right lane at the SH 6 test bed. The EIS representative instructed TTI personnel concerning the optimum mounting position and angle of the RTMS with respect to the road for its "forward-looking mode" (facing approaching vehicles). The EIS installer initially set up the software for accurate counts, so speeds should also have been optimized.

A few days following completion of the setup, TTI calibrated the RTMS speed measurements using a Pro Laser II Infrared Lidar System. To accomplish this test, researchers placed the Lidar speed device on a stationary tripod beside the roadway and adjusted the RTMS speed via software until the RTMS calibrated speed closely matched the Lidar speed. However, even after calibration, an inordinate number of vehicles passed the site undetected by the RTMS. Inquiries to EIS revealed that the installed height of 22 ft was higher than optimal, so EIS instructed researchers to adjust the fine-tuning via its software interface. Following this adjustment, TTI then re-calibrated RTMS speed using the Lidar. This process solved most of the problem of undetected vehicles, but a small number of vehicle speeds were still not reported.

TTI collected multiple sets of speed data to ensure consistency in the technique and fairness to the test systems. One problem that may have minimally affected accuracy during initial tests was the wind. With the RTMS mounted near the end of the long mast arm, wind and wind gusts could have caused enough movement to compromise accuracy. However, wind effects are thought to be insignificant in the data set under consideration. Table 1 shows average 15-minute wind speeds based on weather station data for the RTMS tests conducted on April 19, 2000.

Table 1. Average Wind Speed During RTMS Tests on April 19, 2000.

Start Time	Wind Speed (mph)
14:45	7.22
15:00	8.22
15:15	7.64

RTMS comparisons with the Lidar system on April 19, 2000, revealed reasonably close speed comparisons in a sample of 70 vehicles. Field personnel were very careful in selection of vehicles to use in the sample. Their criteria included: vehicles with constant speeds, vehicles in the right lane, and vehicles with long spaces in front of them. Fifteen percent of the speeds for selected vehicles were the same, while 38 percent were different by 1 mph. Fourteen percent of the speeds were different by 2 mph, and 3 percent were different by 3 mph. Differences between the two systems narrowed with larger sample sizes, with sample sizes of 10 or more being desirable.

There were two primary reasons why the Lidar was not directly suitable for these comparisons. One was its requirement for human presence and the other was its output being limited to a per-vehicle basis. It has to "lock on" to each individual vehicle and the user must be sufficiently skilled to know which vehicle is being tracked. Test detectors that output speeds only after a user-defined time interval (bin data) could not have compared directly to another system that output vehicle-specific speeds for only a few selected vehicles. In fact, this factor was a problem in use of the RTMS as well, albeit a much smaller problem.

To conduct the speed studies, researchers set the SAS-1 and VideoTrak to output speed data in one-minute intervals. The 3M system and the RTMS generate vehicle-specific speeds, so analysts grouped their speed data in one-minute bins based on the time-stamp associated with each vehicle record for subsequent comparison. Results indicated that the number of vehicle speeds recorded during some of these intervals was different among detectors. For example, during a selected one-minute interval, the RTMS might have detected speeds for 12 vehicles, while the SAS-1, 3M microloops, and Peek VideoTrak might have detected 11, 13, and 11, respectively. They could not have all measured speeds of the same vehicles. An accurate determination of speed accuracy requires using the same vehicles, as long as the reduced sample size is adequate, and it is.

Final preparation to collect a fair sample of data on all three test systems required several trial runs to both calibrate the systems and work out minor glitches that seemed to interfere with simultaneous data collection on all four systems. This preparation required synchronizing clocks on all four systems. Testing involved mostly dry weather, with the exception of May 1 data when there was rain. Rain was predicted to be a factor for the SAS-1 and Peek VideoTrak. Only one other weather-related factor may have altered the accuracy of the VideoTrak. Shadows cast on sunny days may have affected its results compared to those

on cloudy days. TTI's SH 6 weather station was not equipped with a solar radiation sensor to make this comparison.

DETECTOR INSTALLATION

3M Microloops

The 3M Canoga™ Vehicle Detection System Model 701 and Model 702 non-invasive microloops use the earth's magnetic field to detect vehicles. TTI installed the Canoga C800 4-channel rack-mounted detectors in one of the three roadside equipment cabinets. These detectors are compatible with NEMA TS1, TS2, and Type 170 card racks. The software is very user-friendly and generates either real-time speed and length or binned counts and occupancy. TTI installed Model 702 probes under SH 6 and Model 701 probes under the FM 60 bridge. Figures 1 and 2 show the locations of these systems. The microloop probes slide into the conduit after being placed individually in special interlocking carriers, each one foot in length. The probe carriers snap together, then the assembly is pushed into the conduit from the ground box to the pre-measured position with a vertical orientation.

Installation under SH 6 on September 29, 1999, required horizontal boring and installing two parallel 3-inch, schedule 80 conduits under the roadway at a depth of 18 inches, with a depth tolerance of plus or minus 3 inches. Figure 3 shows a stage of the installation process. TTI positioned the Model 702 probes in the conduit such that there were single probes in the left lane and dual probes in the right lane. Researchers centered individual probes under the left lane in each conduit, with longitudinal separation of 20 ft between stations. The right lane had two probes at each station separated by 4 ft and centered under the lane, again with stations separated by 20 ft. Consultation with 3M technical support and its manual was required to properly set up the detectors.

3M sent a product development specialist to the TTI test bed on November 8, 1999, to install the microloops under the FM 60 bridge and check the probes installed under SH 6. According to 3M personnel, each bridge is unique and must be surveyed with a magnetometer to determine whether microloops will work properly. For example, probes function differently on a north-south roadway compared to an east-west roadway due to the angle that the earth's lines of magnetic flux intersect the ground.

The FM 60 bridge tests used two probes under the center lane and one probe under each of the other two lanes. Each probe set came with the designated length of lead wire to avoid splices. The manufacturer wired the probes in series where dual probes (side-by-side) were installed at a station (right lane on SH 6 and center lane on the FM 60 bridge). The bridge application required 500 ft of lead wire, but TTI requested the probes with 800 ft of leads to determine the effect the lead length might have. Wiring in series resulted in a total length of lead for the bridge center lane of 1,600 ft. The extra length did not seem to compromise performance in any way. Figure 4 shows the aluminum brace designed and built by TTI to support the probes underneath the bridge structure.
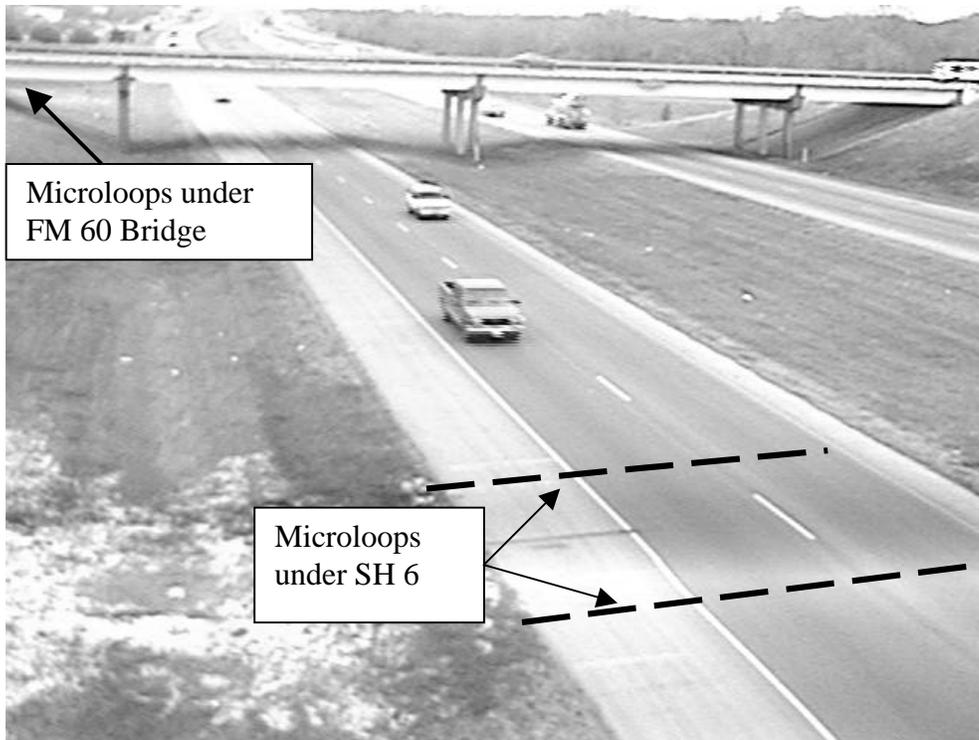
7

Figure 1. Surveillance Camera View of SH 6 and FM 60 Bridge.

Peek VideoTrak 900

The Peek VideoTrak 900 is a video vehicle tracking and detection system. The camera used with this system was a Philips TC590 series high-resolution charged couple display (CCD) monochrome camera using a 1/3-inch format lens with an 8 mm focal length. The camera was equipped with an auto iris and infrared filter. TTI installed the Peek camera 40 ft above the roadway on the 15-ft mast arm shown in Figure 3 and 19 ft away from the outside lane (measured at a 90-degree angle with the roadway).

SmarTek SAS-1

The SAS-1 is a passive acoustic (listen only) detector that mounts beside the roadway with the capability of monitoring up to five lanes from its sidefire orientation. The detector needs to be mounted as high as 35 ft above the roadway to accurately monitor five lanes. TTI mounted the detector 20 ft above the travel lanes because the detector was monitoring only two lanes and because of the mast arm's height. Its offset from the right lane was 25 ft (as measured at a 90-degree angle with the roadway). After test results became available, the vendor suggested that presence detection accuracy would have been better with a height of 25 ft to 30 ft and smaller offset.
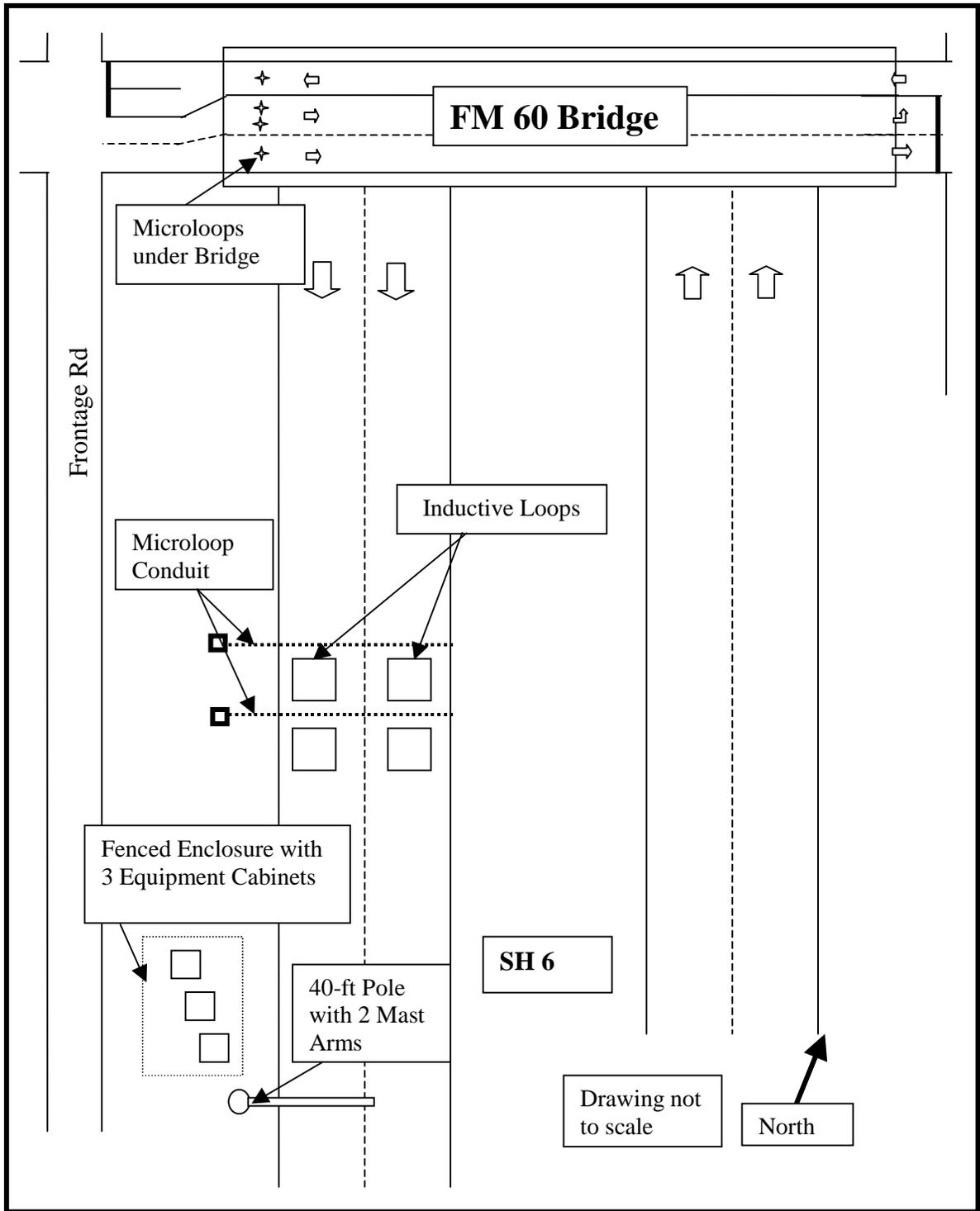
Figure 2. Schematic of Test Bed Layout.

Labels within figure:
- FM 60 Bridge
- Microloops under Bridge
- Frontage Rd
- Microloop Conduit
- Inductive Loops
- Fenced Enclosure with 3 Equipment Cabinets
- SH 6
- 40-ft Pole with 2 Mast Arms
- Drawing not to scale
- North

Figure 3. Installation of Microloop Conduit under SH 6.
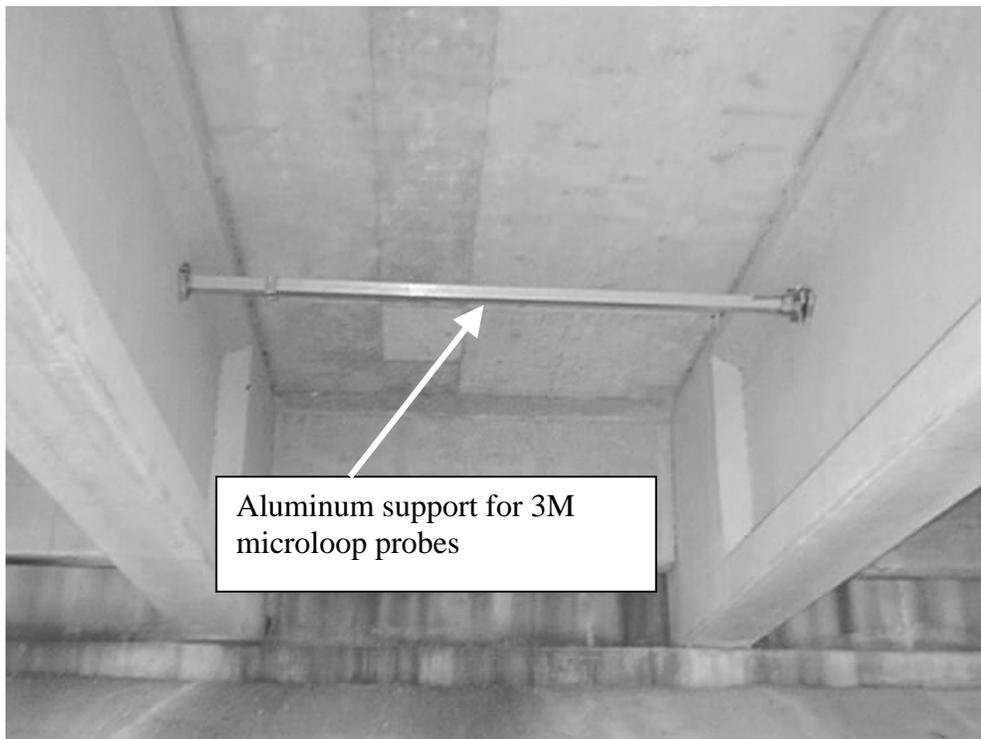
Aluminum support for 3M microloop probes

Figure 4. View of Probe Support underneath FM 60 Bridge.
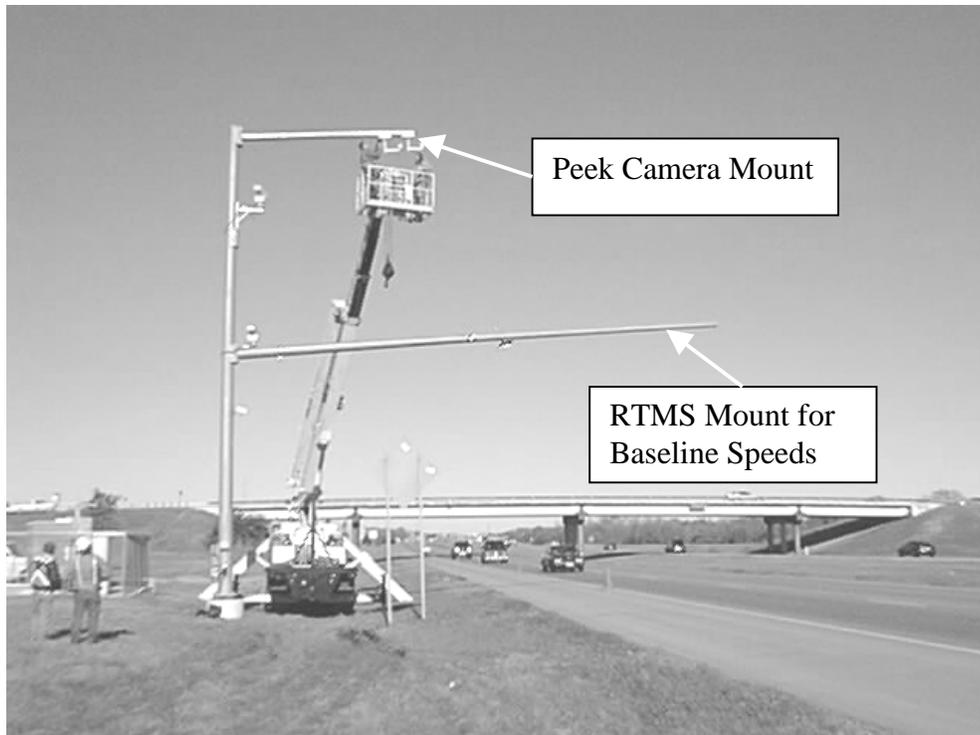
Figure 5. Installation of the Peek Camera 40 Ft above the Roadway.

Mounting the sensor was a simple process, requiring banding the detector's mounting bracket to the mast arm and orienting the detector generally toward the lanes to be monitored. Precise orientation is not normally required, although adjustments are sometimes necessary. An example of such an adjustment occurred when TTI mounted the detector behind the mast arm (as viewed by approaching motorists). A diamond-shaped warning sign on that same side of the mast arm initially caused the detector to double-count vehicles. TTI simply moved the detector to the "front" side of the mast arm to solve the problem. Figure 6 shows the SmarTek SAS-1 mounted on the mast arm, with the view looking toward the end of the lower mast arm.

Figure 6. SmarTek SAS-1 Mounted on the Lower Mast Arm.

DETECTOR TESTING

Baseline *count comparisons* came from either multiple observer manual counts or automated data recorder systems using inductive loops and an automatic data recorder. TTI synchronized internal clocks on all systems so that each of the three test systems was counting the same traffic stream simultaneously.

Baseline *speed comparisons* came from the RTMS detector placed over the right southbound travel lane on the pole's lower mast arm. The basis of comparison was one-minute intervals of speeds from the three test detectors. Researchers again synchronized all internal clocks to ensure that each detector monitored the same vehicles. Speed tests followed vehicle count comparisons, so the initial setup of each detector had already been accomplished. However, there was preparation required for two of the systems, specifically for speed tests (3M microloops and VideoTrak). The third, the SAS-1, had to be post-calibrated to correct for speed bias because that feature of the software was not ready for release prior to these tests.

3M Microloops

Tests on the FM 60 bridge for vehicle presence used multiple observer manual counts for baseline comparisons, whereas the SH 6 tests used the inductive loops already in the pavement for baseline counts. On SH 6, TTI began by verifying the accuracy of the inductive loops in the pavement, finding that counts were consistently close enough for this purpose.

One objective of the microloop evaluation for vehicle presence on the FM 60 bridge was to determine microloop accuracy in counting vehicles during stop-and-go conditions. These conditions occurred each weekday afternoon in the eastbound direction from approximately 4:45 p.m. to 5:15 p.m. In order to ensure capture of these time periods, TTI began baseline counts at 3:30 p.m. and ended at 5:30 p.m. Appendix A shows the results graphically. The other objective was to test microloop performance in the vicinity of ferrous metal. For such tests, 3M informed the authors that vertical ferrous metals might affect performance, whereas horizontal metals generally would not. The FM 60 bridge beams had vertical reinforcing steel but probes were placed as close as one foot from these beams without apparent degradation of performance.

Preparation of the 3M microloops on SH 6 for speed tests first required calibration. This calibration for speed tests required trial-and-error changes in the 3M Canoga software of the spacing between the microloop probes. Actual spacing was 20 ft, but the adjusted nominal spacing in the software was 22.2 ft.

Peek VideoTrak

TTI used Peek's software to create detection areas along each lane of SH 6 that coincided with the baseline inductive loops. According to Peek, the VideoTrak performs better at night with street lighting. Therefore, the absence of lighting devices on this section

of SH 6 undoubtedly contributed to its poorer performance during nighttime hours. Optimizing the performance of the Peek system required substantial support from Peek personnel using a modem connection.

VideoTrak speeds were adjusted using the calibration points in the setup software. Night speeds output by the VideoTrak were too inaccurate to be used in the speed comparison. Again, according to the manufacturer, the VideoTrak must have street lighting to be accurate for speed or counts at night.

SmarTek SAS-1

Inductive loops in the pavement provided the baseline data for vehicle count comparison with the SAS-1. One minor source of error with the comparison was the separation of approximately 80 ft between the inductive loops and the location downstream where the SAS-1 was monitoring traffic in its sidefire orientation.

Field personnel made no adjustments to the SAS-1 for speed data collection compared to the initial setup for vehicle counts. The SAS-1 software does not currently allow adjustment of the reported average speeds. (It only outputs average speed over a user-selectable time interval, and not vehicle-specific speeds.) The user must apply a post-adjustment factor to calibrate to the true speed on the roadway.

RESEARCH FINDINGS

EVALUATION CRITERIA

Researchers used the following basic evaluation criteria to evaluate the three test systems: ease of setup and calibration, cost, and count and speed detection accuracy. For vehicle count accuracy, the ground truth comparison for all three test systems on SH 6 used an inductive loop and classifier system. However, TTI used manual counts as ground truth for the 3M microloops under the FM 60 bridge simply because other reliable systems were not readily available. Speed accuracy was based on the RTMS for baseline one-minute averages. For cost comparisons, life-cycle costs would have been desirable, but insufficient data existed for this comparison. Therefore, only initial equipment and installation costs were used. Ease of setup and calibration was based on three things: 1) documentation included with the unit, 2) technical support from the vendor, and 3) intuitive feel of the system by installers.

One additional factor should be considered with the 3M microloop. It is designed to be installed at a very shallow depth below the pavement, at only 18 inches from the surface. This shallow depth caused several boring contractors concern for the College Station installation, to the point that most of them were not willing to bid on the project. There may be cases in which the microloop installation could be staged as part of the initial construction and thus overcome this problem. One TxDOT district considered installing the detectors at 36 inches below the surface to reduce the likelihood of compromising the structural integrity of the pavement. According to 3M, each probe's detection zone is shaped like a vertical cone, getting larger with height. Therefore, placement at greater depths may result in undesirable detection of tall vehicles in adjacent lanes.

Ease of Setup and Calibration

3M Microloops. Installing the microloop probes in the conduit was simple. The first probe snapped into a hole in the first carrier piece. The first carrier had a rope attached for pulling out the carriers and marking the location of the probes. Each probe carrier has holes for probes and is one foot long. Installers snap together probe carriers, then push them into the conduit one by one to position the probes under the lanes.

3M Canoga C824 Loop Detector and ITS Link Software. The standard rack detector can be set up with the front switches or by using the software. All the setup procedures are well documented and easy to follow. The available setup procedure guides the user step by step through the process of configuring the detector to bin counts and occupancy, or to record and display individual real-time speeds and lengths. The one parameter TTI had to adjust to get the highest count accuracy was "bridge time." Bridge time setting is directly proportional to the average speed of vehicles detected. The Windows™ software always ran reliably and was easy to use, install, and understand. The subsequent setup for detecting vehicle speeds was also simple, but it required trial-and-error

settings of the spacing between the microloops. This procedure was not difficult, but it took approximately 4 hours to complete.

Peek VPK Camera. The camera came from Peek ready to install in the field. All adjustments were already made to the camera inside its sealed enclosure. TTI aimed the camera to the position on the roadway as recommended by the vendor on-site.

Peek VideoTrak 900 and VideoTrak for Windows Software. The VideoTrak 900 hardware was relatively easy to set up. The communications port connects to a computer and the video connects to the Peek harness. The VideoTrak for Windows software has documentation on how to install the system hardware and view the digital image. TTI was unable to use the analog video because installers did not have a compatible video capture card in their personal computers (PC). The software configuration was difficult to set up and get the VideoTrak 900 to count vehicles accurately. The software documentation did not include any tips to help the operator configure the many parameters, tracking strips, and detection zones. The Windows™ software was easy to install and use, but it crashed occasionally.

SAS-1 and SAS Monitor and Setup Software. The sensor came with a mounting bracket and could easily be strapped to a pole or mast arm. The aim of the sensor toward the road does not have to be precise. The manual has detailed instructions on how to mount the sensor and on communication cable wiring for connecting to a serial port on a PC running the Windows setup software. The Windows setup software is easy to use and calibration is relatively simple.

Installation Cost

The cost of the total installation process for the two-lane SH 6 site for 3M microloops includes several factors: boring, conduit, ground boxes, microloops, detector amplifiers, and TTI staff time. The total cost for two lanes of installation was $9,900. The cost viability of this system will depend on its stability over a long time period.

The initial cost to TTI for the Peek VideoTrak 900 detection processor was $10,000 with software provided at no cost to TTI. The "normal" cost of the processor would be significantly greater than TTI paid, probably in the range of $20,000. Setup and calibration of the VideoTrak requires a PC (typically a laptop) running the Peek software, but that cost is not included. Staff time to set up and calibrate the system was estimated at $1,500. The camera, lens, housing, cable, and other related component costs were an additional $1,700 for a total of $13,200, assuming a pole or other support is available for the camera.

The current cost of the SmarTek SAS-1 is $3,500. The mounting requirements for the SAS-1 are such that an existing pole typically provides the necessary support. Staff time to install and calibrate the system is minimal. Total installation cost if a pole is available is estimated to be no more than $4,000.

Count Accuracy

Field personnel made almost all of the count accuracy tests in dry weather, with the exception occurring on January 27 when rain fell from 10:30 a.m. to 3:15 p.m. The rain was steady throughout this time interval with periods of intermittent heavier rain. Rain was a probable factor affecting performance accuracy for both the SAS-1 and the VideoTrak. Wet pavement caused the VideoTrak to overcount due to headlight reflections. Very heavy rain could also impair visibility and thus reduce performance. Lighting was a direct factor for only the VideoTrak; it demonstrated reduced accuracy at night and with long vehicular shadows during the daytime. Placement of the camera directly over the lanes might have improved both its day and its night performance, but TxDOT does not typically place cameras over lanes. Speed tests all occurred in dry weather.

Appendices A, B, and C provide graphical results of detector count testing at the TTI test bed in College Station. Because vehicle count error rates go up with small sample sizes for all detectors, the count plots show the time periods of relatively high volumes. They begin at 7:00 a.m. and end at 8:30 p.m. This counting still includes some periods of darkness to demonstrate its effect. The discussions that follow are based primarily on count performance during daylight hours.

3M Microloops. TTI installed microloops at two locations, under the SH 6 main lanes and under the FM 60 bridge. One objective of the microloop evaluation on the FM 60 bridge was to determine its vehicle count accuracy during stop-and-go conditions. This type of traffic occurred each weekday afternoon in the eastbound direction from approximately 4:45 p.m. to 5:15 p.m.

FM 60 Bridge Installation. During this time period of two consecutive days using 5-minute intervals, 13 of the total 14 (93 percent) intervals were within 5 percent error. One of the 14 intervals (7 percent) was between 5 percent and 10 percent error. Appendix A shows the results in graphical format by 5-minute intervals. It should be noted that the total error rates for the total 3-hour, 15-minute combined count period for the two days for each of the three bridge lanes was 1.21 percent in the eastbound (EB) left lane, 0.13 percent in the EB right lane, and 1.50 percent in the westbound (WB) lane. These rates reflect extremely accurate and consistent counts across all three lanes. Combining all three lanes and all monitored intervals, the microloops were within 5 percent 71.0 percent of the time and within 10 percent 93.2 percent of the time. Table 2 provides a summary of error rates tabulated by lane for both count periods.

A second objective for the bridge testing was to evaluate microloop performance in the vicinity of ferrous metal since the probe uses changes in the earth's magnetic field to detect vehicles. 3M informed the authors that vertical ferrous metals might affect performance, whereas horizontal metals generally would not. The FM 60 bridge beams had vertical reinforcing steel, but probes were placed as close as one foot from these beams without apparent degradation of performance. 3M information suggests that each bridge is

unique due not only to steel placement but to its orientation relative to the earth's magnetic flux lines.

SH 6 Installation. It should be noted that the right lane had dual probes and the left lane had single probes. Therefore, smaller relative error rates were expected in the right lane. Also, even though the SH 6 pavement structure included continuous reinforcing steel, it was oriented primarily horizontally and should not have significantly reduced probe performance. Table 3 is a summary of error rates for all the dry plus wet weather day and night counts. Researchers evaluated the wet and dry weather data from the other two detectors separately since rain could affect performance. As expected, the microloop system was not affected by rain.

Appendix A shows graphical results of field tests for 3M count accuracy. The 3M detector was the only one of the three that was not affected by rain in count tests (see error plots for January 27, 2000). The data show that, for a six-day count period, the 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. These two were within 10 percent of baseline. 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 1.0 percent were over 10 percent different from baseline.

**Table 2. 3M Microloop Count Error Rates on FM 60 Bridge
for December 15 & 16, 1999.**

Error Range (%)	Lane		
	EB Right	EB Left	WB
0 to 5	27 of 39 (69.2 %)	33 of 39 (84.6 %)	22 of 39 (56.4 %)
5 to 10	11 of 39 (28.2 %)	6 of 39 (15.4 %)	10 of 39 (25.6 %)
10 to 15	1 of 39 (2.6 %)	0	5 of 39 (12.8 %)
15 to 20	0	0	2 of 39 (5.2 %)

Table 3. 3M Microloop Count Error Rates on SH 6.

Error Range (%)	Lane	
	Left	Right
0 to 5	404 of 432 (93.5 %)	430 of 432 (99.5 %)
5 to 10	25 of 432 (5.8 %)	2 of 432 (0.5 %)
10 to 15	3 of 432 (0.7 %)	0

Peek VideoTrak 900. Count accuracy for the VideoTrak was significantly worse after dark compared to accuracy during daylight hours. Therefore, the results in Table 4 represent the time periods between 7:00 a.m. and 5:30 p.m. Plots in Appendix B show the VideoTrak's performance after dark as well. Appendix D also shows a plot of rainfall intensity generated by the test bed's weather station to correlate detector count performance with rainfall. The drop in accuracy indicated by Table 5 for the Peek 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.

Table 4. VideoTrak Daytime Count Error Rates on SH 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

Table 5. VideoTrak Daytime Count Error Rates on SH 6 During Wet Weather.

Error Range (%)	Lane	
	Left	Right
0 to 10	6 of 18 (33.4 %)	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 %)

SAS-1 by SmarTek. 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 6 and 7 below. It should be noted that the vendor, who was involved on-site in the initial setup, discovered an error in the lane sensitivity setting that probably accounted for the undercounting that occurred during rain. Increasing the sensitivity probably solved the problem, but there was no other wet weather to verify the assumed improvement. Appendix C graphically shows the results, and Appendix D shows a plot of rainfall along with count accuracy to allow correlation of performance with rainfall intensity.

Table 6. SAS-1 Count Error Rates on SH 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

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Table 7. SAS-1 Count Error Rates on SH 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 %)

Speed Accuracy

Results of selected speed comparisons for the 3M microloop, the VideoTrak 900 and the SmarTek SAS-1 are provided below. Comparisons of means and standard deviations of sample sets provide the primary basis of comparison, along with what is provided in Appendices E, F, and G. The line plots shown in these appendices are least squares regression lines for the two categories of "Full Data Set" and "Partial Data Set." The partial data set eliminates one-minute intervals in which the number of vehicles detected by each detector are different for that interval. Analysts also plotted speed differences by time of day, but detected no discernable trends except in rain data as discussed below. Both the R-square values and the mathematical expression for the regression line indicate poor correlation between the test systems and the baseline speed system except for the partial plot of microloop speeds from May 1, 2000. One reason for this poor result for other data sets is the narrow range of speeds, predominantly from 60 mph to 75 mph. If sufficient speeds on the low end of the scale had occurred, the prediction of true speeds by test systems would have been better. Finally, it should be noted that all of the test detectors occasionally, for no known reason, generated anomalous speeds, including the RTMS. In fairness to test systems, those data samples were eliminated in which the baseline RTMS speed data were erroneous.

3M Microloops. Soon after the initial installation, TTI installers discovered that with "power line filtering" enabled, speed measurements were erratic. After this feature was disabled, speed measurements improved. The comparison used mean values of one-minute intervals of the baseline RTMS detector compared against the same one-minute intervals of the 3M detector (only in the right lane where two detectors per lane per station were available). Figure 7 is a histogram of speed differences between the 3M and the RTMS. The mean value of this sample was –0.25 mph, which reflects very close calibration, and the standard deviation was 3.6 mph. By view of the Normal Probability plot, these results suggest that microloops will predict one-minute interval average speeds within plus or minus 7.3 mph 95 percent of the time. Speed test comparisons of the 3M microloops against the RTMS indicated that, of the three detectors tested, the 3M product was closest to the RTMS. Appendix H shows performance of all three detectors during rain on May 1, 2000, as measured by TTI's weather station at the site. It was set to record rainfall in 15-minute intervals. The plotted data begin at 7:45 a.m. and end at 1:45 p.m. Sunrise was at 6:41 a.m. on that morning with sunset at 8:04 p.m. As expected, microloop performance did not change during the rain.

Peek VideoTrak 900.   Speed results for the VideoTrak indicate a mean of +1.4 mph and a standard deviation of 6.9 mph. Because speeds, as well as counts, were significantly worse during nighttime hours (due probably to no street lighting), no data for those hours are provided. The data and results are for dry, daylight conditions except for May 1, 2000, as shown in Appendix H. Appendix H shows that performance of the VideoTrak during rain was worse than depicted in Figure 8. The histogram below also shows that the data are more dispersed about the sample mean than for the other two devices tested. The mean value also indicates speed bias on the high side. The tall bar at the extreme right on Figure 8 shows the frequency of speeds that are over 14 mph.

SAS-1 by SmarTek. Figure 9 is an example of speed test results in dry weather. Appendix H shows results during rain, indicating that on May 1, 2000, the SAS-1 speeds increased by approximately 10 mph compared to both the RTMS and the 3M microloops. The mean value of the speed data plotted in Figure 9 is –0.5 mph (based on post-calibration), and the standard deviation is 4.84 mph. This accuracy is very close to that of the 3M microloops, with slightly higher standard deviation. By view of the Normal distribution, these results suggest that the SAS-1 will predict one-minute interval average speeds within plus or minus 10 mph 95 percent of the time.
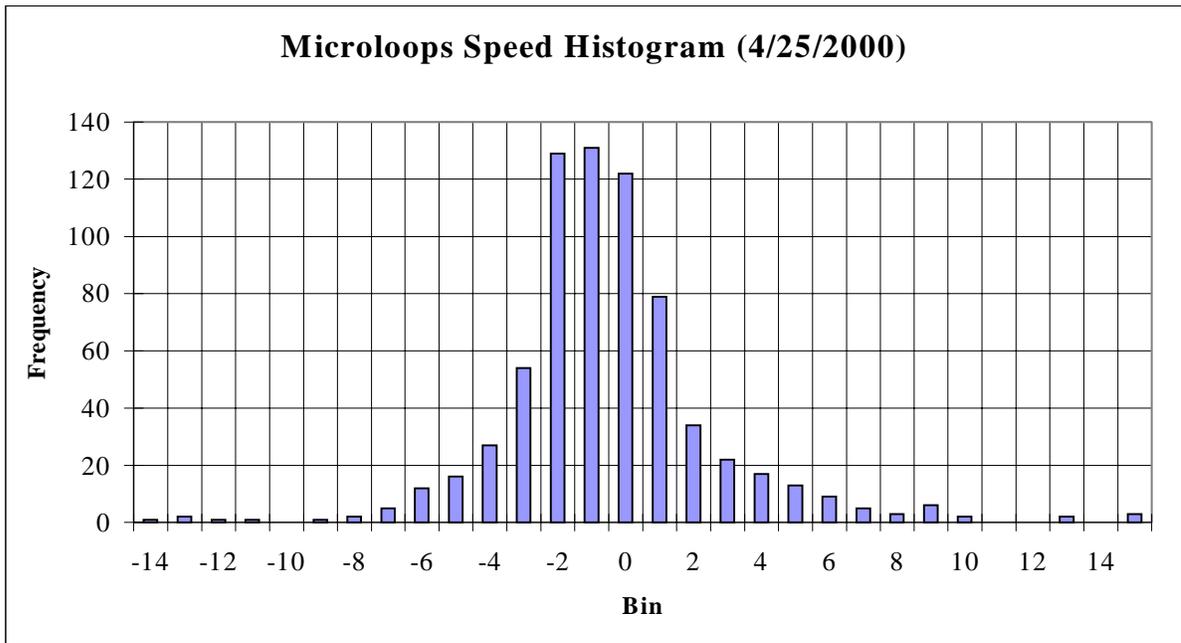
Figure 7. Example Microloop Speed Histogram.
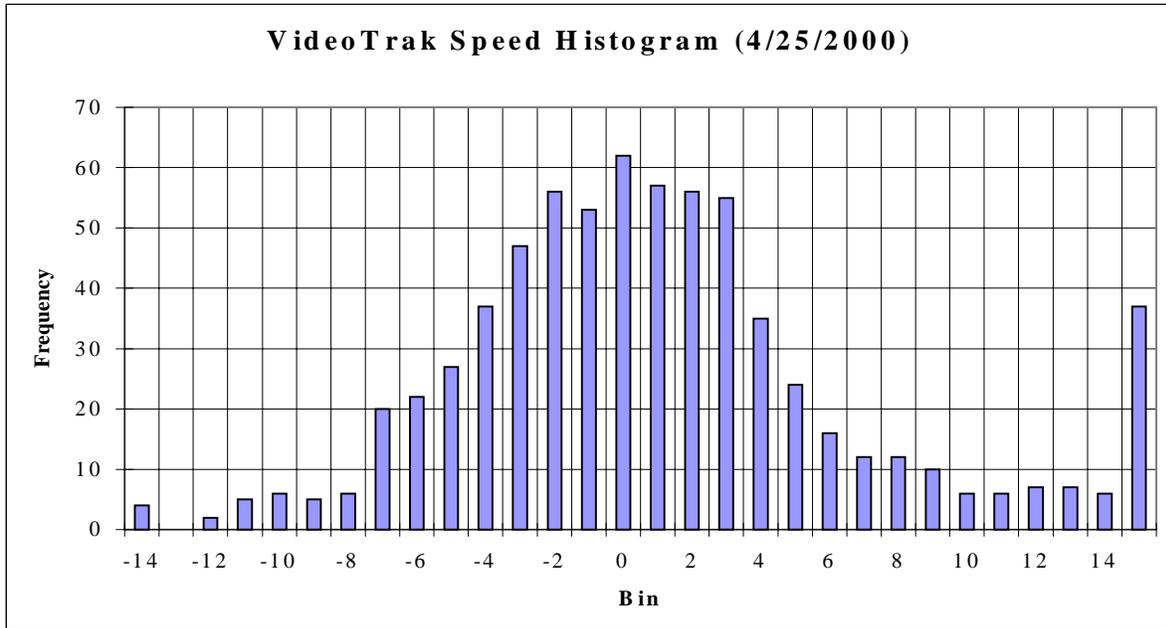
Figure 8. Example VideoTrak Speed Histogram.
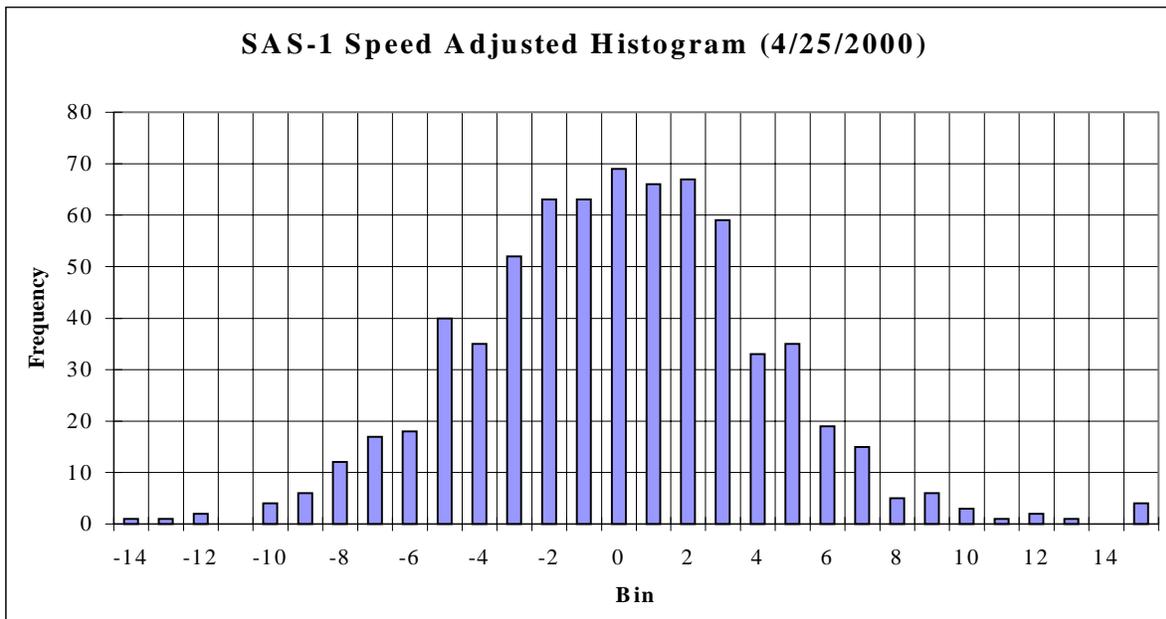
Figure 9. Example SAS-1 Speed Histogram.

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CONCLUSIONS

The purpose of this research was to screen selected devices to determine their merit. Traffic volumes at the TTI test bed were light to moderate, especially on SH 6, so promising devices should be tested longer term and under more challenging conditions. This could include heavier traffic volumes (all devices), stop-and-go traffic (acoustic), on structures (acoustic), under different bridges (3M microloop), or in other conditions yet to be determined. The following list of findings is essential in the decision regarding whether to pursue further testing of any or all of the test systems.

Count and Speed Accuracy

- In a sample of 70 carefully selected individual vehicle comparisons, 53 percent of the RTMS speeds were within 0 or 1 mph of the laser speeds. Fourteen percent differed by 2 mph, while 3 percent differed by 3 mph. None were different by more than 3 mph.
- In this same data set, aggregating data into samples of 10 and comparing means between RTMS and a laser speed detector revealed differences that were usually less than 1 percent and never more than 2 percent.
- The 3M microloop was the only one of the three test detectors unaffected by rain; it also demonstrated the best speed accuracy of the three systems being tested.
- The 3M microloop performed better both on the bridge and on SH 6 when two probes were used in each lane compared to one probe in each lane.
- The VideoTrak and the SAS-1 demonstrated significantly worse speed performance during wet weather; the VideoTrak was more erratic, and the SAS-1 speeds increased by 10 mph compared to those measured during dry conditions.
- The VideoTrak performance at night was unacceptable, due at least in part to no street lighting.
- The plotted histograms suggest that the 3M and the SAS-1 predict speed within 8 mph and 11 mph, respectively, 95 percent of the time.

Ease of Setup and Calibration

- The VideoTrak was by far the most difficult system to set up and calibrate. Some public agencies will find this difficulty a serious impediment to using this detector.
- Both the 3M microloop/Canoga system and the SmarTek SAS-1 had reasonably user-friendly interfaces and provided the needed functionality for setup, calibration, and downloading of data (except that the SAS-1 needs a speed calibration algorithm added).

Installation Cost

- The installation cost of the SAS-1 was significantly less than that for either of the other two systems. Its cost is attractive on a per-lane basis, since it can monitor up to five lanes.
- For the two-lane SH 6 site, the 3M microloop system cost $9,900, the VideoTrak system cost $13,200, and the SAS-1 system cost $4,000.

Other Considerations
- It is critically important that each detector be set up properly to optimize performance. The novice installer could easily think that a detector is set up properly but get poor performance due to the improper setup. This problem is common with new technologies, especially if they are complex.
- In real-world operations, an agency must filter out anomalous speed data to avoid meaningless alarms being generated. All of the test detectors occasionally generated anomalous speeds, including the RTMS. There were seven one-minute intervals in an example day's data set where the RTMS generated anomalous data.
- During loss of power, the VideoTrak required being physically reset for it to resume operation.
- The shallow installation depth recommended by 3M is a constraint to its use in many locations unless it can be integrated into the initial construction process.
- A diamond-shaped warning sign near the SAS-1 acoustic detector initially caused the detector to double-count vehicles, apparently due to sounds reflected from the sign. Re-positioning the detector solved the problem.

Based on these findings related to count and speed accuracy, cost, and ease of setup and calibration, the authors believe that the 3M microloops and the SAS-1 are acceptable for monitoring traffic under low to moderate free-flow traffic. Limited testing indicated good performance of the 3M microloops under stop-and-go traffic on the FM 60 bridge. The SAS-1 still needs to be tested in stop-and-go traffic. The authors, therefore, recommend the following:

- further evaluation of the 3M microloop and the SAS-1, to include life-cycle costs, and
- evaluating the feasibility of installing the 3M microloop system at greater depths since horizontal boring at the manufacturer's recommended depth of 21 inches (plus or minus 3 inches) could cause roadway damage.

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2.   Minnesota Department of Transportation - Minnesota Guidestar and SRF Consulting Group, *Field Test of Monitoring of Urban Vehicle Operations Using Non-Intrusive Technologies*, Volume 5, Task Three Report: Extended Field Tests, Minnesota Department of Transportation - Minnesota Guidestar, St. Paul, MN, and SRF Consulting Group, Minneapolis, MN, December 1996.

3.   J. Kranig, E. Minge, and C. Jones, *Field Test of Monitoring of Urban Vehicle Operations Using Non-Intrusive Technologies*, Report Number FHWA-PL-97-018, Minnesota Department of Transportation - Minnesota Guidestar, St. Paul, MN, and SRF Consulting Group, Minneapolis, MN, May 1997.

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6.   D. Middleton, D. Jasek, and R. Parker, *Evaluation of the Existing Technologies for Vehicle Detection*, Research Project 0-1715, Research Report 1715-S, Texas Transportation Institute, College Station, TX, September 1999.

APPENDIX A

3M Microloop Error Plots
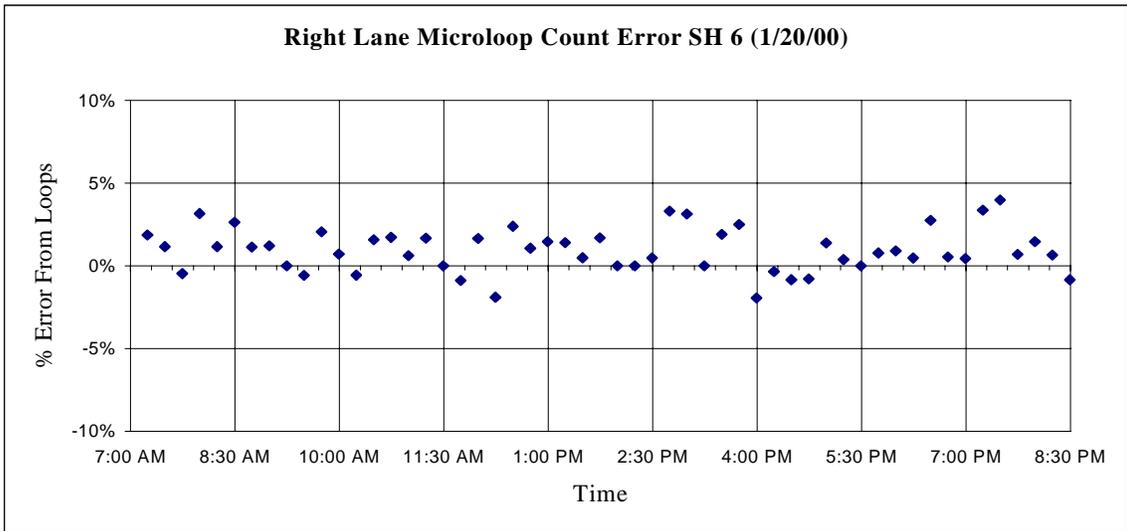
Figure A-1. 3M Microloop 15 Minute Percent Error Right Lane (1/20/00).
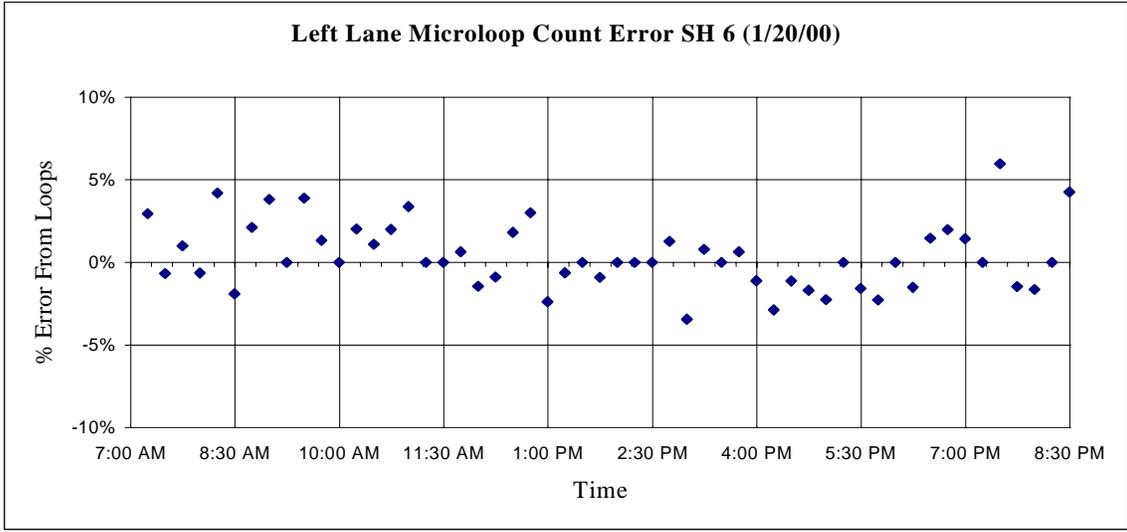
Figure A-2. 3M Microloop 15 Minute Percent Error Left Lane (1/20/00).
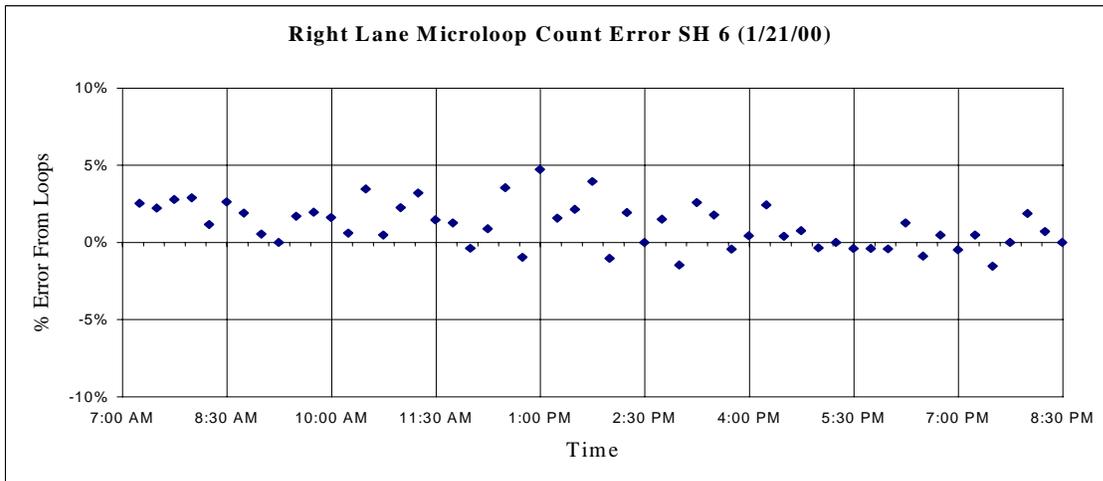
Figure A-3. 3M Microloop 15 Minute Percent Error Right Lane (1/21/00).
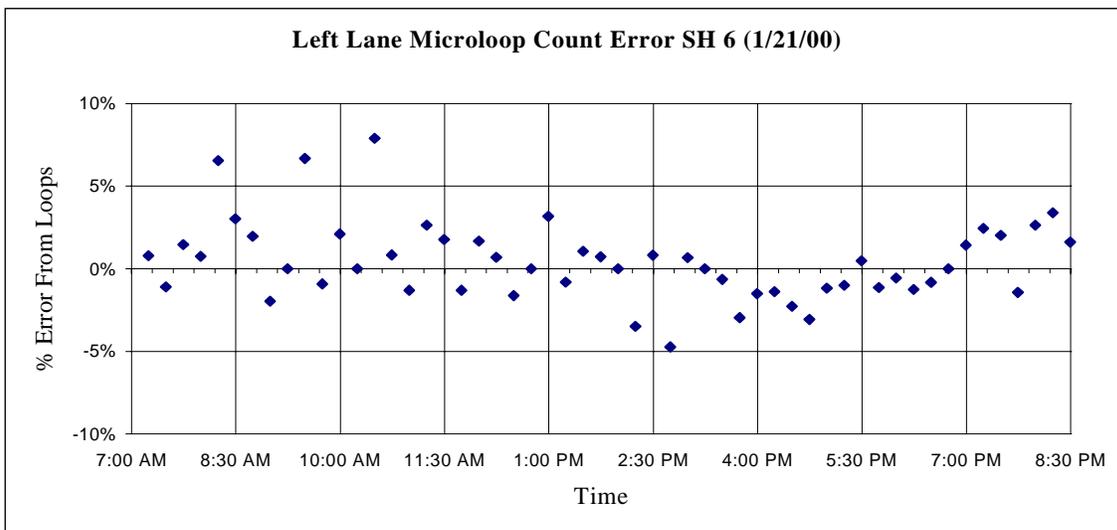
Figure A-4. 3M Microloop 15 Minute Percent Error Left Lane (1/21/00).

30
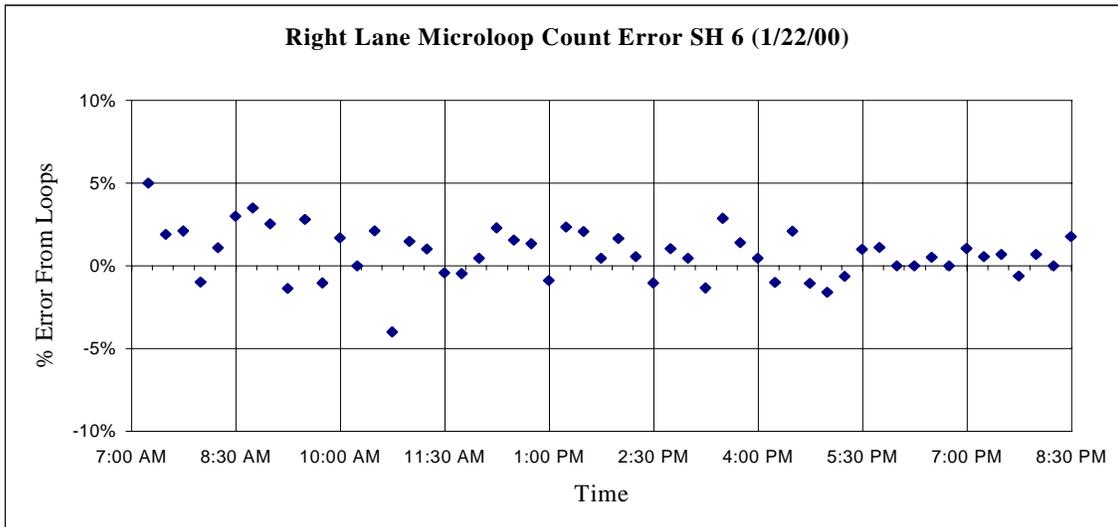
Figure A-5. 3M Microloop 15 Minute Percent Error Right Lane (1/22/00).
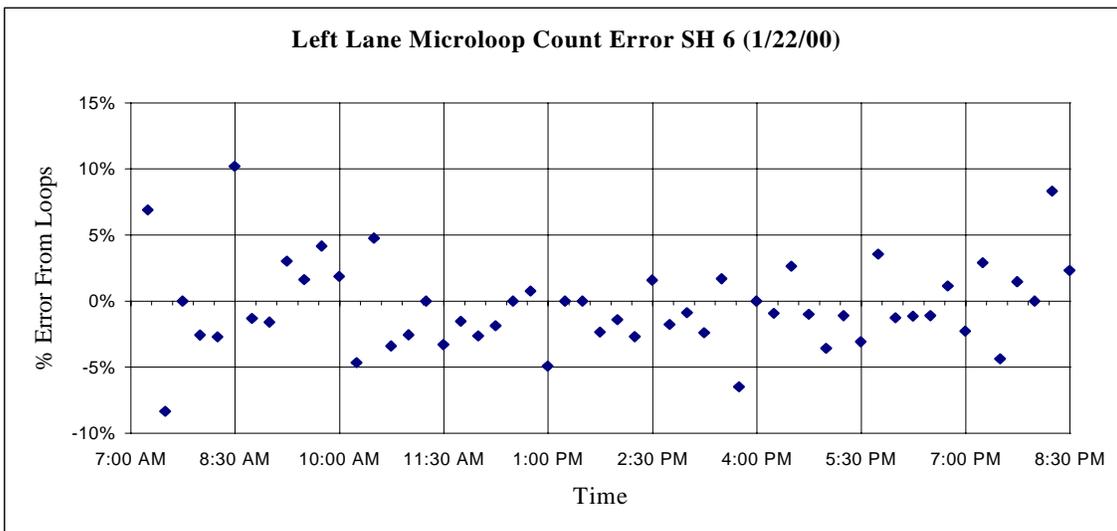
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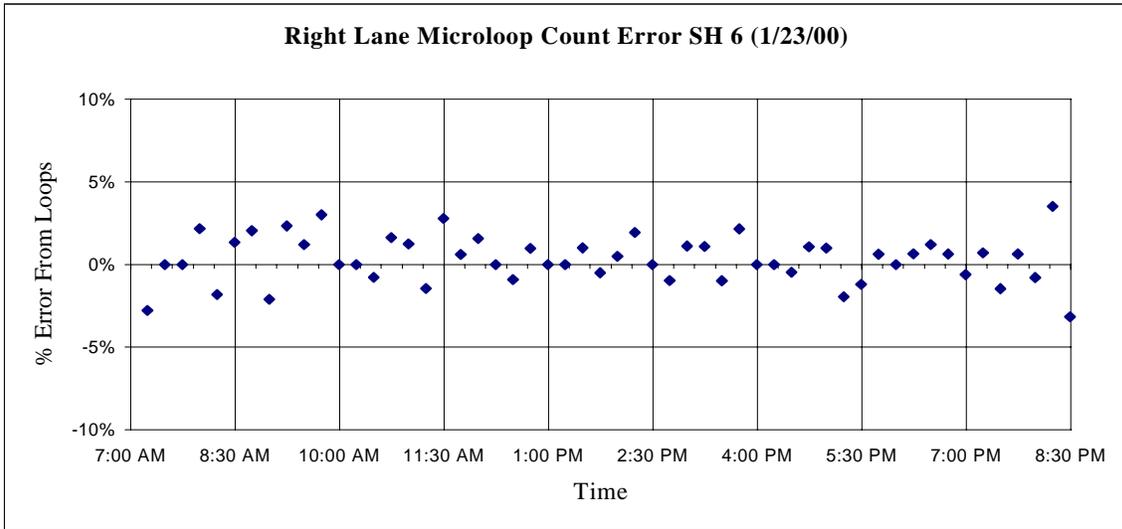
Figure A-7. 3M Microloop 15 Minute Percent Error Right Lane (1/23/00).
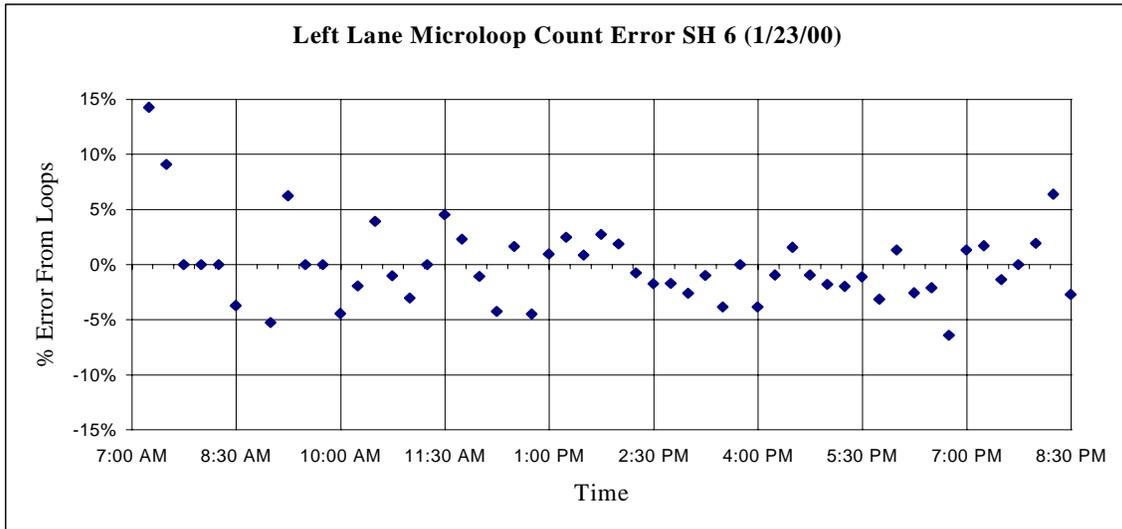
Figure A-8. 3M Microloop 15 Minute Percent Error Left Lane (1/23/00).
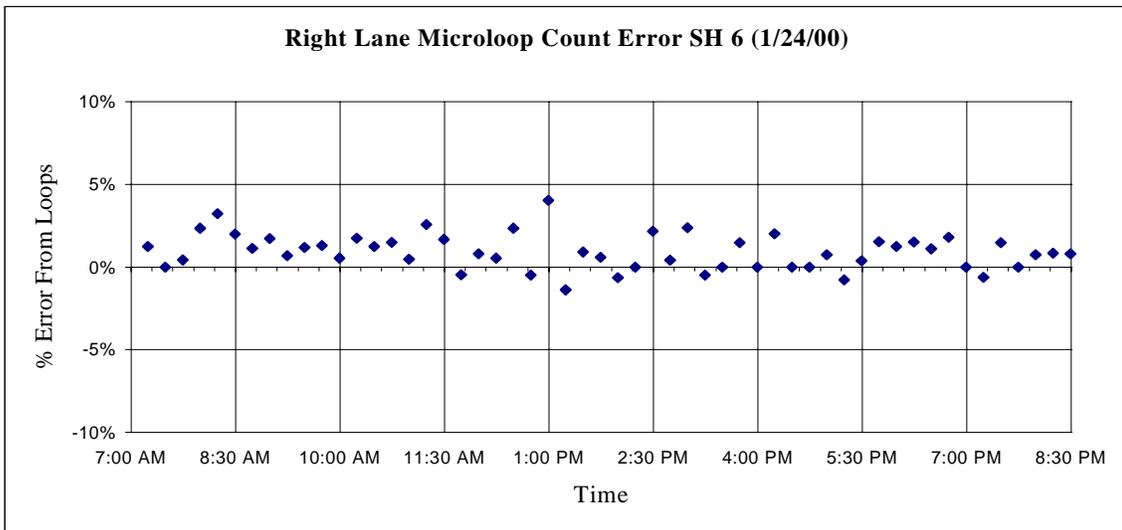
Figure A-9. 3M Microloop 15 Minute Percent Error Right Lane (1/24/00).
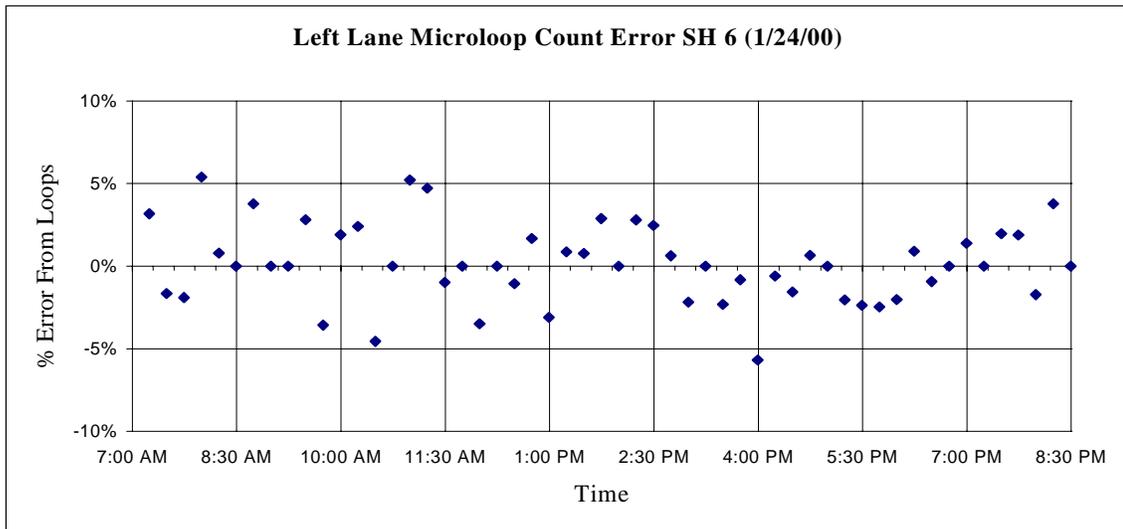
Figure A-10. 3M Microloop 15 Minute Percent Error Left Lane (1/24/00).

33
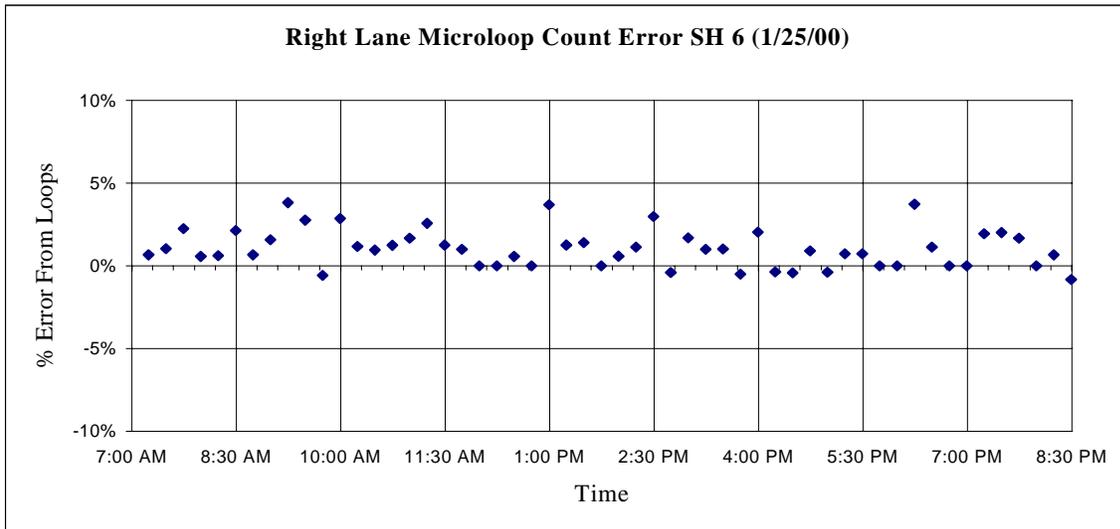
Figure A-11. 3M Microloop 15 Minute Percent Error Right Lane (1/25/00).
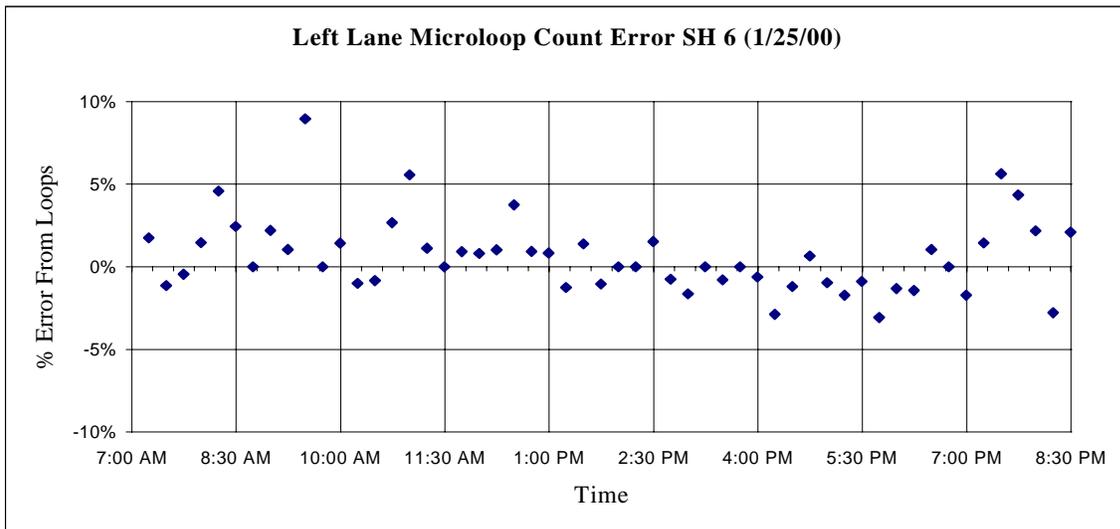
Figure A-12. 3M Microloop 15 Minute Percent Error Left Lane (1/25/00).

34
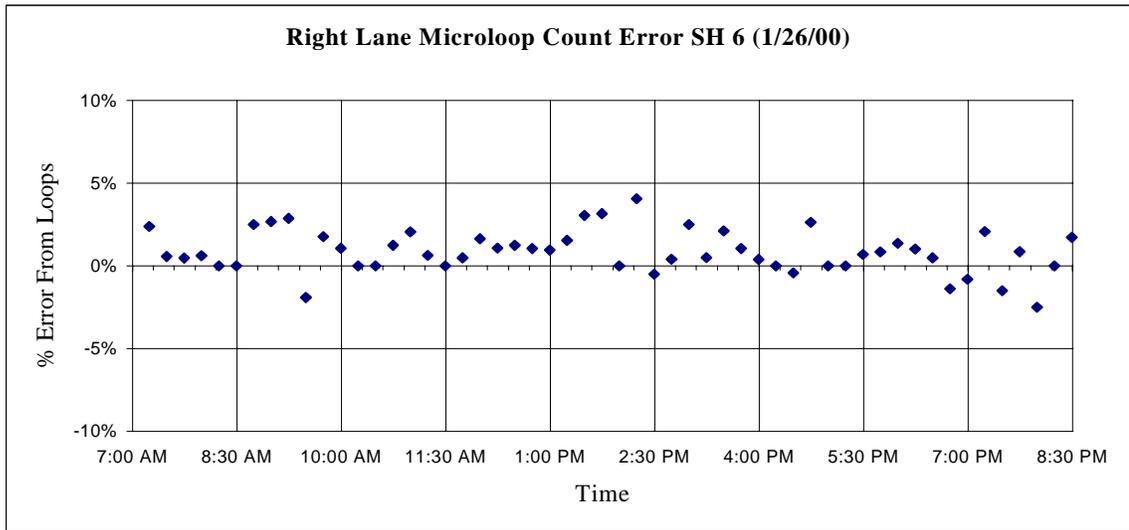
Figure A-13. 3M Microloop 15 Minute Percent Error Right Lane (1/26/00).
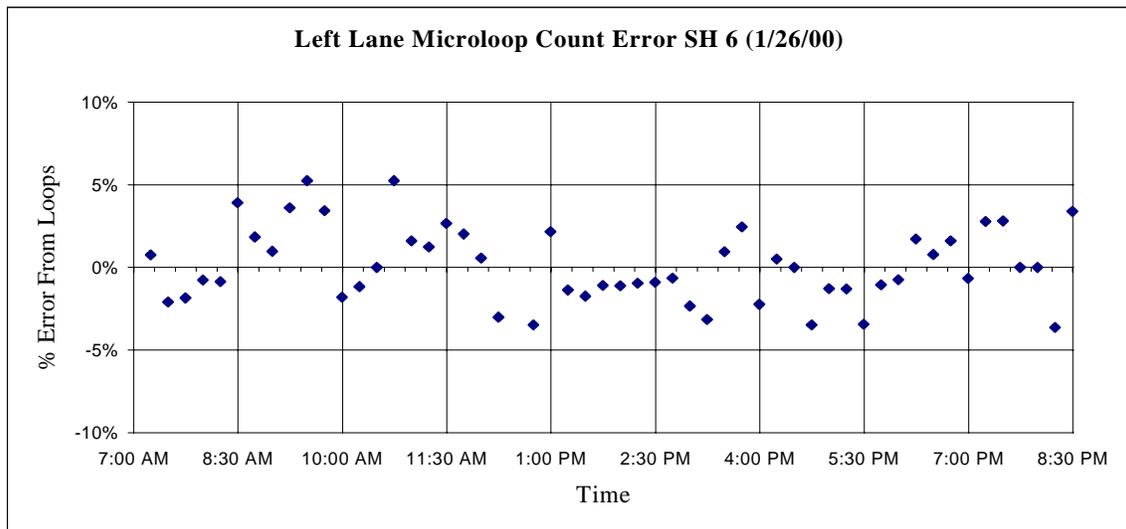
Figure A-14. 3M Microloop 15 Minute Percent Error Left Lane (1/26/00).

35
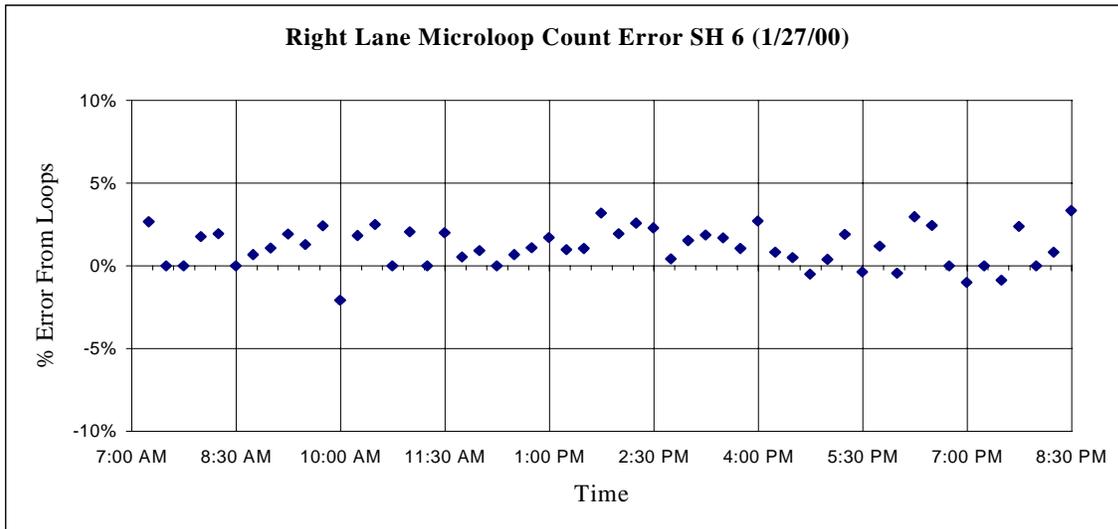
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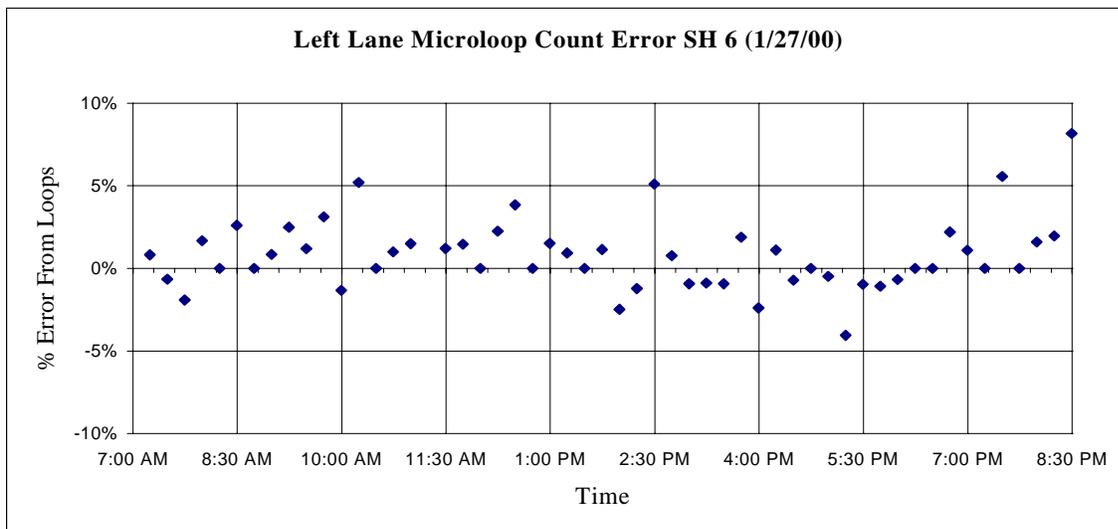
Figure A-16. 3M Microloop 15 Minute Percent Error Left Lane (1/27/00).

APPENDIX B

Peek VideoTrak Error Plots
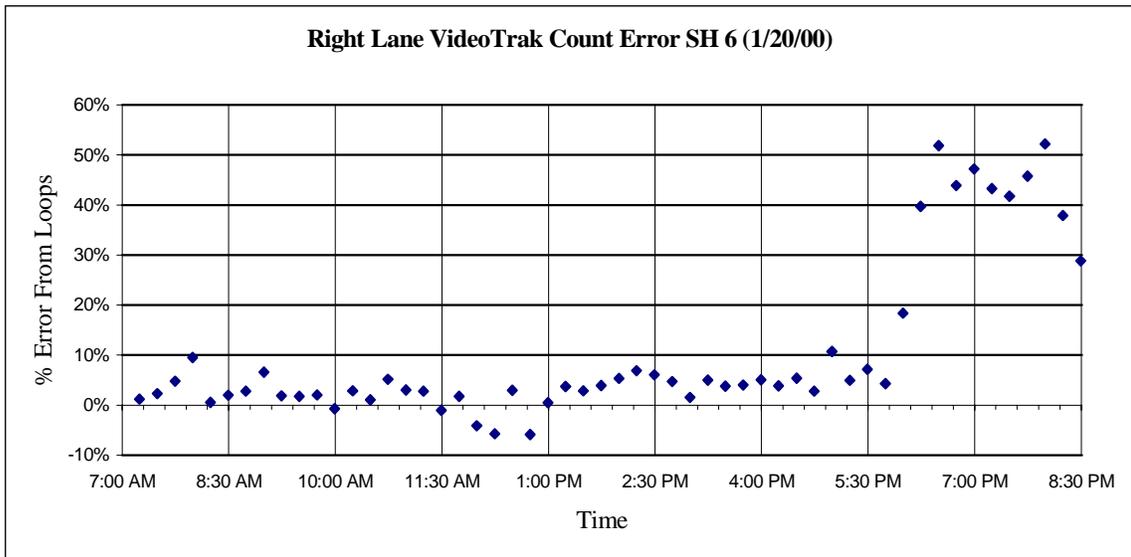
Figure B-1. VideoTrak 15 Minute Percent Error Right Lane (1/20/00).
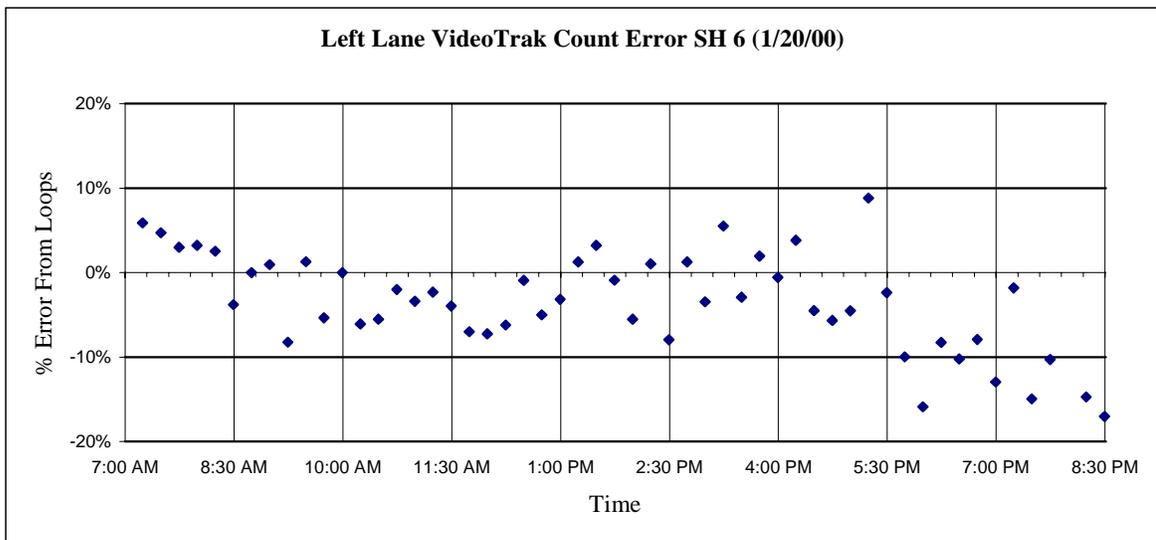
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39
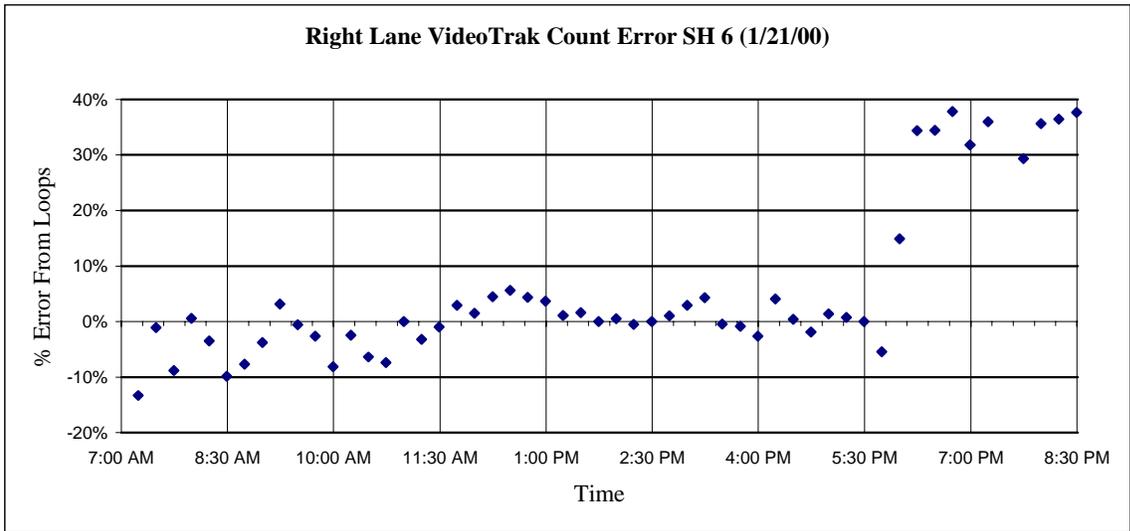
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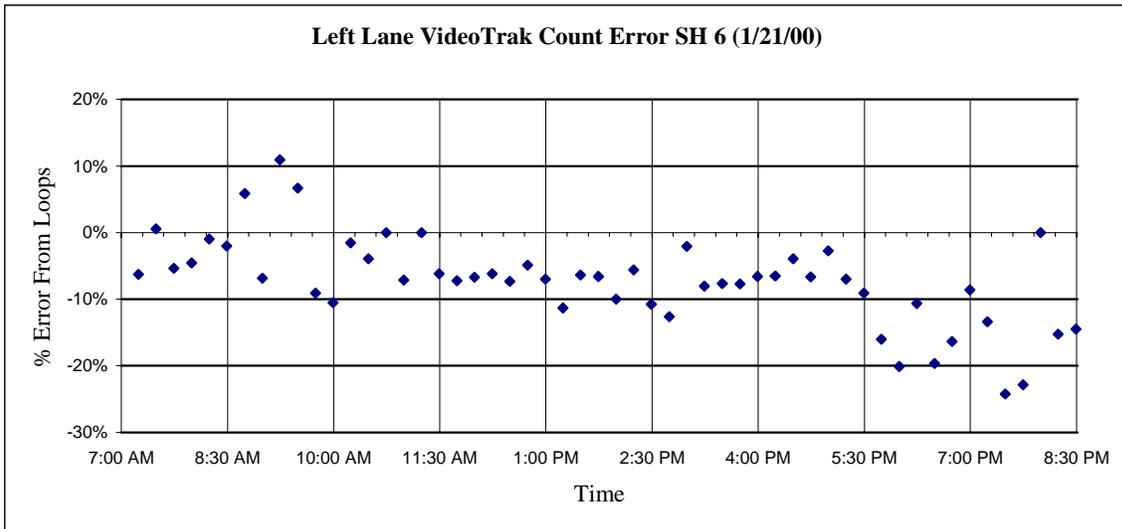
Figure B-4. VideoTrak 15 Minute Percent Error Left Lane (1/21/00).
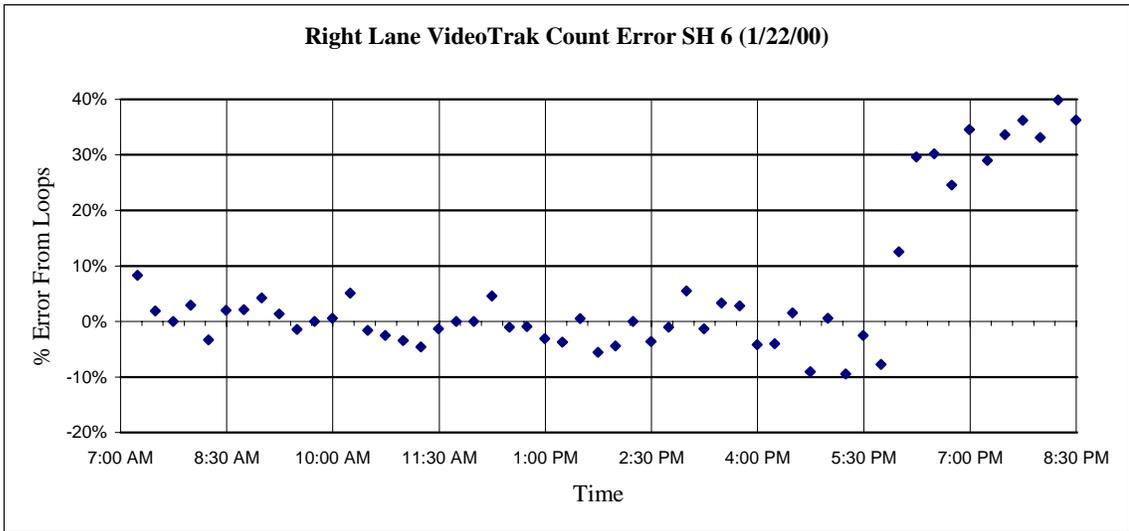
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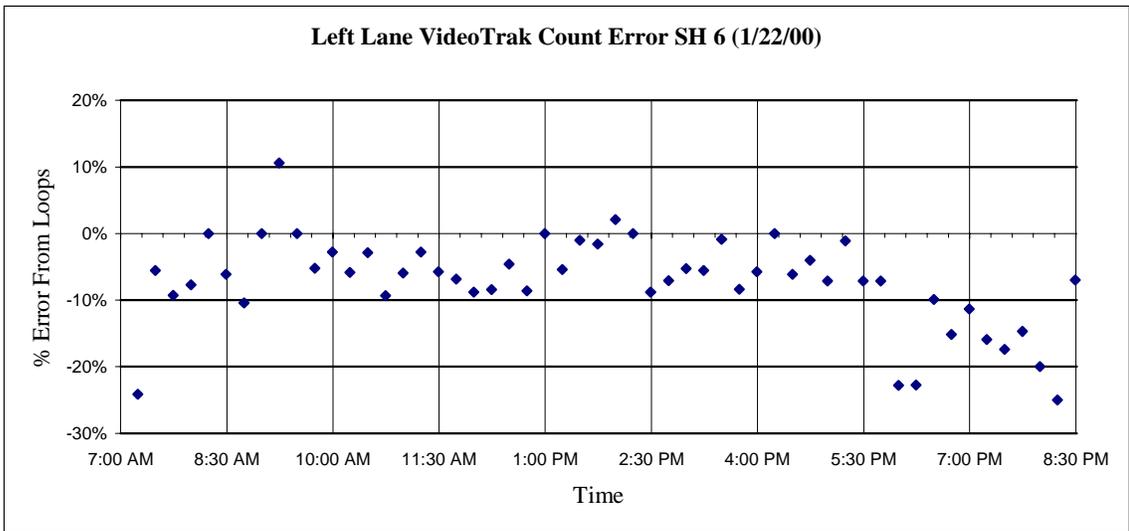
Figure B-6. VideoTrak 15 Minute Percent Error Left Lane (1/22/00).

41
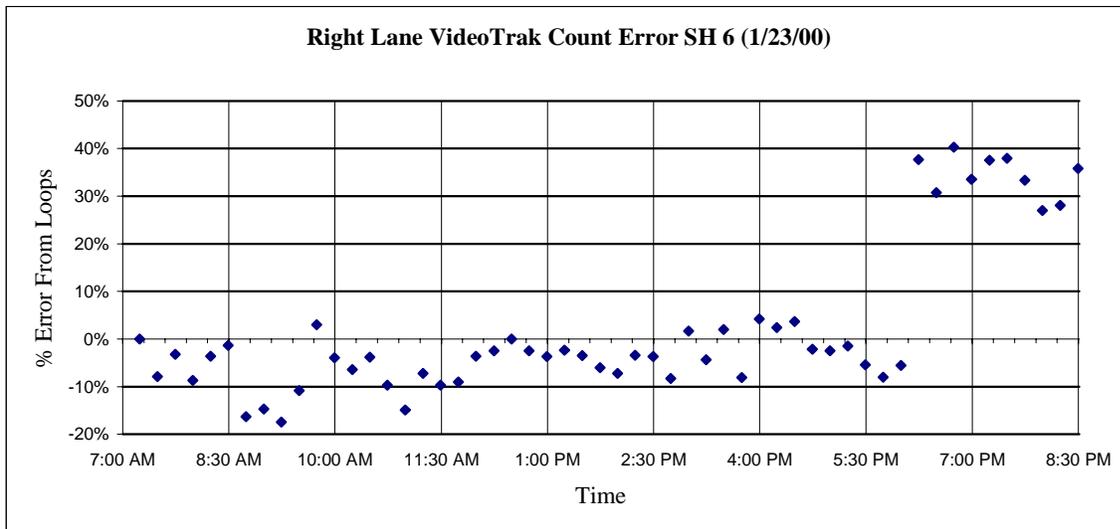
Figure B-7. VideoTrak 15 Minute Percent Error Right Lane (1/23/00).
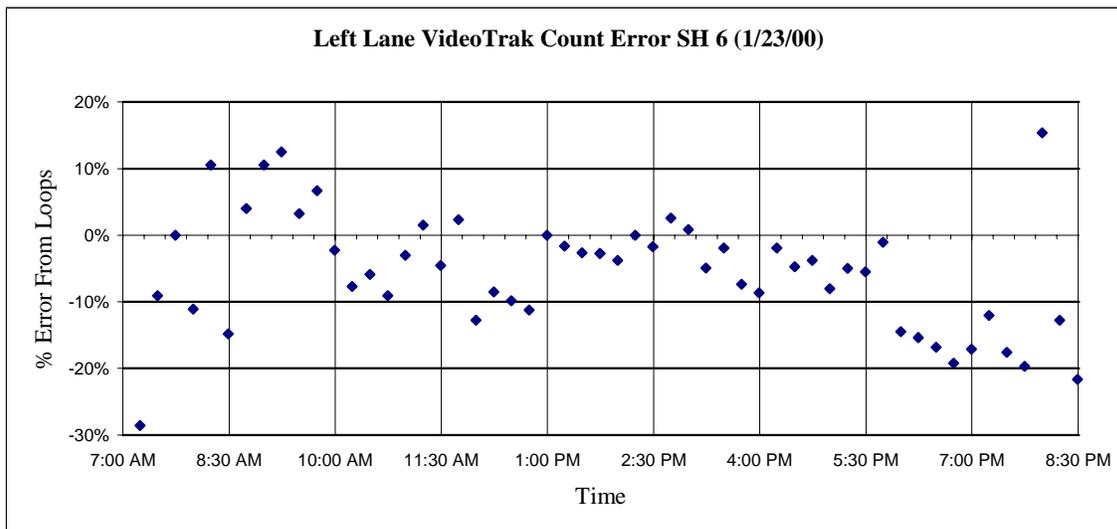
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42
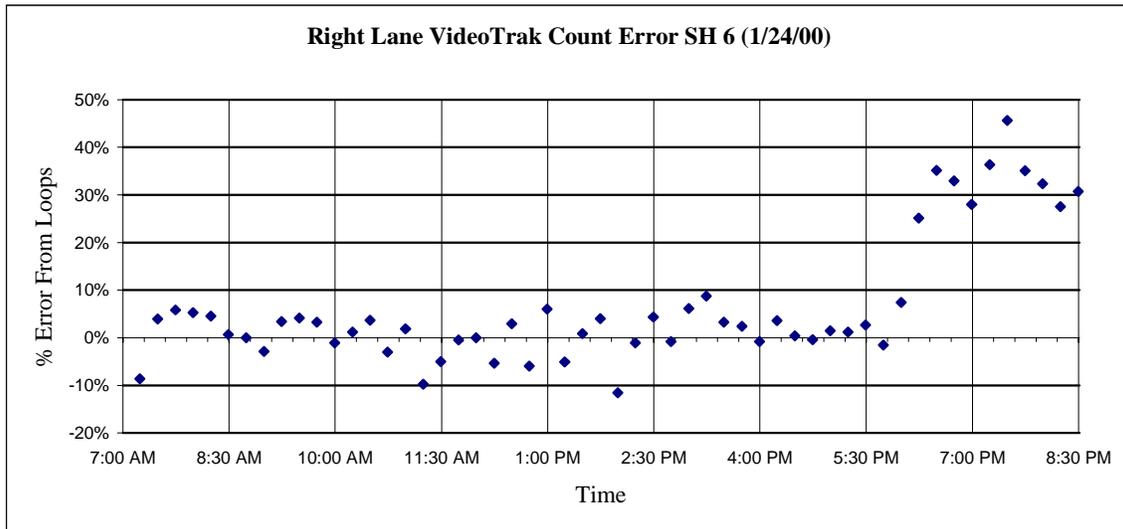
Figure B-9. VideoTrak 15 Minute Percent Error Right Lane (1/24/00).
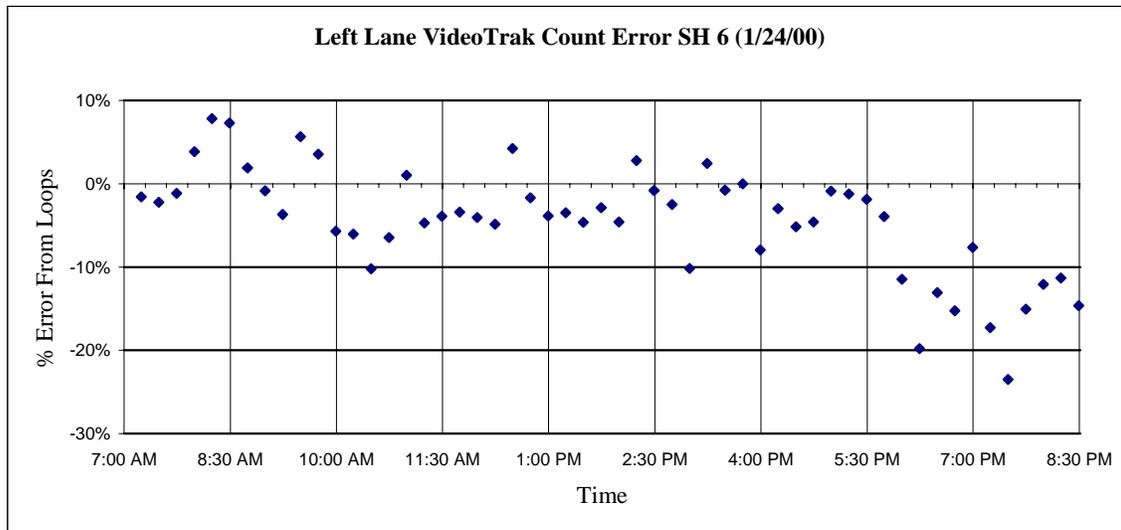
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43
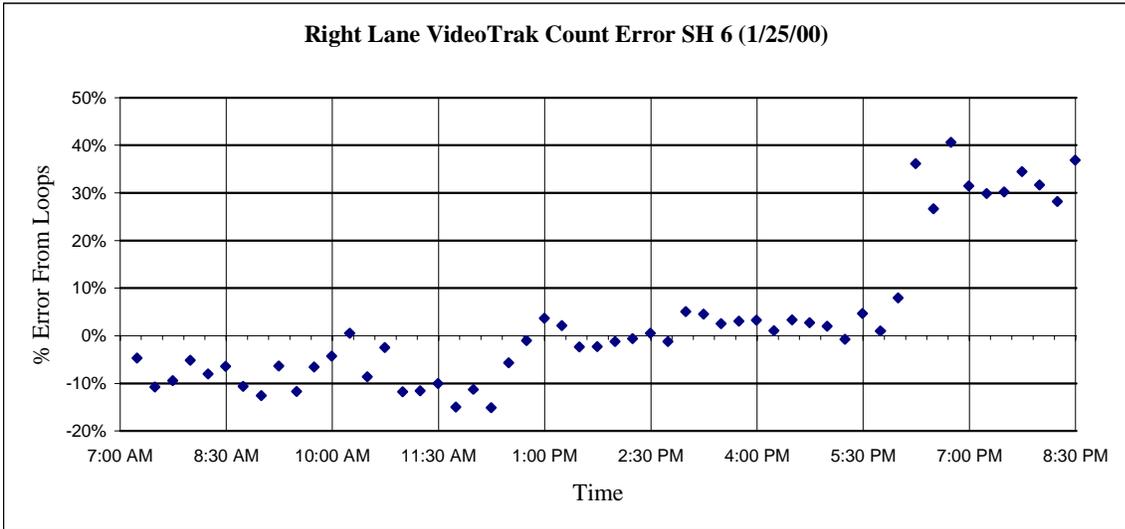
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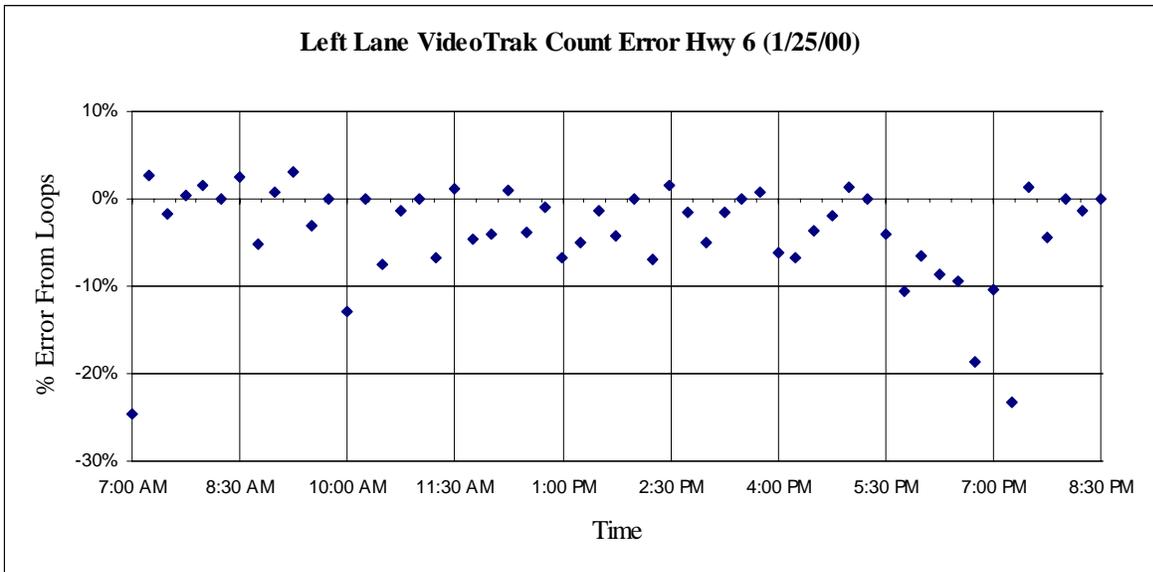
Figure B-12. VideoTrak 15 Minute Percent Error Left Lane (1/24/00).

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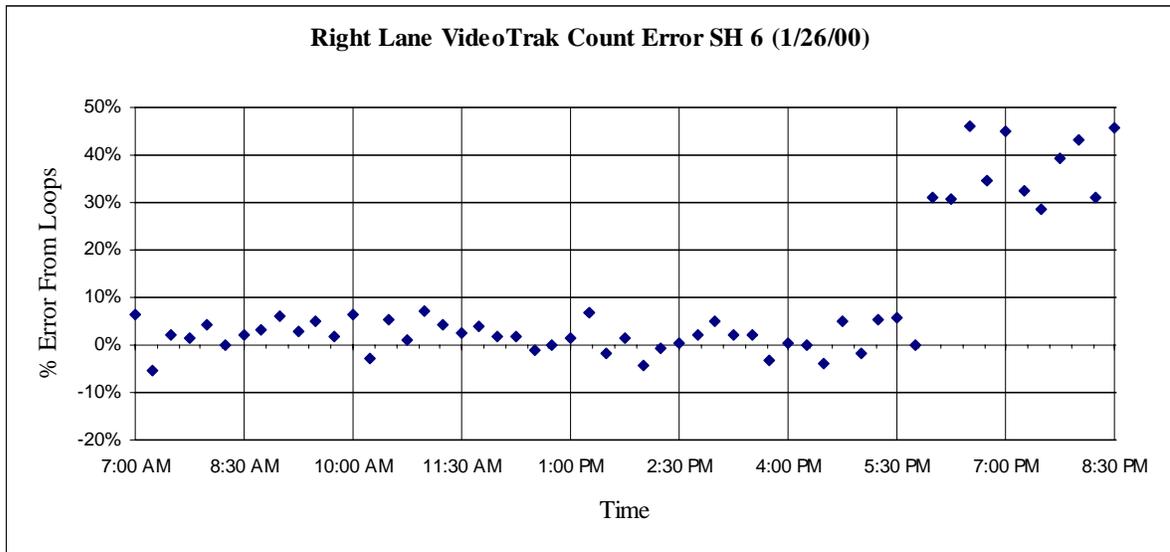
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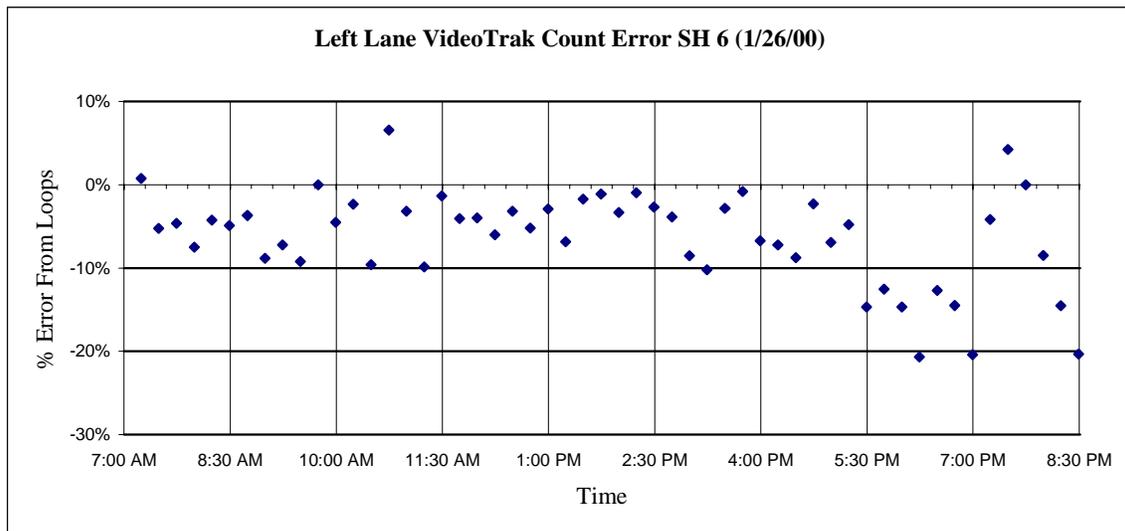
Figure B-14. VideoTrak 15 Minute Percent Error Left Lane (1/26/00).

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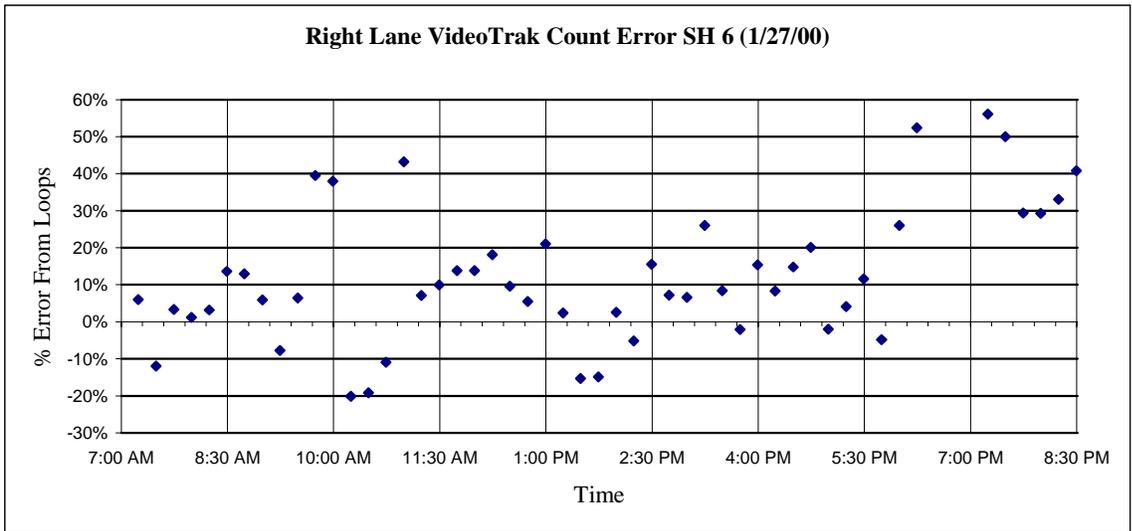
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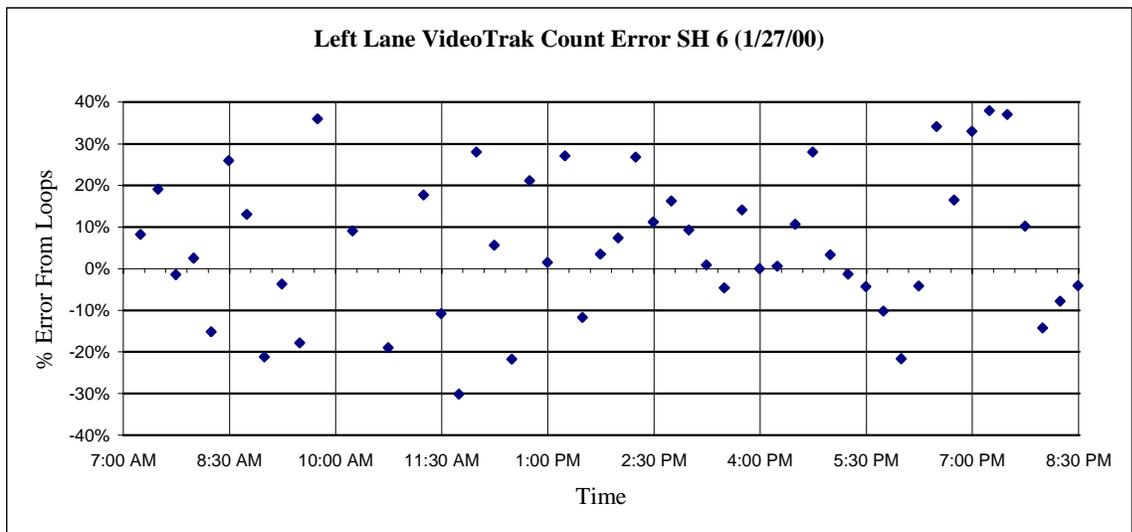
Figure B-16. VideoTrak 15 Minute Percent Error Left Lane (1/27/00).

46
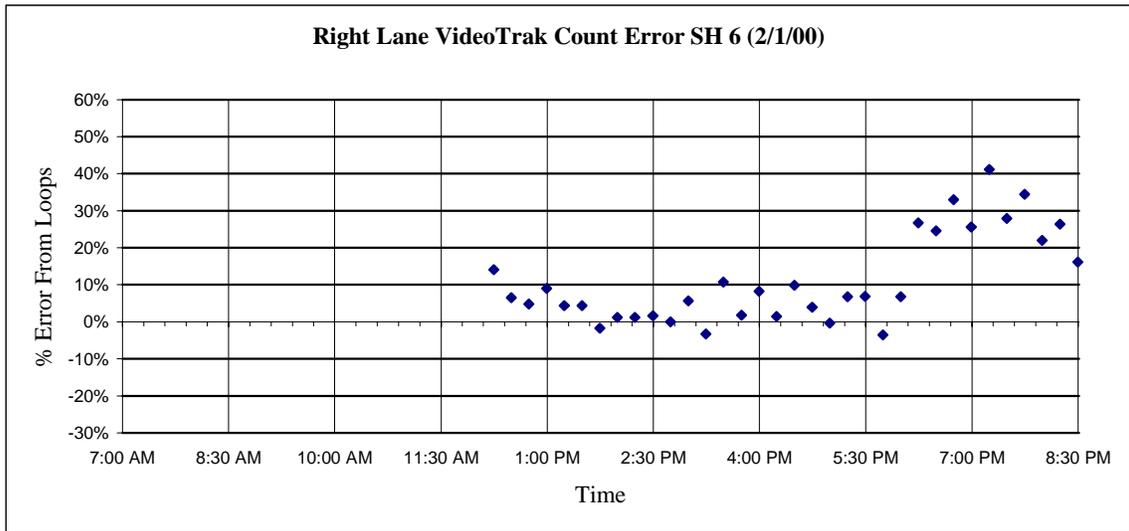
Figure B-17. VideoTrak 15 Minute Percent Error Right Lane (2/1/00).
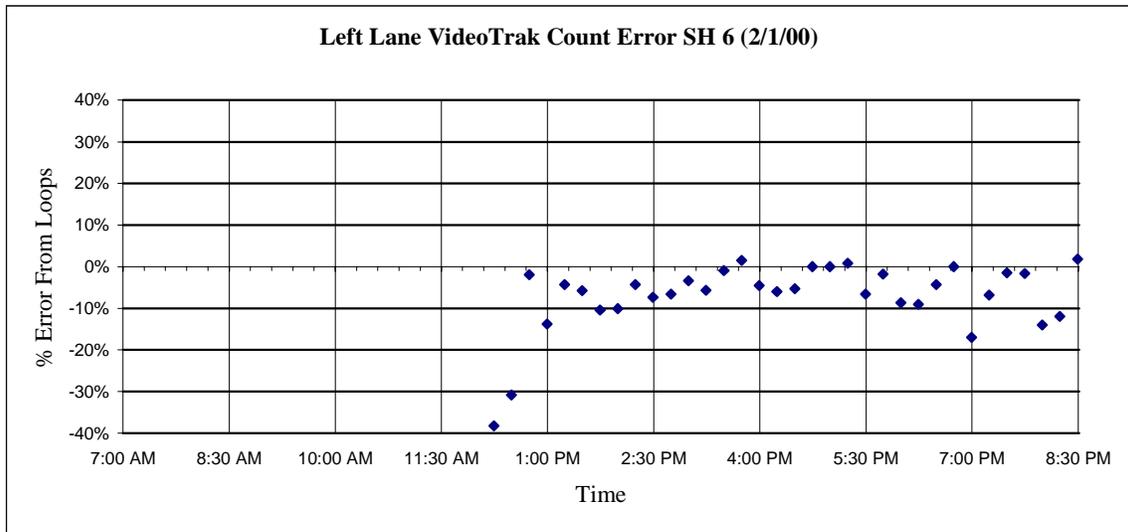
Figure B-18. VideoTrak 15 Minute Percent Error Left Lane (2/1/00).

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APPENDIX C

SAS-1 Error Plots
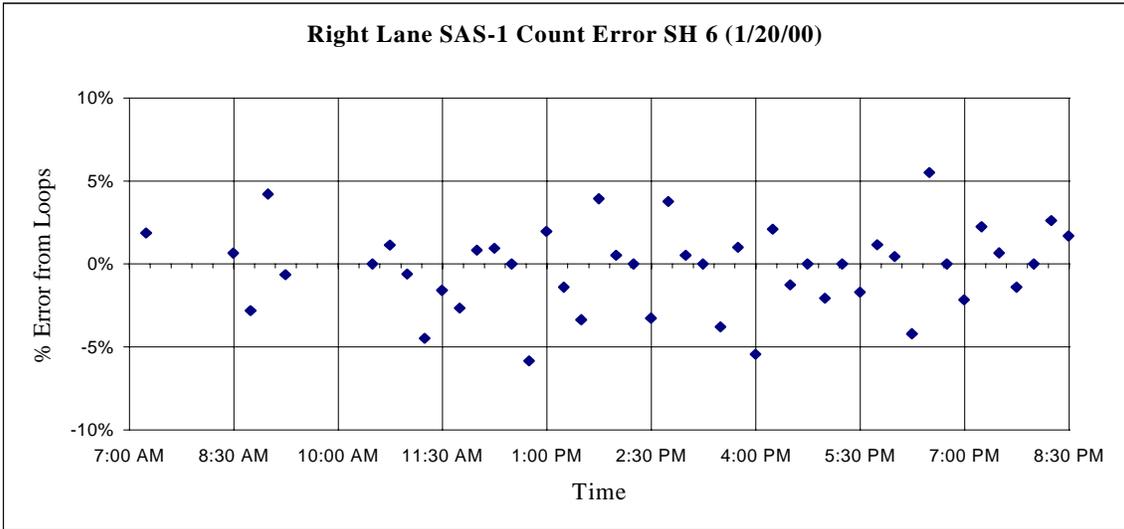
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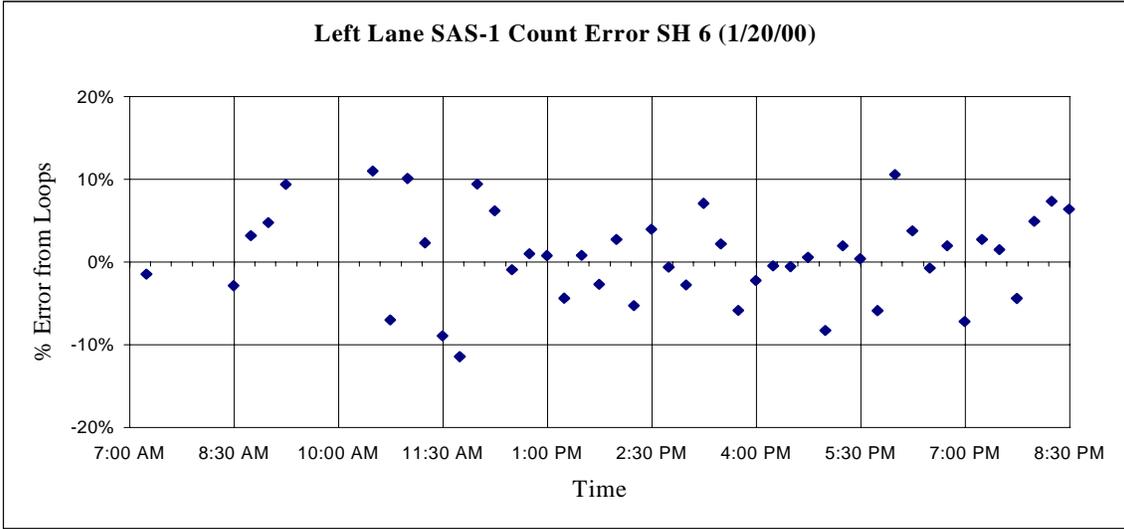
Figure C-2. SAS-1 15 Minute Percent Error Left Lane (1/20/00).

51
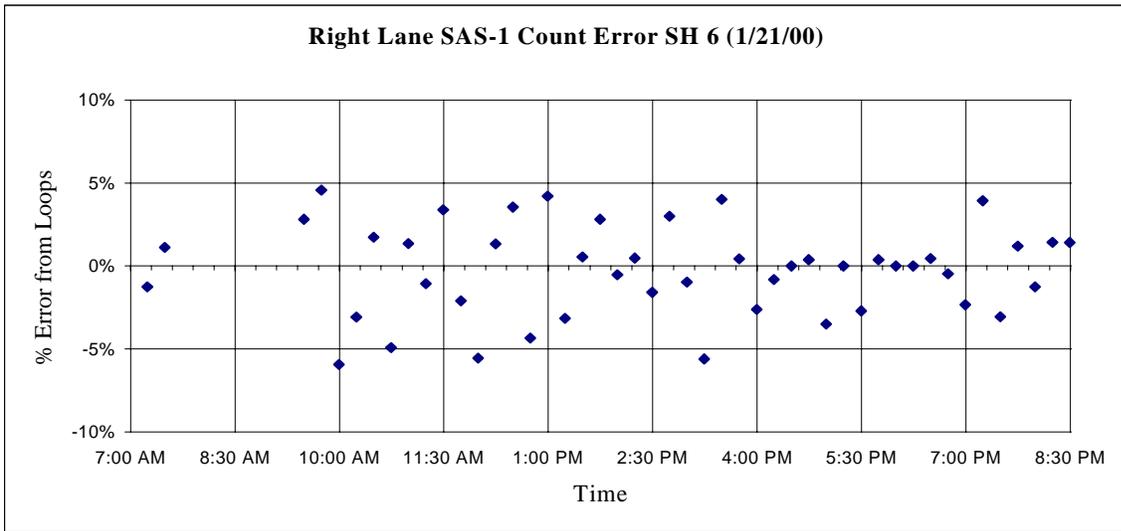
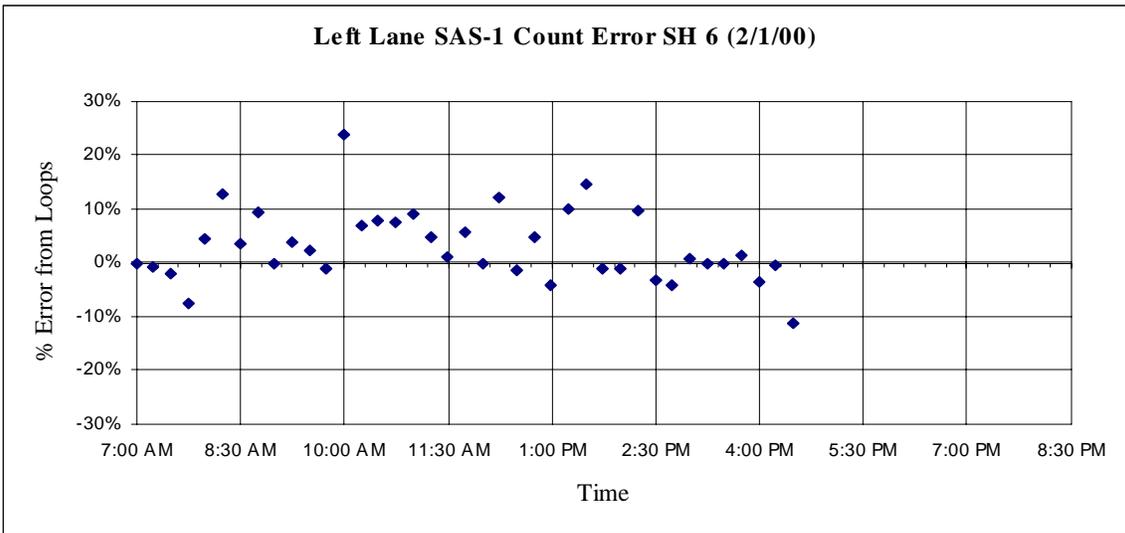**Figure C-3. SAS-1 15 Minute Percent Error Right Lane (1/21/00).**
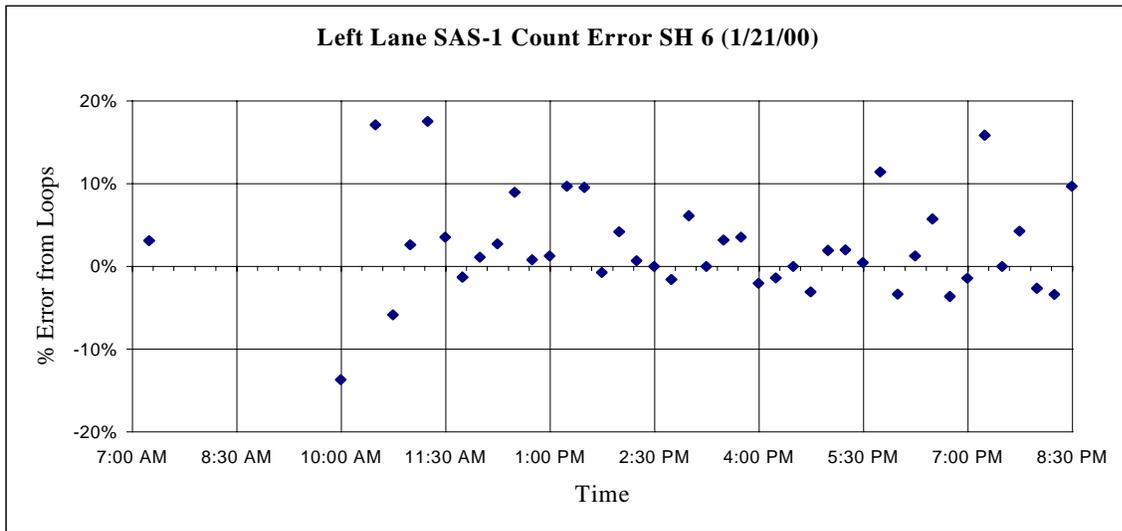
Figure C-4. SAS-1 15 Minute Percent Error Left Lane (1/21/00).

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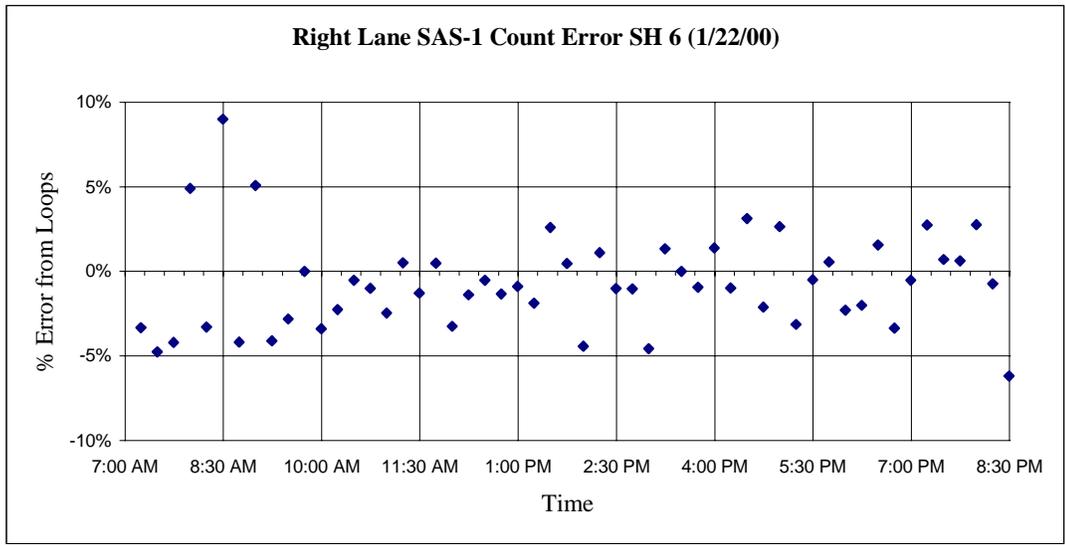
Figure C-5. SAS-1 15 Minute Percent Error Right Lane (1/22/00).
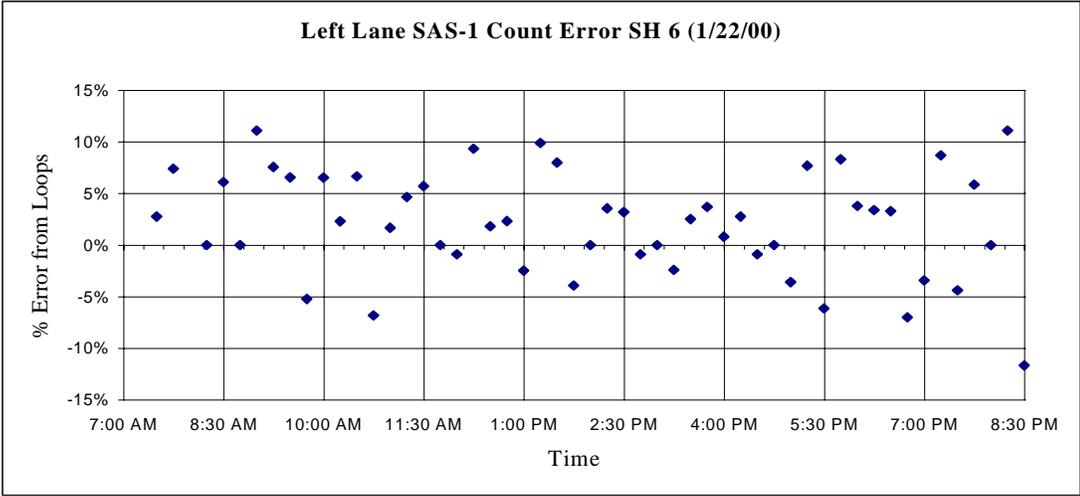
Figure C-6. SAS-1 15 Minute Percent Error Left Lane (1/22/00).
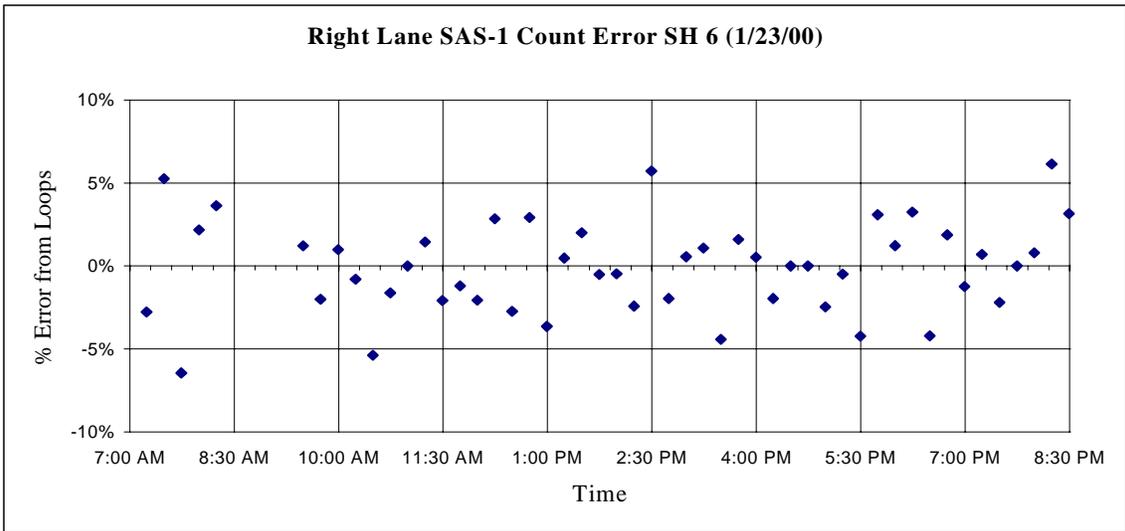
Figure C-7. SAS-1 15 Minute Percent Error Right Lane (1/23/00).
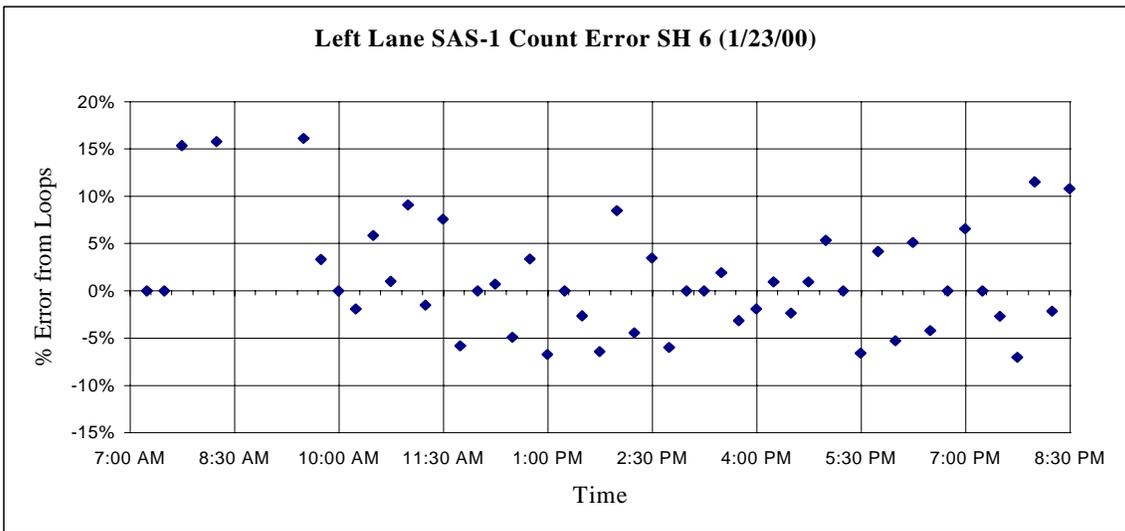
Figure C-8. SAS-1 15 Minute Percent Error Left Lane (1/23/00).

54
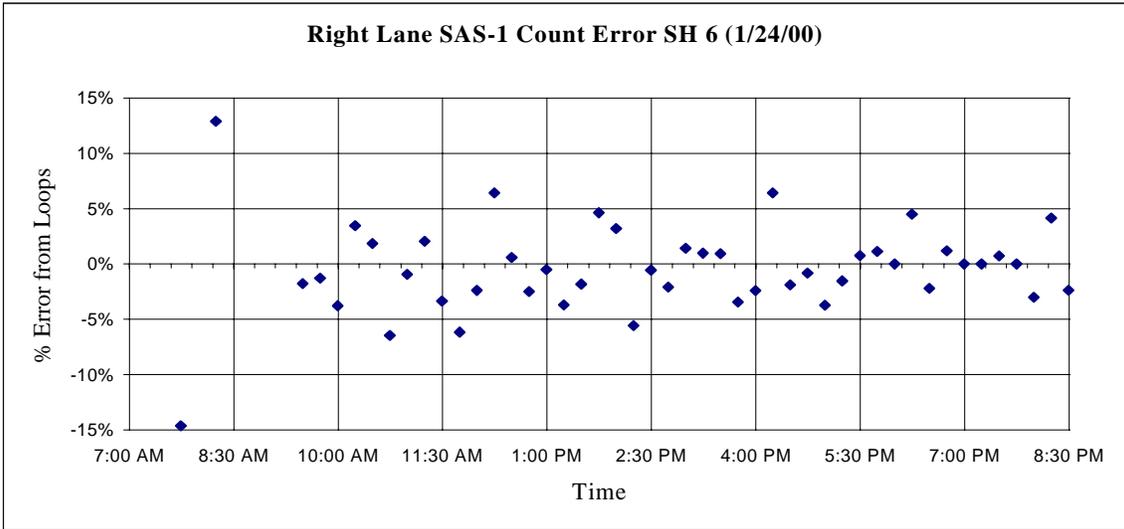
Figure C-9. SAS-1 15 Minute Percent Error Right Lane (1/24/00).
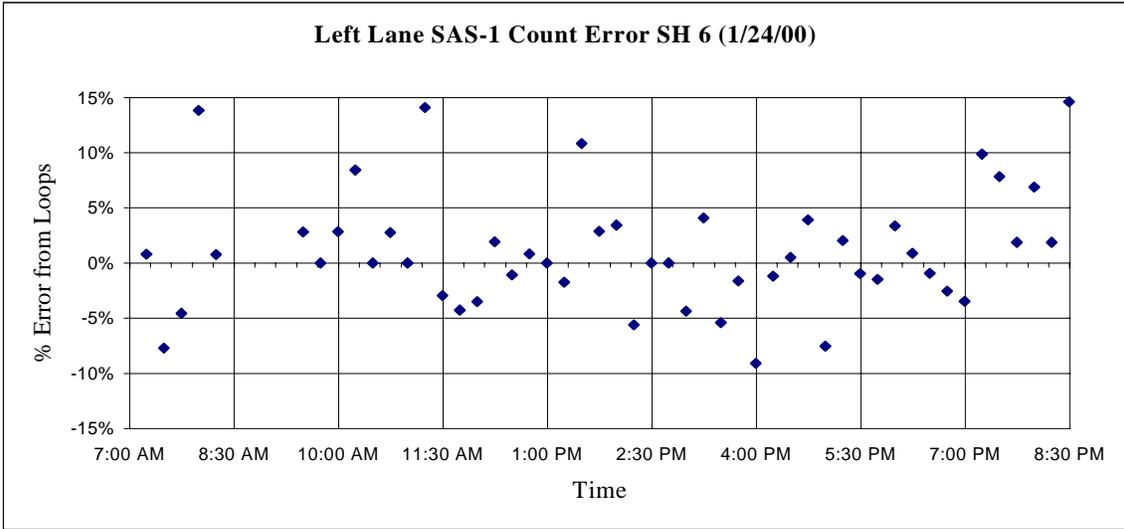
Figure C-10. SAS-1 15 Minute Percent Error Left Lane (1/24/00).

55
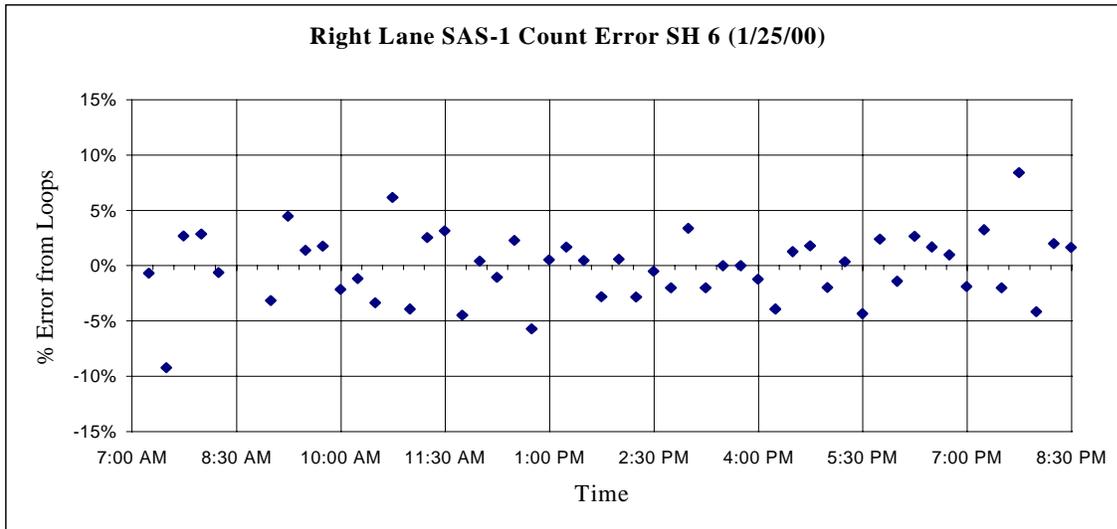
Figure C-11. SAS-1 15 Minute Percent Error Right Lane (1/25/00).
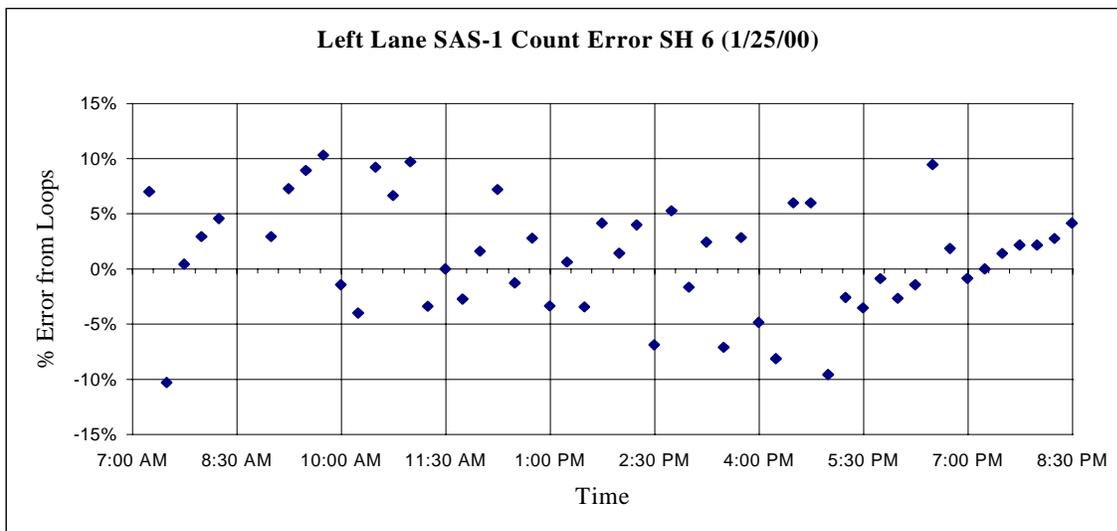
Figure C-12. SAS-1 15 Minute Percent Error Left Lane (1/25/00).

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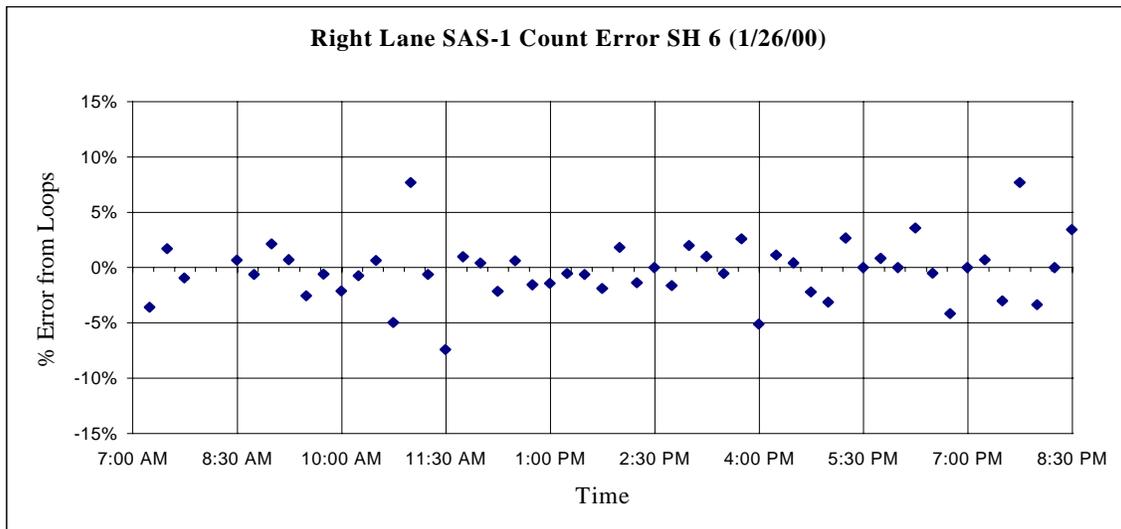
Figure C-13. SAS-1 15 Minute Percent Error Right Lane (1/26/00).
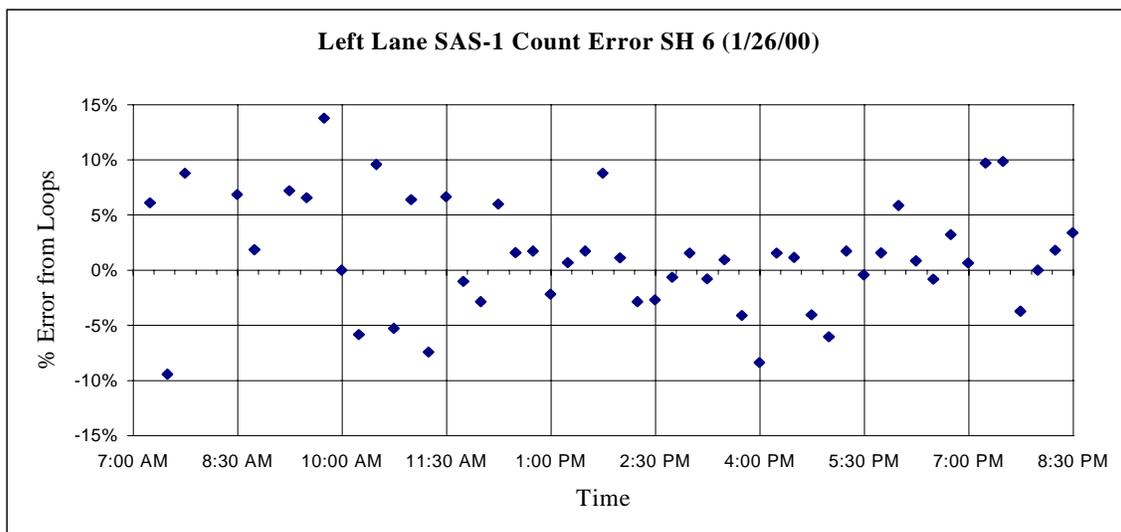
Figure C-14. SAS-1 15 Minute Percent Error Left Lane (1/26/00).
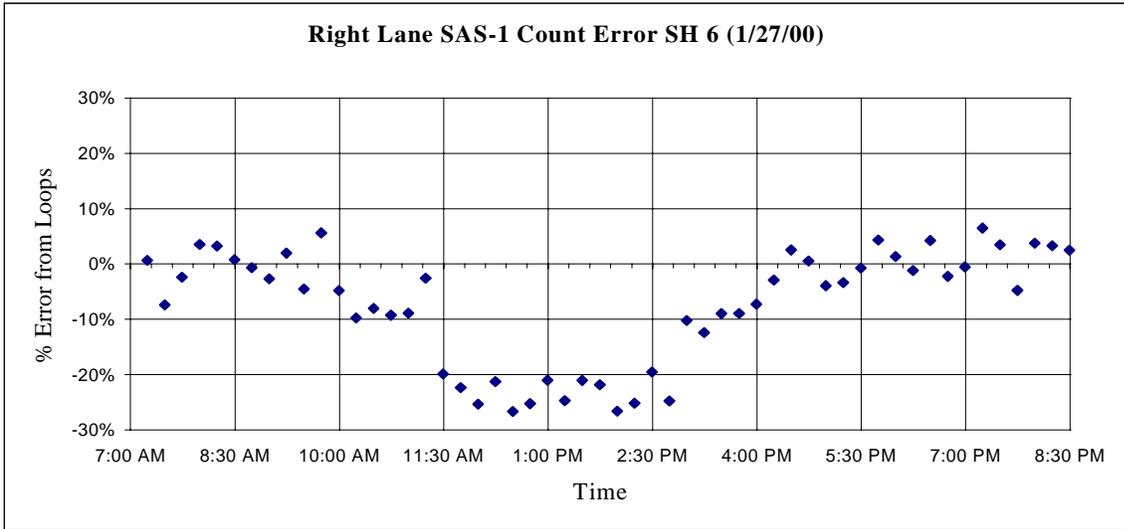
Figure C-15. SAS-1 15 Minute Percent Error Right Lane (1/27/00).
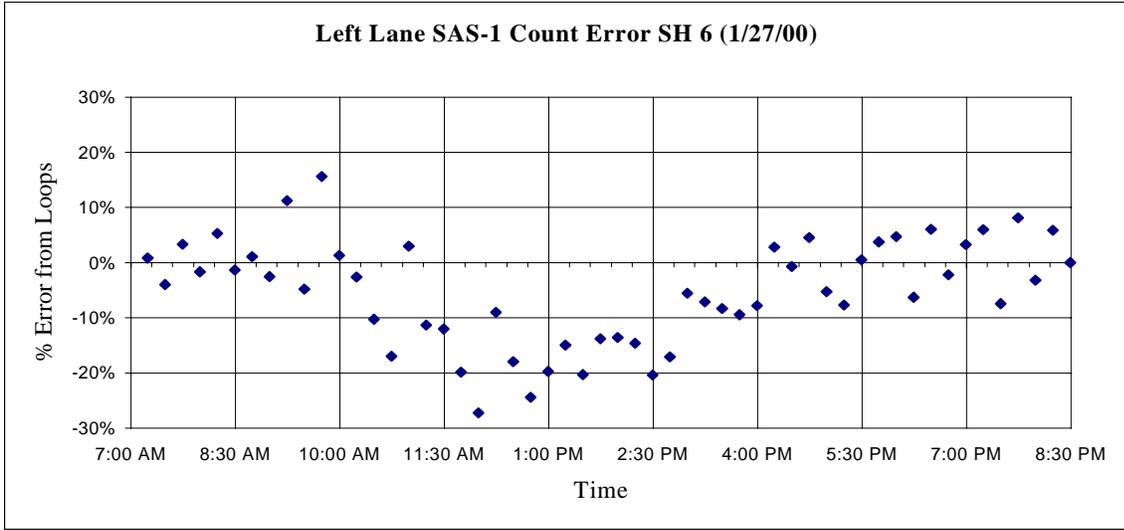
Figure C-16. SAS-1 15 Minute Percent Error Left Lane (1/27/00).
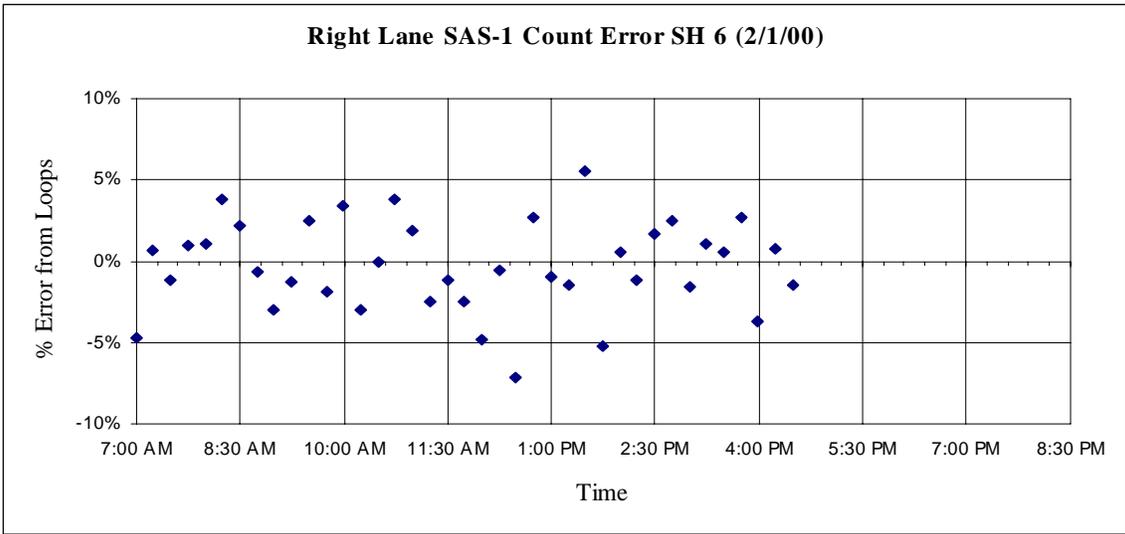
Figure C-17. SAS-1 15 Minute Percent Error Right Lane (2/1/00).

Figure C-18. SAS-1 15 Minute Percent Error Left Lane (2/1/00).

APPENDIX D

Rainfall Plot (1/27/00)
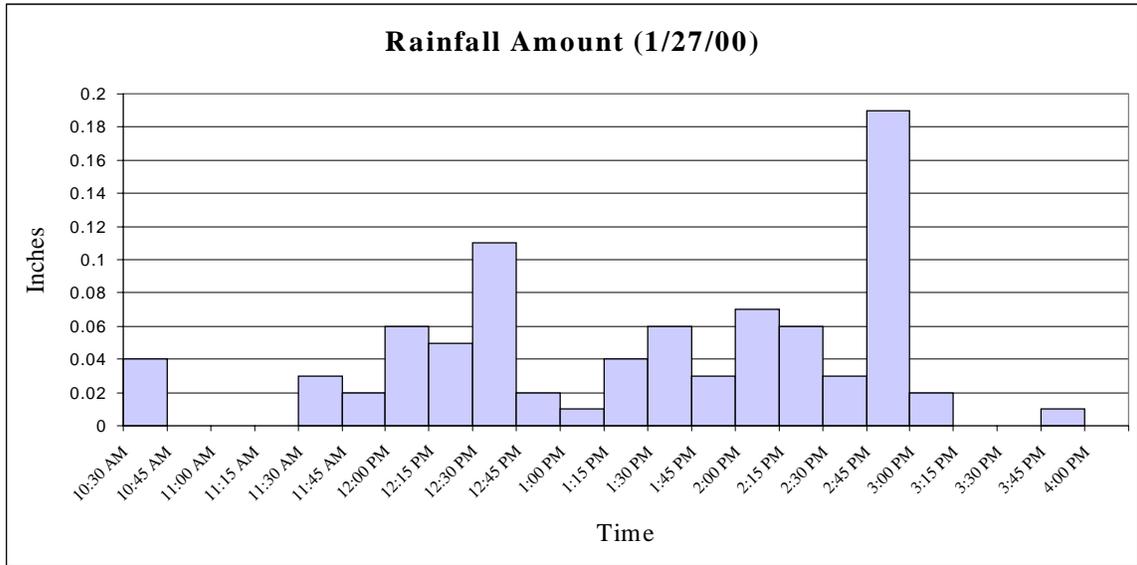
Figure D-1. Rainfall Amount (1/27/00).

APPENDIX E

3M Microloop Speed Plots
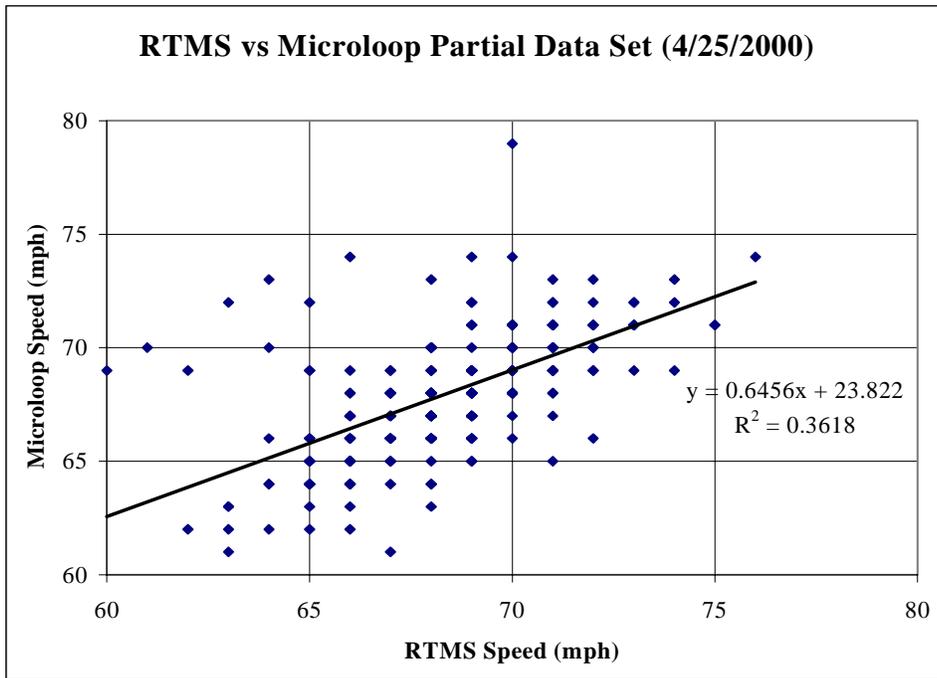
Figure E-1. 3M Microloop Speed Plot Partial Data Set.
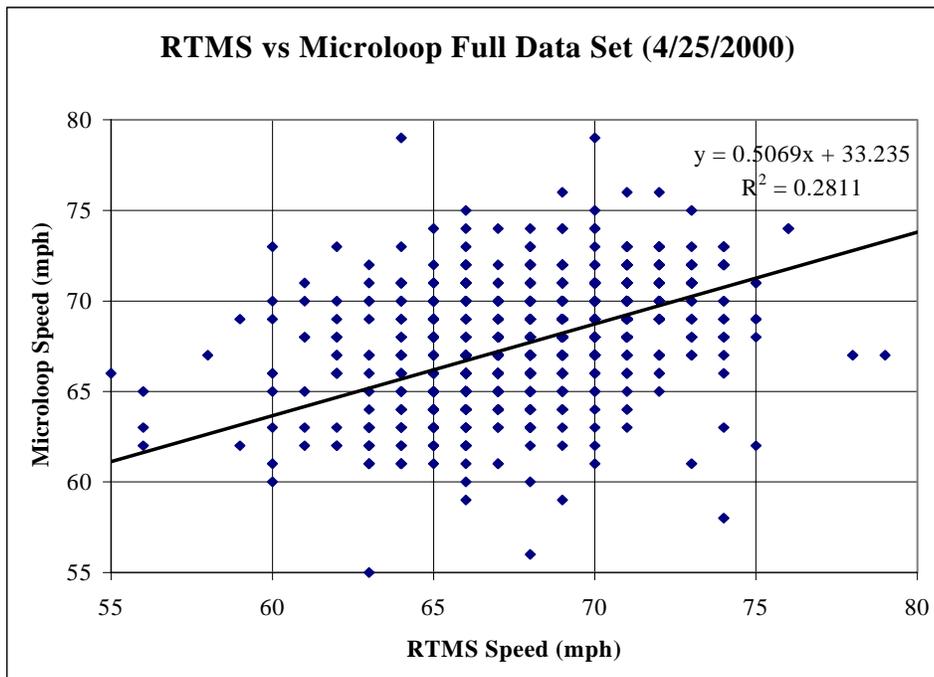
Figure E-2. 3M Microloop Speed Plot Full Data Set.

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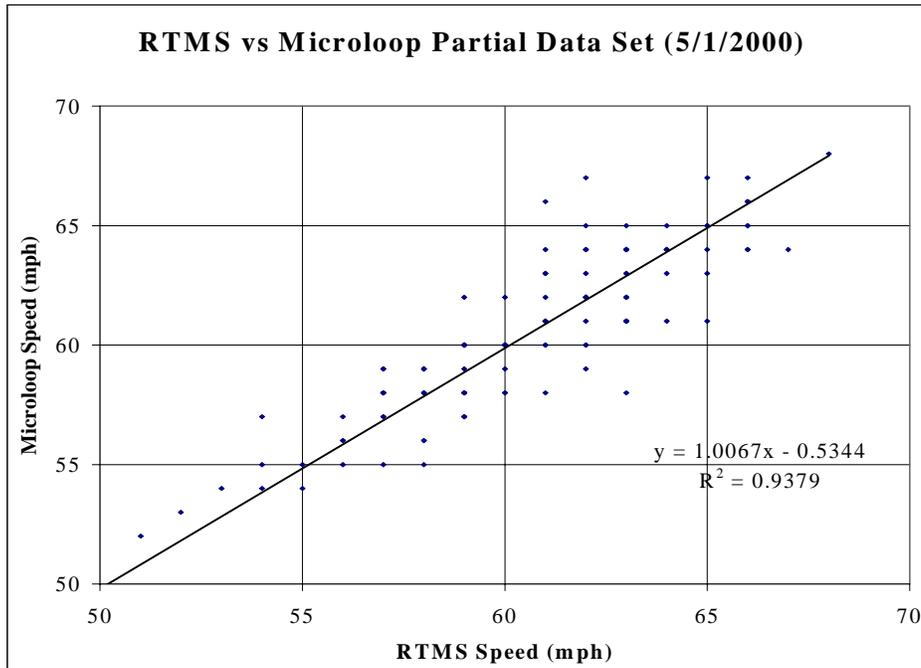
Figure E-3. 3M Microloop Speed Plot Partial Rain Data Set.
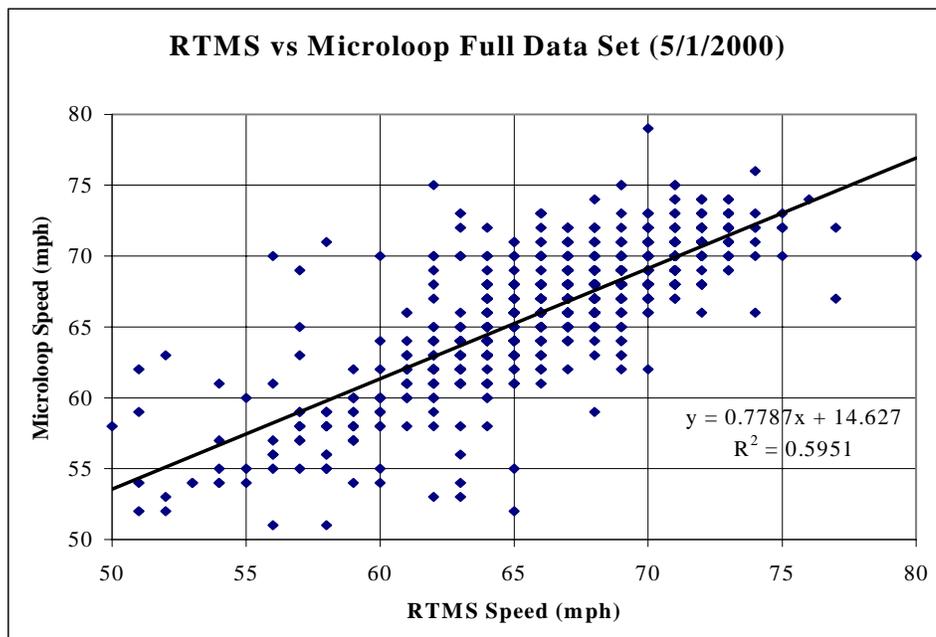
Figure E-4. 3M Microloop Speed Plot Full Rain Data Set.

APPENDIX F

Peek VideoTrak Speed Plots
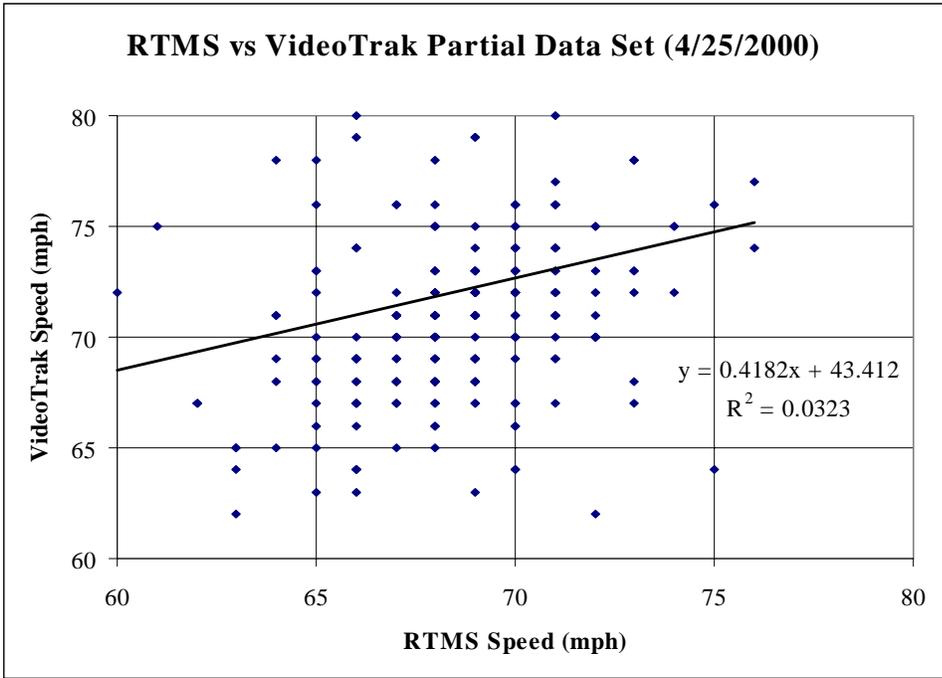
Figure F-1. VideoTrak Speed Plot Partial Data Set.
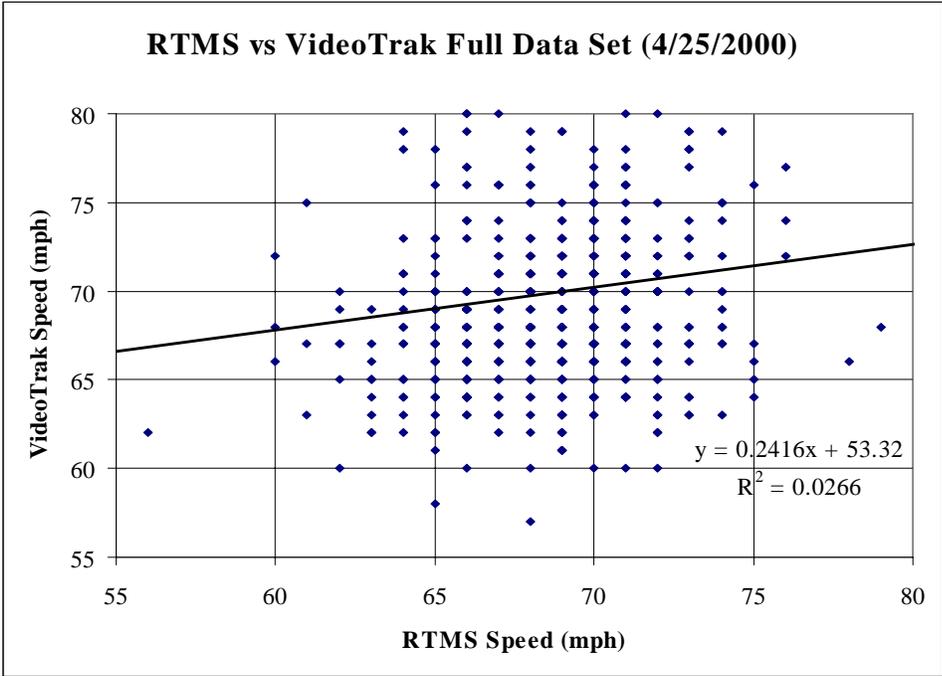
Figure F-2. VideoTrak Speed Plot Full Data Set.

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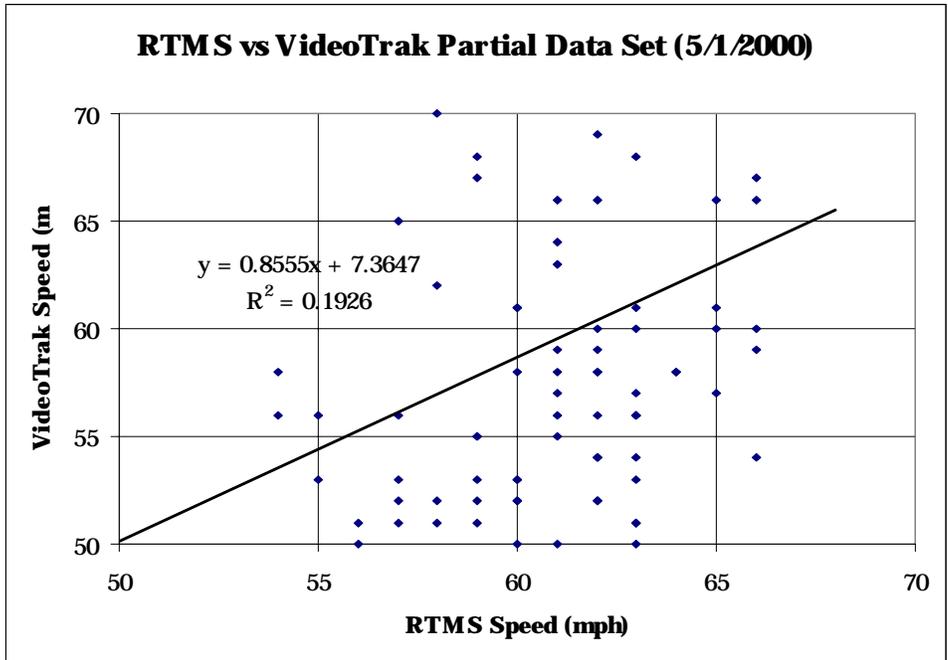
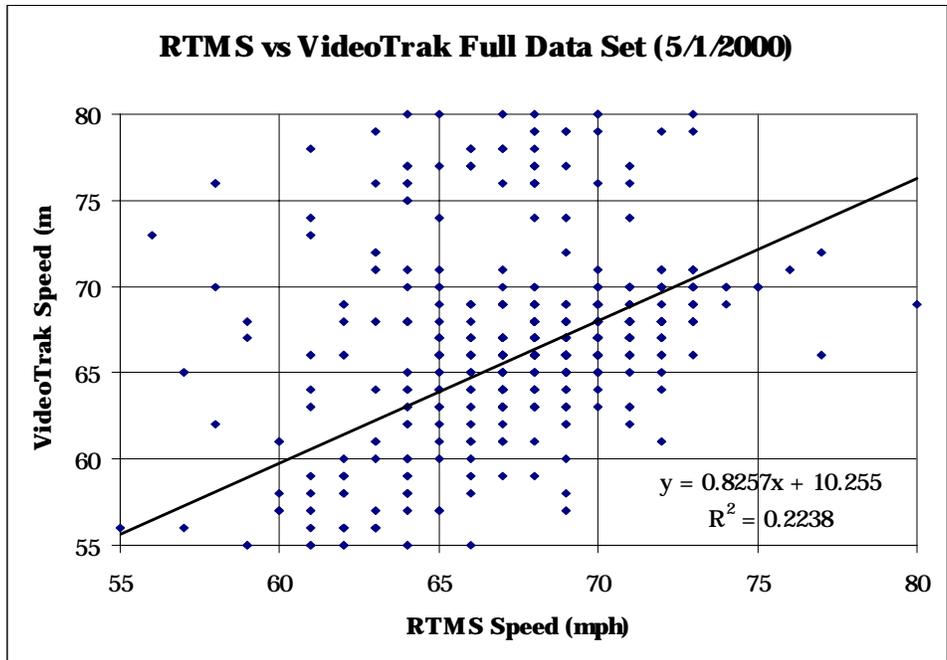**Figure F-3. VideoTrak Speed Plot Partial Rain Data Set.**

Figure F-4. VideoTrak Speed Plot Full Rain Data Set.

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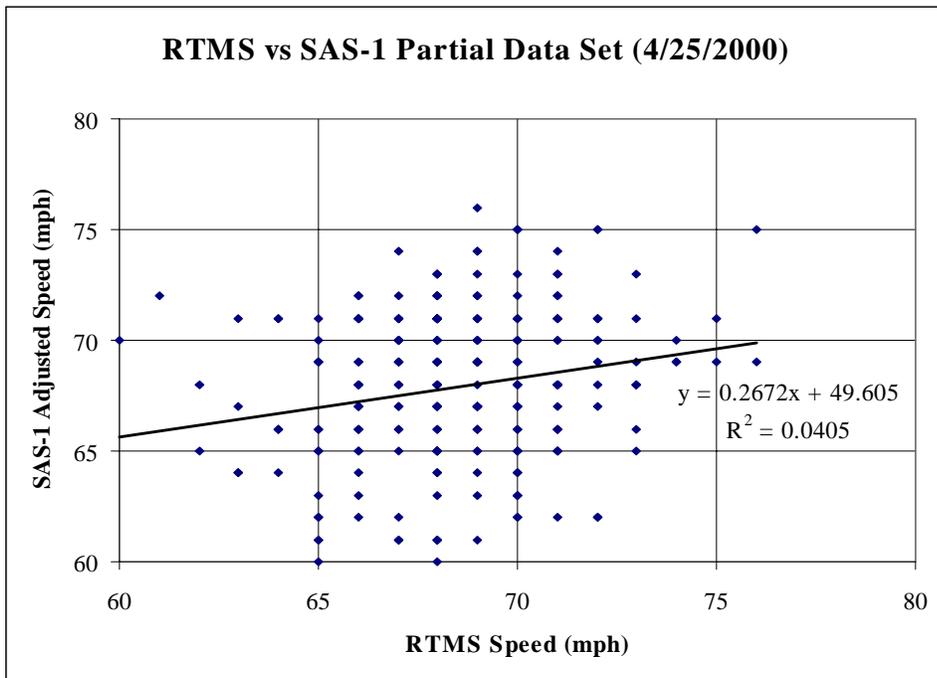**APPENDIX G**

SAS-1 Speed Plots
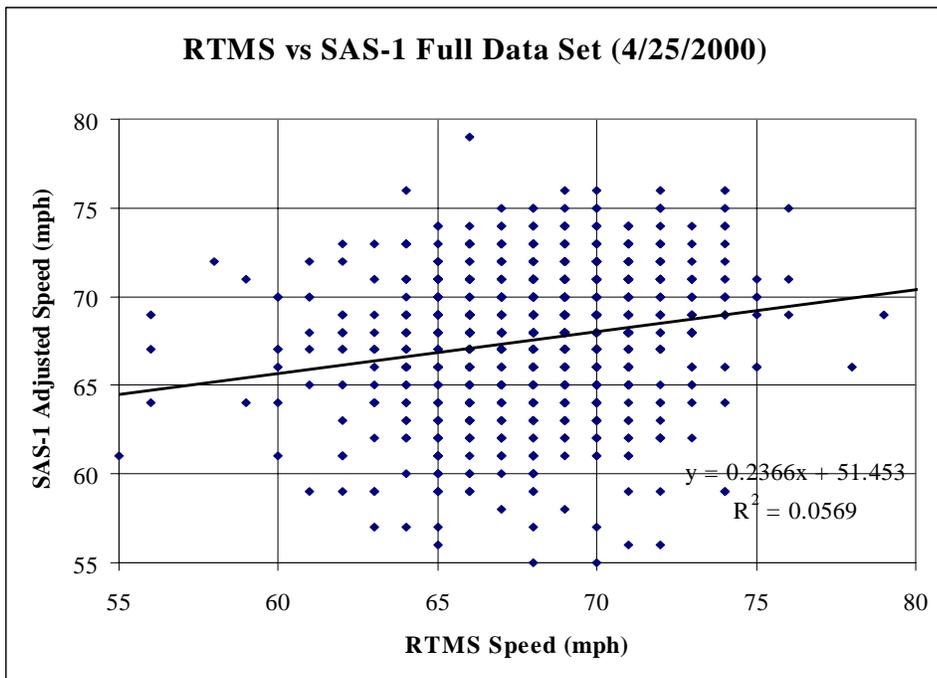
Figure G-1. SAS-1 Speed Plot Partial Data Set.

The equation shown on Figure G-1: $y = 0.2672x + 49.605$, $R^2 = 0.0405$

Figure G-2. SAS-1 Speed Plot Full Data Set.

The equation shown on Figure G-2: $y = 0.2366x + 51.453$, $R^2 = 0.0569$
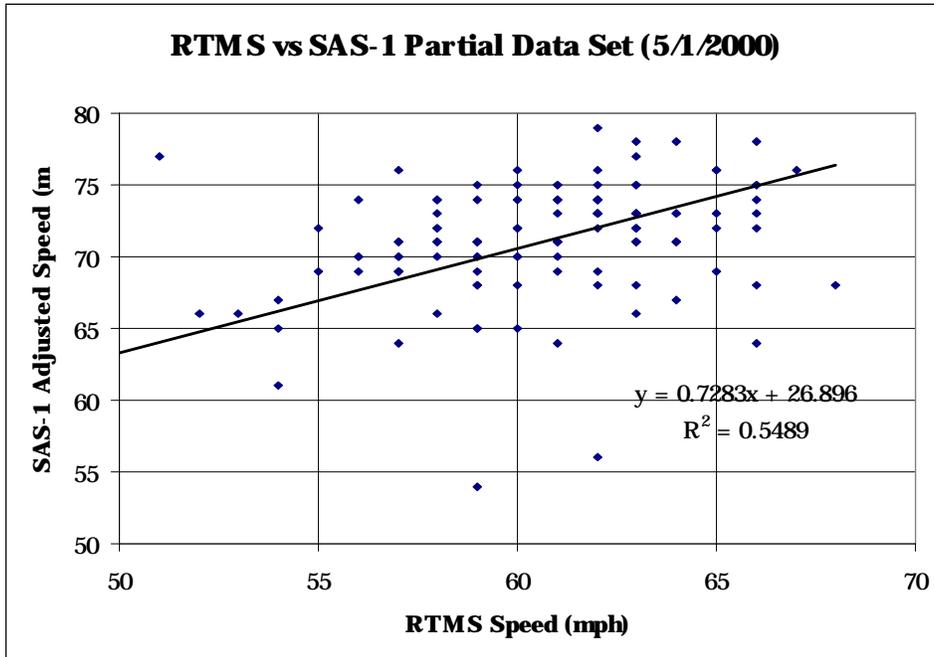
Figure G-3. SAS-1 Speed Plot Partial Rain Data Set.

The chart titled "RTMS vs SAS-1 Partial Data Set (5/1/2000)" shows SAS-1 Adjusted Speed (m) on the y-axis versus RTMS Speed (mph) on the x-axis with the equation:

$$y = 0.7283x + 26.896$$
$$R^2 = 0.5489$$
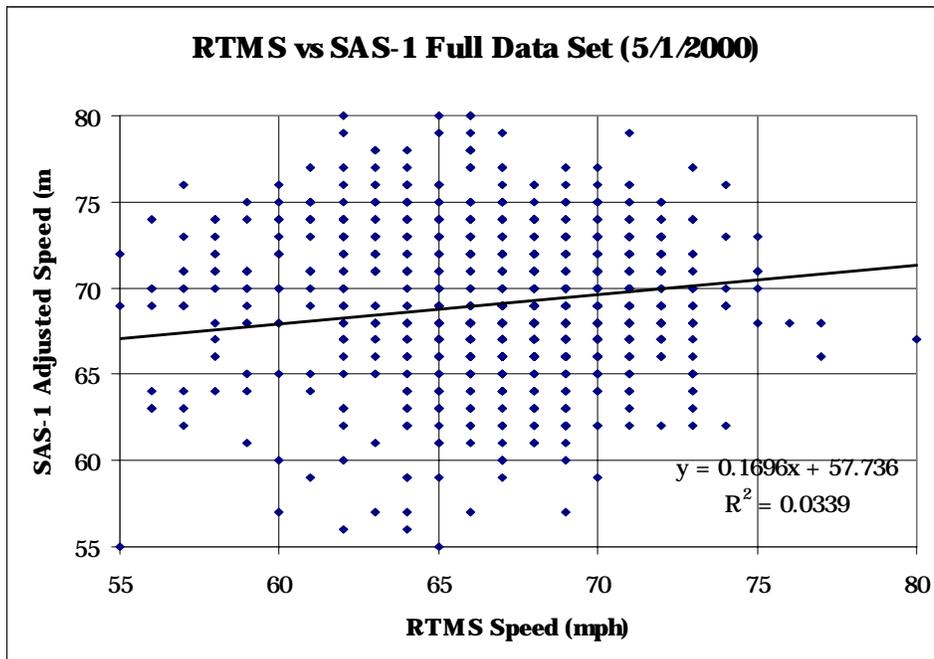
Figure G-4. SAS-1 Speed Plot Full Rain Data Set.

The chart titled "RTMS vs SAS-1 Full Data Set (5/1/2000)" shows SAS-1 Adjusted Speed (m) on the y-axis versus RTMS Speed (mph) on the x-axis with the equation:

$$y = 0.1696x + 57.736$$
$$R^2 = 0.0339$$

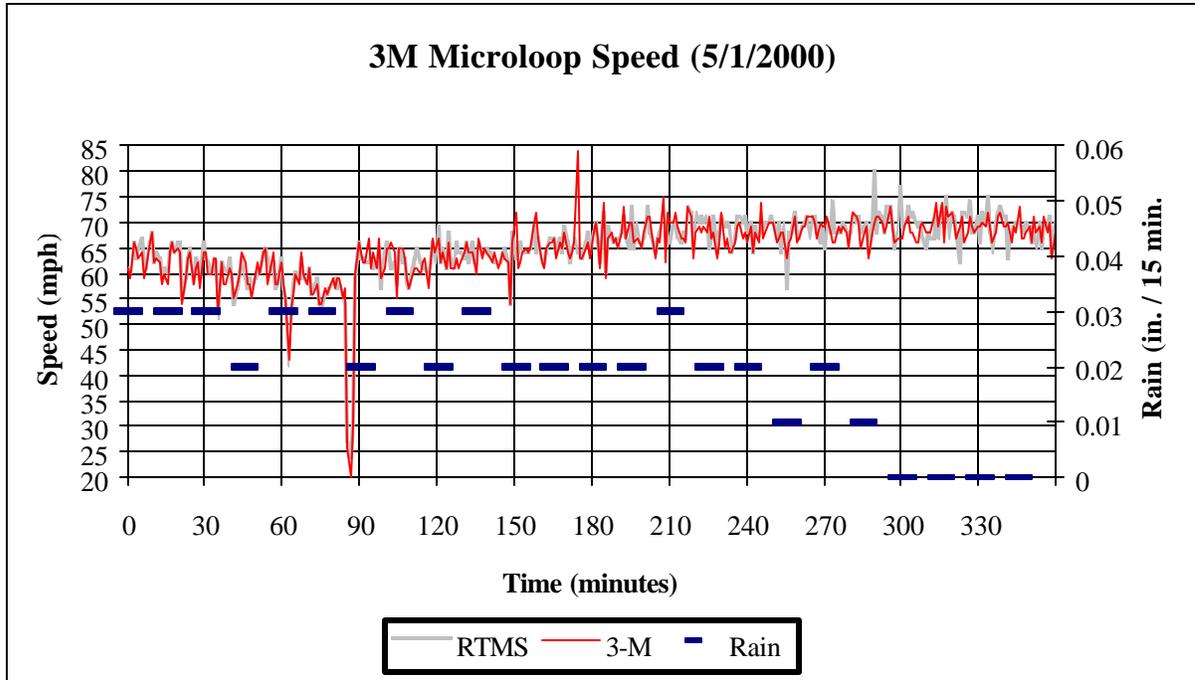**APPENDIX H**

Time Speed Plots
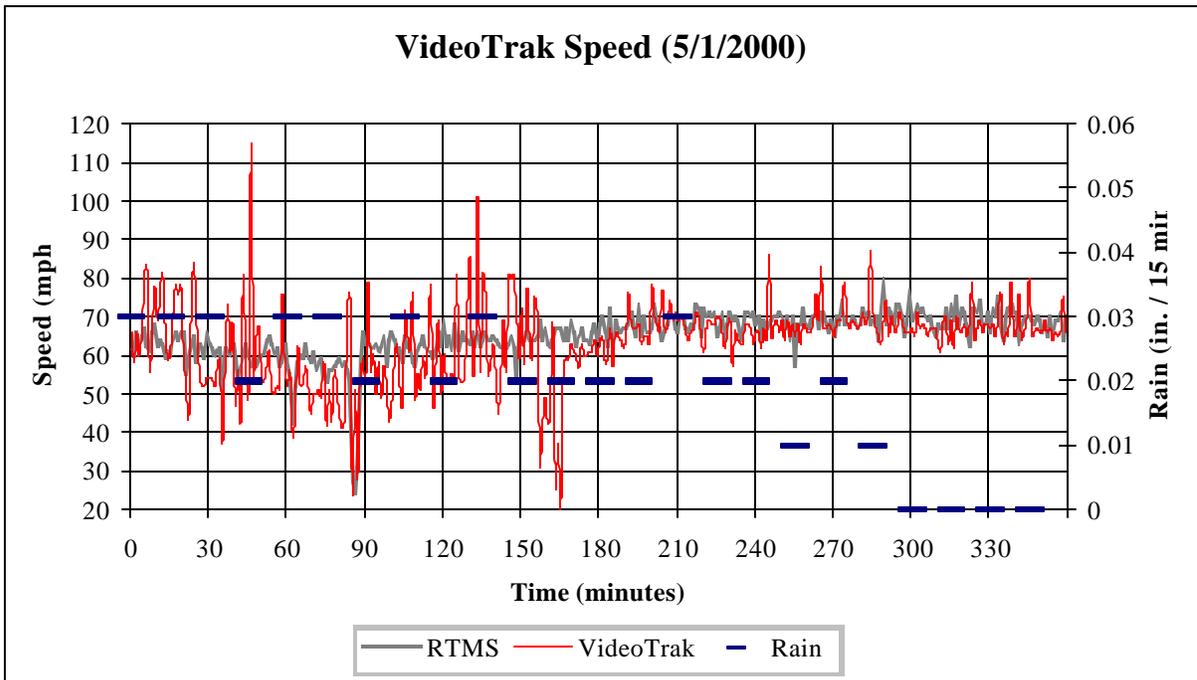
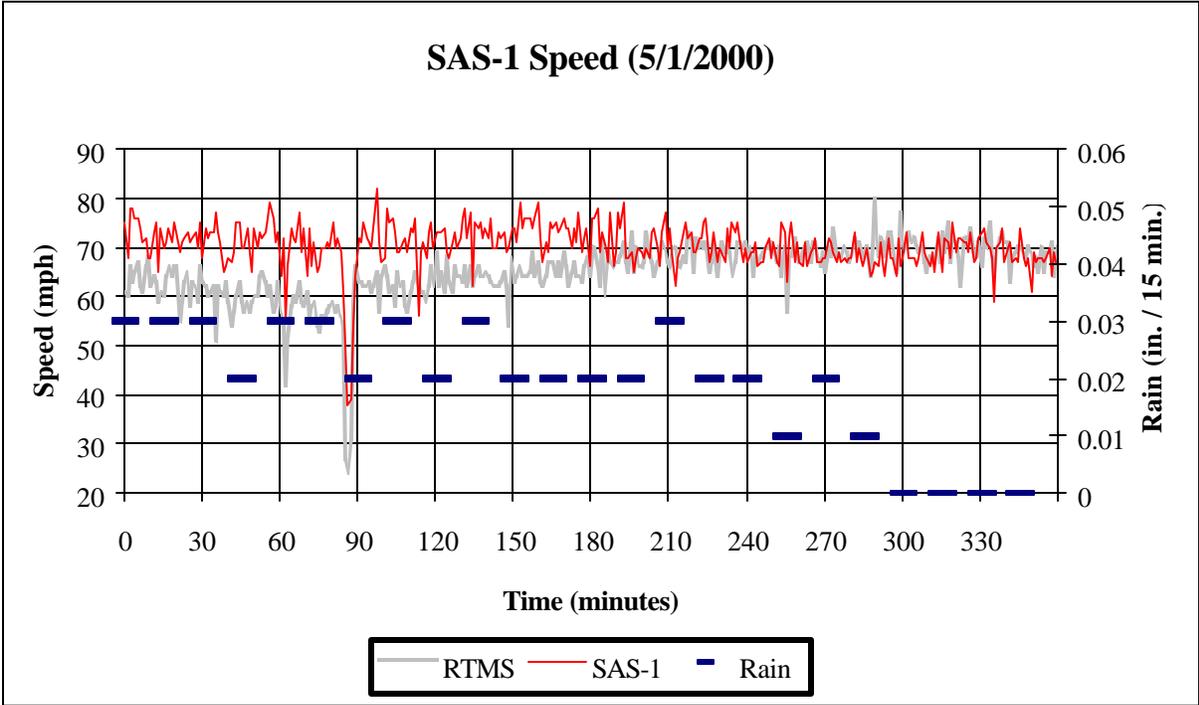**Figure H-1. 3M Microloop Time Speed Plot.**

Figure H-2. VideoTrak Time Speed Plot.

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Figure H-3. SAS-1 Time Speed Plot.