Chapter 4 – AVI Reader Reliability and Accuracy

A crucial component in evaluating the functionality of San Antonio's AVI system is to quantify how well the system correctly reads tags passing beneath its antennas, a property defined as reader *reliability*. In addition, it is desirable to know how accurately the AVI system computes link travel times as each tag-equipped vehicle passes a pair of adjacent antenna sites, which will be defined as reader *accuracy*.

This chapter presents a summary overview of the San Antonio AVI system functionality. In addition, this chapter describes and presents the results of two studies that evaluate the reliability and accuracy of the San Antonio AVI system.

4.1 Functionality of the San Antonio System

The hardware architecture of the San Antonio AVI system consists of three principal components: the AVI Data Processing System, the AVI Reader Field Site System and the AVI Tags. The AVI Data Processing System is located in the Transguide building, TxDOT's San Antonio Traffic Management Center. This system consists of the AVI master computer, a modem server and a set of modems. The AVI Data Processing System is designed to be in constant contact with the AVI Reader Field Site System via telephone line connection. In the field, the AVI Reader Field Site sends a RF signal into the desired lanes of coverage to 'read' AVI tags of passing tag-equipped vehicles. The AVI Reader Field Site sends the tag identification data back to the AVI Data Processing System where tag reads are stored and matched. All tag identification numbers for the San Antonio system are unique. A tag matching algorithm constantly searches for tag matches at adjacent AVI sites and performs five-minute rolling average travel time calculations for each AVI link. Link travel time data derived from the rolling average travel time algorithm is then provided to a data server master computer for use in ATIS services. A graphical schematic of the San Antonio AVI hardware architecture is shown in Figure 4.1.

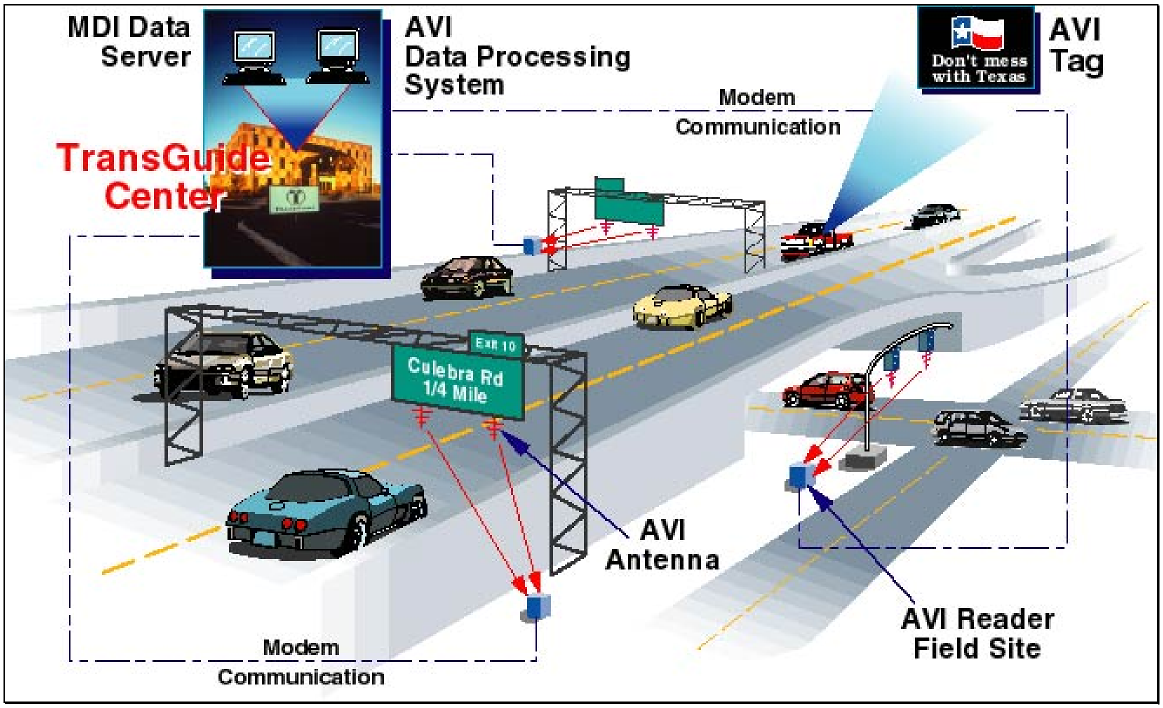

Figure 4.1 – Graphical Schematic of San Antonio AVI Hardware Architecture (source: http://www.transguide.dot.state.tx.us/)

4.1.1 Passive vs. Active Tags

San Antonio AVI tags are passive tags that communicate with the AVI Reader Field Site equipment via modulated backscatter of RF energy. The term 'passive' is given to these tags because they do not emit a signal on their own power. Each AVI tag is energized by the RF frequency broadcast by the field antennas. This RF energy is then modified and reflected by the tag. The modified, reflected signal contains the unique tag identification data required for tag matching to occur.

The system design capture rate for passive San Antonio AVI tags is 80%. For comparative purposes, electronic toll collection (ETC) facilities in the United States utilize a design capture rate of 99.95%. The extremely high reliability is necessary given that toll revenues depend directly upon the successful capture of each toll tag by AVI antenna equipment. For this reason, ETC tags most often are designed to be 'active' tags containing a frequency-emitting battery that is more readily detected by AVI antennas. The original intent of the San Antonio AVI system design was to develop a system that was cost-effective and that produced useful and accurate travel time data. In addressing the cost constraint, the designers of the system ultimately decided that it would not be necessary to have an antenna covering every lane of the 53 AVI sites. This decision allowed the designers to utilize existing infrastructure (overhead sign bridges, traffic bridges, span wires, etc.) for the mounting of AVI antennas, which significantly reduced the initial capital costs of bringing the AVI system on-line. Furthermore, by establishing a minimum design capture rate of 80%, the designers felt that the AVI equipment could effectively record tag data at a satisfactory cost to the city of San Antonio.

4.1.2 Communication from Readers to Operating System

To evaluate the reliability of the AVI system, it is important to understand how the Amtech AVI system handles tag reads under various situations. When an AVI Reader Site antenna receives a signal from an AVI tag, the reader records the tag's unique identification number along with the time-of-day. The reader then attempts to send that information via modem to the central computer where tag reads are stored and tag matches are performed. In some instances, the AVI readers experience a timeout situation when their attempt to communicate with the server via modem is blocked. If the reader does not receive a response from the server in a certain amount of time, it will attempt to send the tag data repeatedly until it receives an acknowledgement within the correct amount of time. In such an instance, the system may record the singular passage of a tag more than once. Tag reads that are recorded multiple times show identical time stamps. Under normal operating conditions, however, the tag is read once and recorded once by the master computer.

4.1.3 Estimation of Link Travel Times

AVI link travel times are calculated by a rolling average travel time algorithm. To provide more accurate travel time information, this algorithm filters travel times that exceed user-defined threshold link travel time values. A complete description of the San Antonio AVI rolling travel time algorithm is found in Appendix A (AVI MDI System Design Document).

4.1.4 Directional Distinction

In general, AVI Reader Field Sites handle tag reads of traffic traveling in both directions of a given instrumented facility. Tag read data is not appended by the AVI Reader Field Site equipment to indicate the direction of travel of each tag-equipped vehicle. This task is accomplished by the rolling average travel time algorithm. By matching tag reads at adjacent sites, the rolling average travel time algorithm automatically identifies the direction of travel of tag-equipped vehicles read by the system.

4.2 System Reliability Study

The AVI System Reliability Study consists of two parts: AVI antenna *system* functionality and AVI antenna *site* functionality. In the first analysis, the AVI system functionality is observed for a one-month period to determine the frequency of antenna non-functionality. In the second analysis, individual AVI sites are analyzed to observe their ability to correctly capture a passing tag-equipped vehicle.

4.2.1 Overall System Reliability

From time to time, AVI Reader Sites fail to perform properly in the field. When AVI Readers experience such a "downtime," AVI tag reads are not made available to the AVI Master computer from that location. In an ATIS application such as San Antonio's AVI system, the availability of information is critical to the success of informing users of traffic conditions. For this reason, the frequency of AVI Reader failures has significant importance.

The purpose of the overall system reliability study is to determine how well the 53-site AVI system functions as a whole during an extended period of time. This system study serves as an overview for the more detailed site reliability study described later in this chapter. A one-month study was performed on the San Antonio AVI system, spanning from June 11 to July 10, 1998. AVI data for each day during this 30-day period was acquired and filtered to determine which sites failed to report tag reads for each day. During this time, it was found that 6 of the 53 sites (11.3%) experienced down-time for at least one day. These included AVI Sites 1, 15, 38, 50, 52 and 53. The locations of these sites are shown circled in red in Figure 4.2.

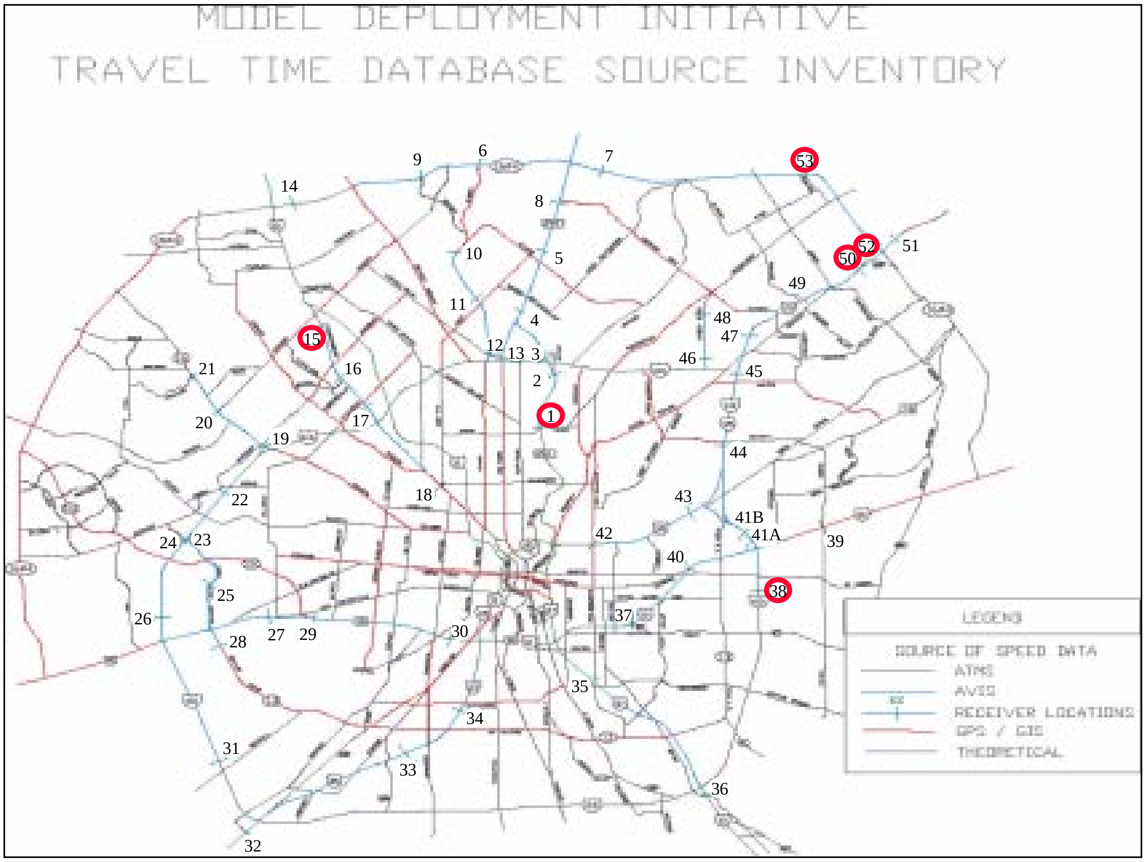

Figure 4.2 – Location of AVI Reader Sites Experiencing Non-Functionality (June 11 – July 10, 1998)

Non-functional sites are defined as sites returning zero or near-zero tag reads for a given 24-hour period of time. The shortest period of non-functionality for any reader during the test period was one day (Site 53, July 9). The longest period of non-functionality was 25 days (Site 15, June 11 – July 5). A site downtime-day is defined as one AVI Reader site being non-functional for a period of one day. The total number of site downtime-days for the system during the test period was 87 out of a possible 1,590 (5.47%).

A graphical illustration of system functionality based on the percentage of AVI sites functional for each day is given in Figure 4.3.

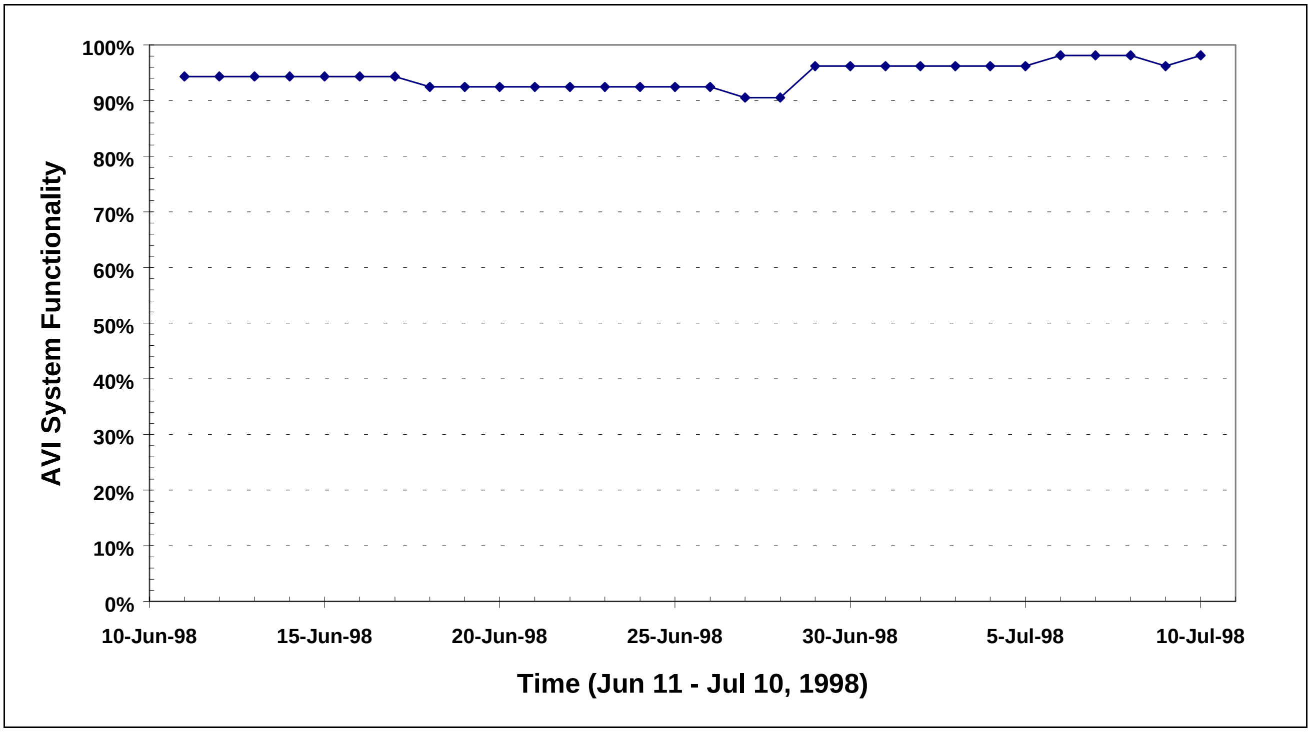

Figure 4.3 – Per-day Percent AVI System Functionality (June 11 – July 10, 1998)

As illustrated in Figure 4.3, the Percent AVI System Functionality fluctuated between 90 and 100% during the 30-day test period. The minimum percentage was 90.6% (June 27-28) while the highest percentage was 98.1% (July 6-8, 10).

As shown in this analysis, the AVI system demonstrated a level of functionality consistently above 90%. With a percentage of downtime days of 5.47%, the system during this study period experienced an average of 2.9 (out of 53) readers down per day.

4.2.2 Controlled System Reliability Study

In surveying the data collected by the AVI system during the June test runs, it was noted that at times the GPS probe vehicle's tag was not recorded when it passed beneath an antenna, while at other times it was recorded twice, or double-counted. In each instance, these reads are deemed 'bad,' in that they failed to accurately record the singular passage of the probe vehicle beneath an antenna. The majority of times, however, the AVI readers recorded one tag read per pass for the tag-equipped test vehicle. In those instances, the reads are classified as 'good.'

4.2.2.1 Experimental Design and Data Collection

The experimental design used to collect AVI tag reads consisted of driving both a San Antonio freeway and arterial section with AVI coverage. Experimental runs were performed during the AM and PM peaks as well as during the midday off-peak in order to discern if the traffic volume impacted system reliability.

Figure 4.4 illustrates the section that was covered during the freeway data collection runs.

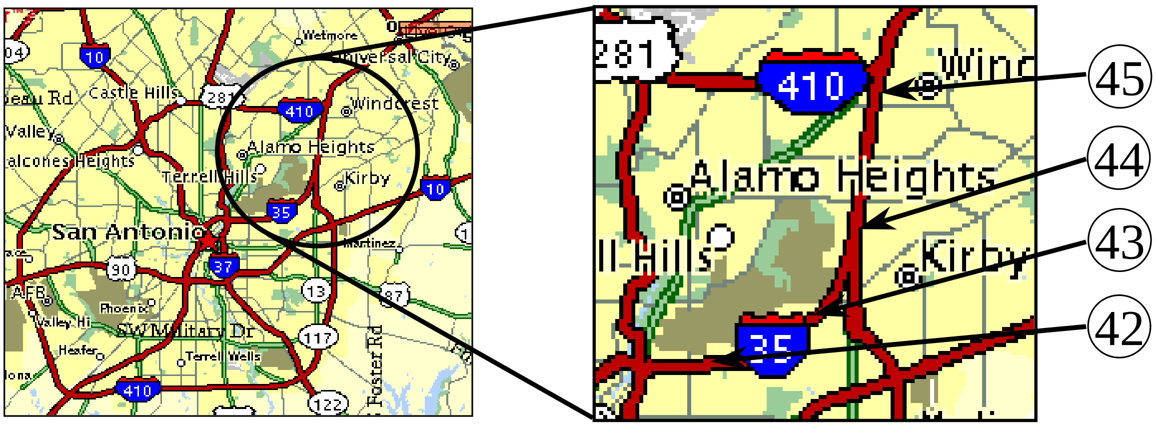

Figure 4.4 – Freeway AVI Data Collection Route: I-35 & I-410/35
(source: http://www.mapquest.com/)

This section extends from exit 167 (located just north of the I-35/I-410 interchange) to exit 158C at the I-35/I-37 interchange. This run covers four AVI sites in the following order (from north to south): 45, 44, 43 and 42. These freeway link lengths and link speed limits are given below in Table 4.1.

Table 4.1 – Freeway Link Characteristics

Link (Direction)	Link Length (mi.)	Link Speed Limit (mph)
45 to 44 (S)	2.431	60
44 to 43 (S)	1.905	60
43 to 42 (S)	2.675	60
42 to 43 (N)	2.675	60
43 to 44 (N)	1.910	60
44 to 45 (N)	2.458	60

In addition, runs were performed on Fredericksburg Rd., a San Antonio arterial that runs parallel and to the south of I-10 in the region just northwest of Loop I-410. As previously illustrated in Chapter 3, Figure 3.4, this test section covers AVI antenna sites 15, 16 and 17 (from north to south), and stretches from Fredericksburg's intersection with I-10 (I-10 Exit 559) south to its intersection with I-410 (I-410 Exit 16A).

A total of 39 runs were performed on the freeway section from June 10 to June 11, 1998, while data were available for 12 runs performed on Fredericksburg Rd. on June 11, 1998. A breakdown of these runs by date, direction, and time-of-day is shown in Table 4.2.

Table 4.2 – Summary of GPS Runs Used for AVI Reader Reliability & Accuracy Study

Route	Date	Northbound Trips			Southbound Trips			Total Trips
		AM	Midday	PM	AM	Midday	PM	
I-35/410	6/10/98	3	4	4	3	3	4	**21**
I-35/410	6/11/98	3	3	3	3	3	3	**18**
Fredericksburg	6/11/98	6	0	0	6	0	0	**12**

4.2.2.2 Study Findings

The study findings for this section were broken into several sections to enhance the results. The sections are as follows: Arterial vs. Freeway; Directional Analysis; Geometric Configurations; Inclement Weather Performance; and, Vehicle Speed.

4.2.2.2.1 Arterial vs. Freeway

Of the two facility types, the I-35 freeway section AVI antennas returned slightly better reliability results than did their arterial counterparts on Fredericksburg Rd. A summary of the results, including Total Chances, Correct Reads, No Reads, Double Reads, Total Mis-Reads and their corresponding percentages is presented below in Table 4.3 for the I-35 freeway section and Table 4.4 for the Fredericksburg Rd. section. Because AVI site 15 (Fredericksburg Rd.) was not functioning on the date of data collection, no results are reported for that site. All tag read data was extracted from raw AVI daily tag read archives.

Table 4.3 – Summary of Reliability Results for I-35 Freeway GPS Runs

AVI SITE	TOTAL CHANCES	CORRECT READS	NO READS	DOUBLE-READS	TOTAL MIS-READS	% CORRECT	% NO READS	% DOUBLE-READS	% MIS-READS
42	39	33	6	0	6	85%	15%	0%	15%
43	39	37	1	1	2	95%	3%	3%	5%
44	39	27	12	0	12	69%	31%	0%	31%
45	39	37	0	2	2	95%	0%	5%	5%
TOT	**156**	**134**	**19**	**3**	**22**	**86%**	**12%**	**2%**	**14%**

Table 4.4 – Summary of Reliability Results for Fredericksburg Rd. Arterial GPS Runs

AVI SITE	TOTAL CHANCES	CORRECT READS	NO READS	DOUBLE-READS	TOTAL MIS-READS	% CORRECT	% NO READS	% DOUBLE-READS	% MIS-READS
15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16	12	10	2	0	2	83%	17%	0%	17%
17	12	8	4	0	4	67%	33%	0%	33%
TOT	**24**	**18**	**19**	**3**	**6**	**75%**	**79%**	**13%**	**25%**

In comparing the overall reliability results by facility type, the freeway AVI readers yielded a higher reliability percentage (86% correct reads) than the arterial section (75% correct reads). The San Antonio AVI system was originally designed and tested to capture a minimum of 80% of all possible tag reads *at each antenna*. Compared to this standard, the freeway AVI section *as a whole* exceeded the design capture rate by 6%. Because each freeway site tested possessed multiple antennas for each direction of travel, and because of the desire to utilize the floating vehicle method, it was neither feasible nor realistic to attempt to collect and analyze data at the microscopic level for individual AVI antennas at the sites tested. Instead, this experiment serves as both a mezoscopic (AVI antenna *sites*) and macroscopic (AVI antenna *facilities*) evaluation of San Antonio's AVI system. Hence the reported results of freeway reader reliability (86%) and arterial reader reliability (75%) are both macroscopic quantities. Although lower than the 80%

desired capture rate, the 75% arterial capture rate recorded during the experimental runs could be deemed inconclusive given the low number of total chances (24).

4.2.2.2.2 Directional Analysis

Because the AVI system does not require lane direction information to calculate travel times, a given AVI site reports reads for tag-equipped vehicles traveling in both directions served by the corridor. For example, a tag read from AVI site #43 could represent a tag-equipped vehicle traveling in either the northbound *or* southbound lanes of Interstate 35. The AVI system discerns the vehicle's direction based upon the location of the AVI site at which it is next recorded. For this reason, AVI reliability results by direction have been manually extracted from the macroscopic effort described above and reported in Table 4.5 (Northbound Reliability Data) and Table 4.6 (Southbound Reliability Data) for both the freeway and arterial runs.

Table 4.5 – Summary of Northbound Reliability Results, Arterial & Freeway

AVI SITE	TOTAL CHANCES	CORRECT READS	NO READS	DOUBLE-READS	TOTAL MIS-READS	% CORRECT	% NO READS	% DOUBLE-READS	% MIS-READS
16	6	5	1	0	1	83%	17%	0%	17%
17	6	5	1	0	1	83%	17%	0%	17%
42	20	18	2	0	2	90%	10%	0%	10%
43	20	19	0	1	1	95%	0%	5%	5%
44	20	16	4	0	4	80%	20%	0%	20%
45	20	19	1	0	1	95%	5%	0%	5%
TOT	**92**	**82**	**9**	**1**	**10**	**89%**	**10%**	**1%**	**11%**

Table 4.6 – Summary of Southbound Reliability Results, Arterial & Freeway

AVI SITE	TOTAL CHANCES	CORRECT READS	NO READS	DOUBLE-READS	TOTAL MIS-READS	% CORRECT	% NO READS	% DOUBLE-READS	% MIS-READS
16	6	5	1	0	1	83%	17%	0%	17%
17	6	3	3	0	3	50%	50%	0%	50%
42	19	15	4	0	4	79%	21%	0%	21%
43	19	18	1	0	1	95%	5%	0%	5%
44	19	11	8	0	8	58%	42%	0%	42%
45	19	18	0	1	1	95%	0%	5%	5%
TOT	**88**	**70**	**17**	**1**	**18**	**80%**	**19%**	**1%**	**20%**

To further develop the parameters of the mezoscopic analysis, the mezoscopic unit shall consist of the individual (or set of) antenna(s) located in the (set of) directional lane(s) at a single AVI site. As presented in Tables 4.5 and 4.6, a variety of reliabilities were observed at the six AVI sites served by the set of twelve directional lane sets. As reported in Table 4.5, all northbound AVI antenna sets for each site met or exceeded the 80% capture rate established in the system's original design. By facility type, both northbound arterial locations recorded 83% of the vehicle passages correctly, while the freeway northbound sites yielded correct tag capture percentages ranging from 80% to 95%.

For the southbound site results reported in Table 4.6, the results varied considerably. The southbound arterial sites (16 & 17) yielded 83% and 50% correct capture rates, respectively. Meanwhile, the southbound freeway sites failed to achieve the 80% design capture rate twice (79% for site 42 and 58% for site 44), while yielding 95% correct capture for sites 43 and 45. An analysis and discussion of the system constraints which influenced the design and layout of each AVI site is helpful in clarifying these varied correct capture results.

4.2.2.2.3 Geometric Configurations

In applying these system design constraints to the reported reliability data, it becomes clear why the capture rates fall below 80% in certain instances, particularly in the southbound corridor of site 44. This site returned a 58% capture rate (11 of 19 passes successfully captured). The highway geometry and the industrial surroundings near AVI site 44 south work together to create a natural weaving section (Figure 4.5). Most often, the congestion due to weaving is caused by trucks entering in the right lane of the freeway north of site 44 and attempting to switch to the leftmost lane in order catch the I-410 exit just south of the site. The freeway at site 44 south contains three lanes, and during numerous runs significant slow-downs in traffic were generated in the leftmost and center lanes because of the weaving traffic. The right lane at site 44 south was consistently the least congested of the three lanes. Coincidentally, site 44 south has only two antennas designed to cover the two leftmost lanes, leaving the right lane without designed coverage. Because the antenna covering the center lane is obliquely mounted, however, it is capable of recording tag reads in the rightmost lane in spite of not being designed to do so (as noted in phone conversation with Amtech personnel). This oblique mounting configuration is illustrated in Figure 4.6. A standard mounting configuration in which each lane is covered by a vertically-mounted antenna is shown for comparison in Figure 4.7. This particular site is for the four southbound lanes of I-35/410 at AVI site 45.

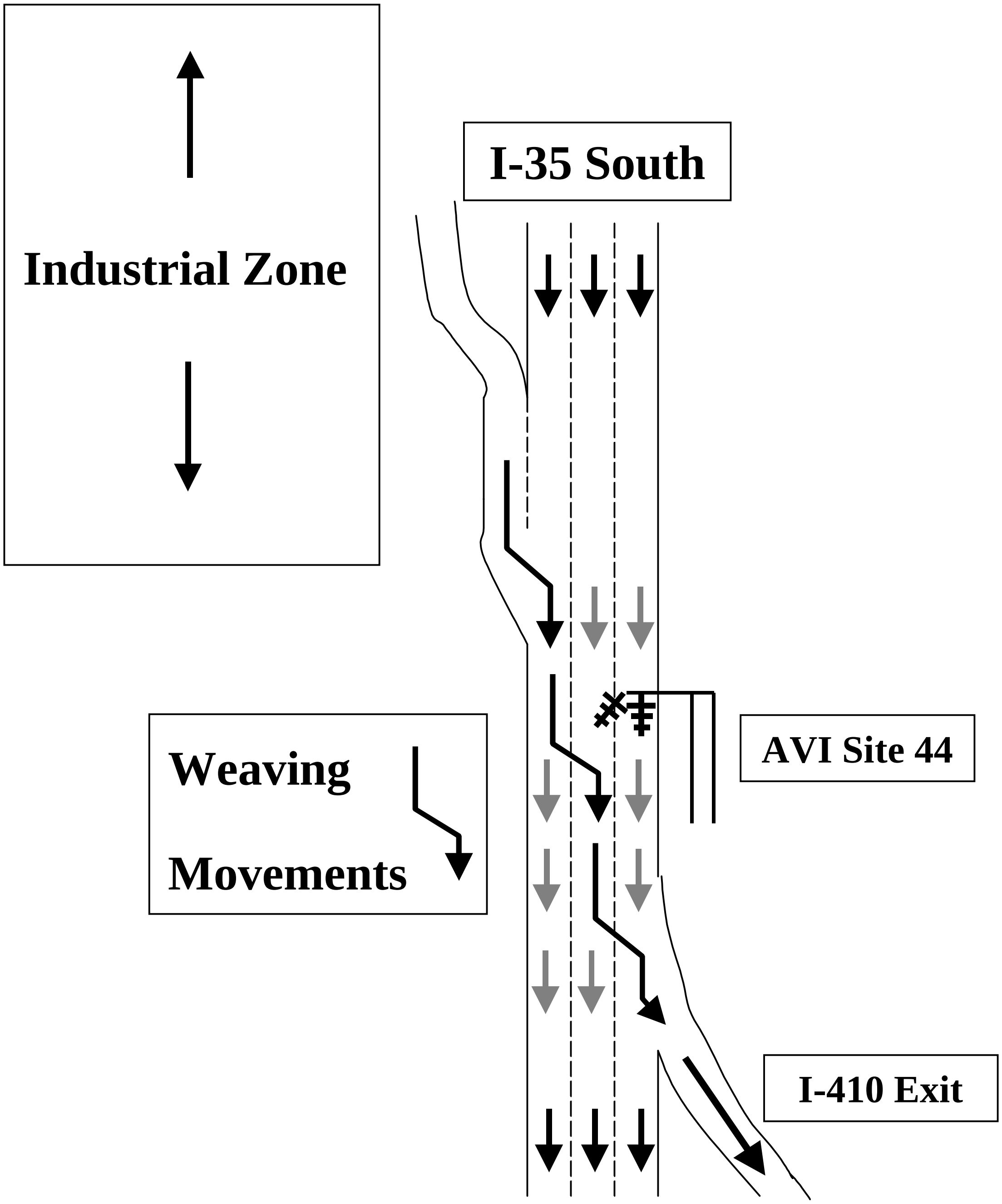

Figure 4.5 – I-35 Southbound Weaving Section, AVI Site 44

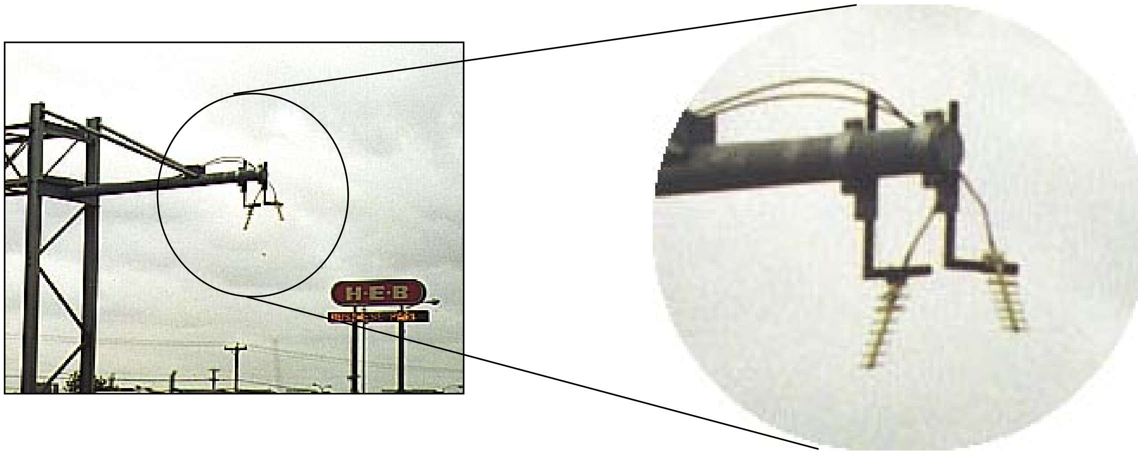

Figure 4.6 – Oblique Mounting Configuration for Southbound Coverage of I-35 at AVI Site 44

Figure 4.7 – Vertical Mounting Configuration for Southbound Coverage of I-35 at AVI Site 45

In an effort to perform floating vehicle data collection, the driver of the test vehicle sought to take the path of least resistance along with the other through-traffic by maneuvering to the rightmost lane, which was usually the least congested. In doing so, the driver inadvertently removed himself from the designed radio frequency curtain generated by the obliquely mounted antenna. At the time of testing, the data collection team was under the impression that the obliquely-mounted antenna covered both the center lane *and the right lane* of traffic at site 44.

For this reason, no special effort was made to stay in a more congested lane to ensure successful capture by the antenna. While this driving behavior no doubt influenced the tag capture rate negatively for this site, it *is* representative of normal driver behavior during congested conditions. In a sense, this test serves to identify how localized highway geometry and recurring traffic flow conditions should be considered in designing an AVI system to effectively capture tag-equipped vehicles. Because AVI site 44 south covers only the two leftmost lanes, which often experience congestion, this site would most likely exhibit poor performance for through drivers while capturing those tag-equipped vehicles attempting to make the exit to I-410.

On a comparative note, AVI Site 43 south has an identical design as site 44 (2 leftmost lanes (out of 3) covered by a vertical mount and an oblique mount), but lacks the surrounding highway geometry to generate weaving traffic. Given that the test driver made an intentional effort to stay in the center lane of the highway during *uncongested* conditions, the test vehicle repeatedly passed this site in the center lane, visible to the oblique antenna. In spite of the structural similarities between sites 44 and 43 south, it is no surprise that the capture rates differed dramatically (58% vs. 95%) for the test runs performed. This difference was due to the weaving congestion at site 44 which influenced through-traffic to maneuver to the rightmost lane.

4.2.2.2.4 Inclement Weather Performance

Given the typically dry climate found year-round in San Antonio, the test crew was fortunate to experience inclement weather in the form of a thunderstorm during driving on the morning of Thursday, June 11, 1998. In extracting the tag capture data from the runs performed during and after the rain, it was found that the AVI system performed efficiently. During the rainfall, which was intense at times, the AVI system captured 15 of 16 possible reads, for a 94% capture rate. Coincidentally, the lone miss was at site 44 south during a run that experienced significant congestion that resulted from a combination of the poor weather and visibility together with two accidents along the route of travel. Because the time and extent of inclement weather conditions was not recorded by the drive-test crew on the Fredericksburg Rd. arterial route, an accurate assessment of the inclement-weather functionality of the AVI readers on this separate facility is unavailable.

4.2.2.2.5 Vehicle Speed

A final analysis of tag capture was performed for different vehicle speeds. Data collected on the freeway and arterial runs was sorted to analyze the tag capture performance for five different speed ranges for the Fredericksburg Rd. section and for six different speed ranges for the I-35 test section. Tables 4.7, 4.8 and 4.9 display results for tag capture by speed for the Fredericksburg Rd. arterial test section, the I-35 freeway test section and for the combined results of both freeway and arterial facilities.

Table 4.7 – Tag Capture by Speed: Fredericksburg Rd. Arterial Test Section

SPEED (mph)	CORRECT READS	MISSED READS	TOTAL CHANCES	% CORRECT
0-15	1	0	1	100%
16-25	2	1	3	67%
26-35	7	1	8	88%
36-45	6	3	9	67%
46-55	2	1	3	67%
TOT	**18**	**6**	**24**	**75%**

Table 4.8 – Tag Capture by Speed: I-35 Freeway Test Section

SPEED (mph)	CORRECT READS	MISSED READS	TOTAL CHANCES	% CORRECT
0-15	2	1	3	67%
16-25	1	0	1	100%
26-35	5	2	7	71%
36-45	8	0	8	100%
46-55	34	5	39	87%
56-65	86	9	95	91%
TOT	**136**	**17**	**153**	**89%**

Table 4.9 – Tag Capture by Speed: Combined Results from Freeway & Arterial Runs

SPEED (mph)	CORRECT READS	MISSED READS	TOTAL CHANCES	% CORRECT
0-15	3	1	4	75%
16-25	3	1	4	75%
26-35	12	3	15	80%
36-45	14	3	17	82%
46-55	36	6	42	86%
56-65	86	9	95	91%
TOT	**154**	**23**	**177**	**87%**

As shown in Table 4.7, tag capture rates range from 67% to 100% for the arterial test section. Because of the small sample size, however, it is difficult to develop any trends from this data. In addition, there appears to be no clear tendency for the tag capture rate to show improvement or worsening with vehicle speed. Table 4.8 yielded an identical range of values as those reported in Table 4.7. Much like the arterial tag capture results, when grouped by test vehicle speed range, the freeway tag capture statistics did not produce a recognizable trend on their own. In giving a representation of the *combined* results from Tables 4.7 and 4.8, however, Table 4.9 does produce a clear trend. As test vehicle speed increases, AVI tag capture rates increase. Again, it is difficult to acknowledge if this trend is valid given the extremely small amount of low-speed tag capture data that were collected. It is suspected that since much of the low-speed freeway data that were collected occurred at AVI site 44 south, the low-speed misread data is unfairly biased. In order to observe the effects of site 44 south's mounting configuration and its recurring congestion condition, Table 4.10 was created. Table 4.10 differs from Table 4.9 in that all tag data from AVI site 44 south have been eliminated.

Table 4.10 – Tag Capture by Speed: Combined Results Less Data From AVI Site 44 South

SPEED (mph)	CORRECT READS	MISSED READS	TOTAL CHANCES	% CORRECT
0-15	3	0	3	100%
16-25	2	1	3	67%
26-35	9	1	10	90%
36-45	13	3	16	81%
46-55	35	1	36	97%
56-65	81	9	90	90%
TOT	**143**	**15**	**158**	**91%**

This revised data set again shows no distinct trend or correlation between test vehicle speed and tag capture rate. For this reason it is concluded that tag capture successes and failures occur independently of the speed of the tag-equipped vehicle being recorded. This conclusion is made with limited confidence because of the small number of observations at lower speeds (< 46 mph). To ascertain the reliability of the correct read rate for each of the six speed ranges, a comparison of the sample capture rates was made with standard deviation envelopes developed about the mean correct read rate of the population (91%). It was found that the sample correct capture rates fell within 2 standard deviations of the population as illustrated in Figure 4.8. Sample standard deviations were computed by dividing the population variance by the square root of the number of sample observations, and then computing the square root. For this reason, the envelope narrows as the observations per sample increases.

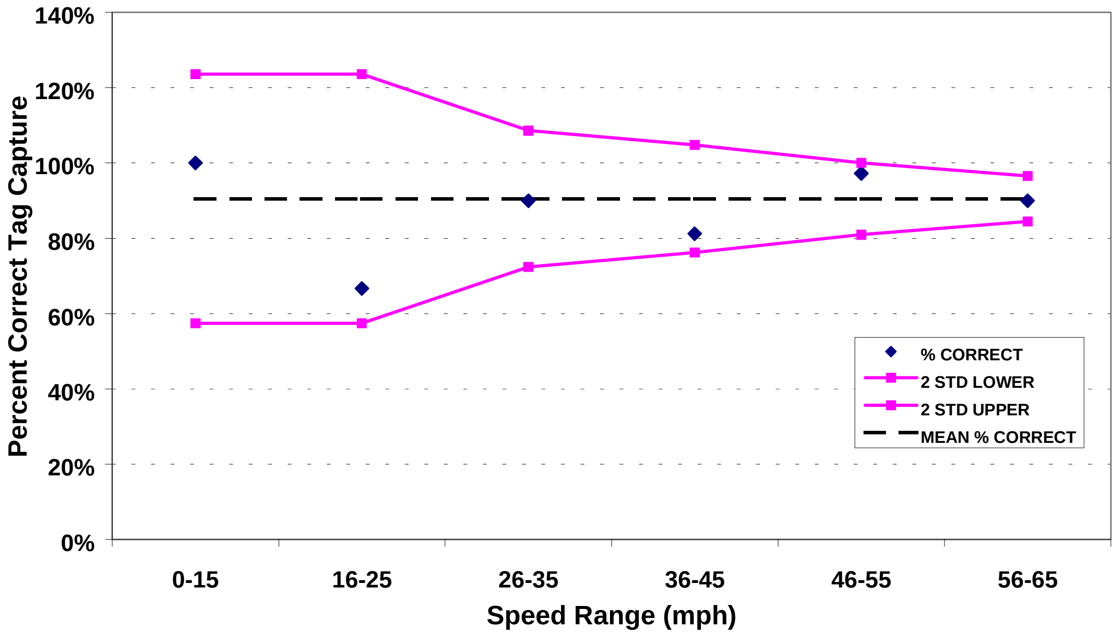

Figure 4.8 – Comparison of Sample Correct Capture Rates with 2 Standard Deviations from Population Mean

4.3 System Fidelity Study

To determine reader accuracy, the comparison of GPS-logged times and AVI-recorded times of passages of AVI sites was performed in order to determine the consistency of travel time calculation by the AVI system. Prior to discussing the method for manually recording GPS travel times, it is first helpful to understand how both the GPS receivers and the AVI systems are calibrated for time.

4.3.1 GPS and AVI System Time Standards

The Trimble Placer 400 GPS units used to gather GPS data receive continual time updates by satellite. GPS time measurements are calibrated to UTC time, which is a French abbreviation for *Universal Coordinated Time* (approximately the same as Greenwich Mean Time, http://www.trimble.com/). The UTC time is received to the nearest microsecond, however, the actual data files generated by the GPS units log times at one-second intervals, which is the maximum position update rate offered by the Trimble GPS units.

The AVI system utilizes a master computer which updates the time clocks located at each AVI site. Each AVI site clock is updated by the central computer when the reader site connects. Reader connections occur whenever an AVI tag is read by a reader. The AVI reader sites do not connect with the master computer if no tag reads are available. The AVI master computer operates on Central Standard Time. After comparing the AVI data with the GPS data collected during the test drives on June 10th and 11th, 1998, the AVI time stamp values were consistently 4 minutes and 4 seconds *slower than* the time data logged by the GPS units.

4.3.2 Data Collection and Study Findings

In performing the test runs, AVI antenna passages were marked with the GPS keypad by pressing 'p' (for probe vehicle) as each antenna was passed. The 'p' notations were recorded as a "User Flag" by the GPS units as shown in the sample GPS output found in Table 4.11. After completing the runs, the GPS link travel times where calculated for each link traversed by extracting the times from each GPS file.

Table 4.11 – Sample GPS Output With User Flags ('p's) to Indicate Passage of AVI Antenna

LATITUDE	_LONGITUDE	_DAY	_TIME	_SPEED_(MP	_DIRECTION	_GPS_RATIN	_USER_FLAG
29.481190	-98.403869	4	07:08:32	48	-169	1	
29.481000	-98.403909	4	07:08:33	48	-169	1	
29.480810	-98.403949	4	07:08:34	48	-169	1	p
29.480710	-98.403969	4	07:08:35	48	-169	1	
29.480420	-98.404029	4	07:08:36	47	-169	1	
:	:	:	:	:	:	:	
:	:	:	:	:	:	:	
:	:	:	:	:	:	:	
29.452250	-98.419589	4	07:11:01	53	-116	1	
29.452150	-98.419809	4	07:11:02	52	-116	1	
29.452060	-98.420019	4	07:11:03	52	-115	1	p
29.451970	-98.420239	4	07:11:04	52	-115	1	
29.451690	-98.420899	4	07:11:07	52	-115	1	

In spite of the potential for human error in logging AVI site passages by hand with the GPS unit, the comparison of GPS link travel times to those calculated by the AVI site proved highly accurate. After analyzing the freeway data collected during the runs on I-35, a total of 81 links were found that had corresponding GPS and AVI link travel times. Required for this was both the accurate capture of the test vehicle's AVI tag at both link boundary AVI antennas as well as the successful keypad entry of each site passage by the data collection crew. A histogram of the AVI/GPS Time Variance is provided in Figure 4.9.

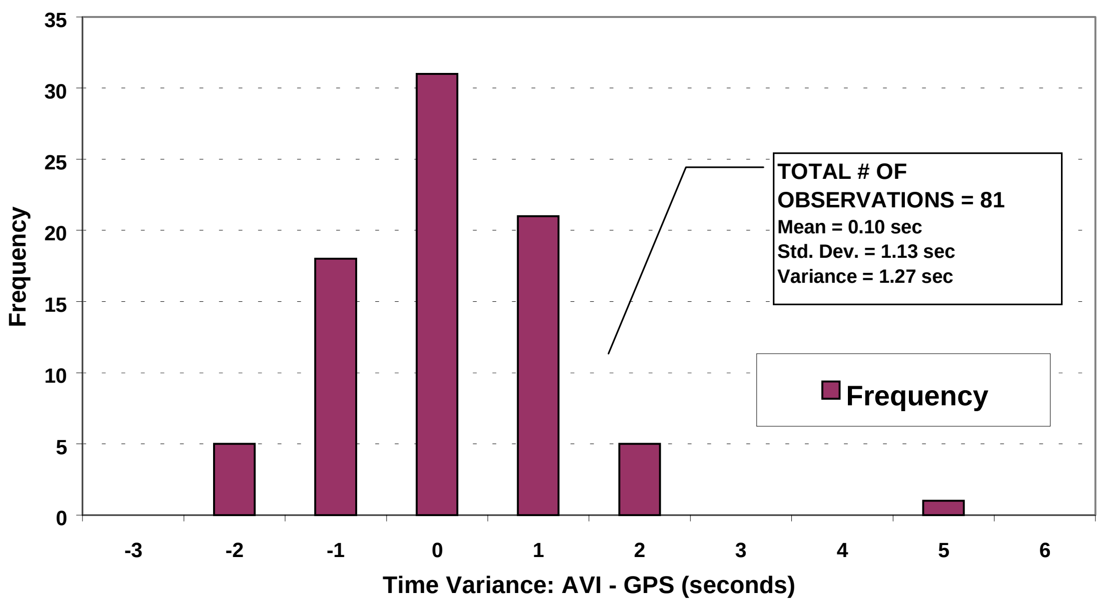

Figure 4.9 – AVI-GPS Travel Time Variance Histogram – I –35

The values calculated for the histogram were found by simply subtracting the GPS link time from its respective AVI link time, as shown by equation 4.1.

$$V_i = AVI_i - GPS_i, \text{ for } i = 1 \text{ to } 81 \qquad (4.1)$$

for …

V_i = Time Variance

As reported in the callout in Figure 4.9, the mean difference between AVI link times and GPS-recorded link times was 0.10 seconds over 81 observations. The standard deviation of the population was 1.13 seconds. As shown, all but one travel time observation fell within 2 seconds of the AVI time. In addressing the stray value of 5 seconds shown in Figure 4.9, a review of the data collector's notes revealed there was an accidental late GPS-entry for the beginning AVI site of that particular link. This value was a result of human error and not AVI system error. To observe the effect of this erroneous data point, its value was removed from the data set and the mean, standard deviations and variance were recalculated. In addition, to observe the relative time variance, the individual time variances were divided by their respective link travel times. The resulting histogram is given in Figure 4.10.

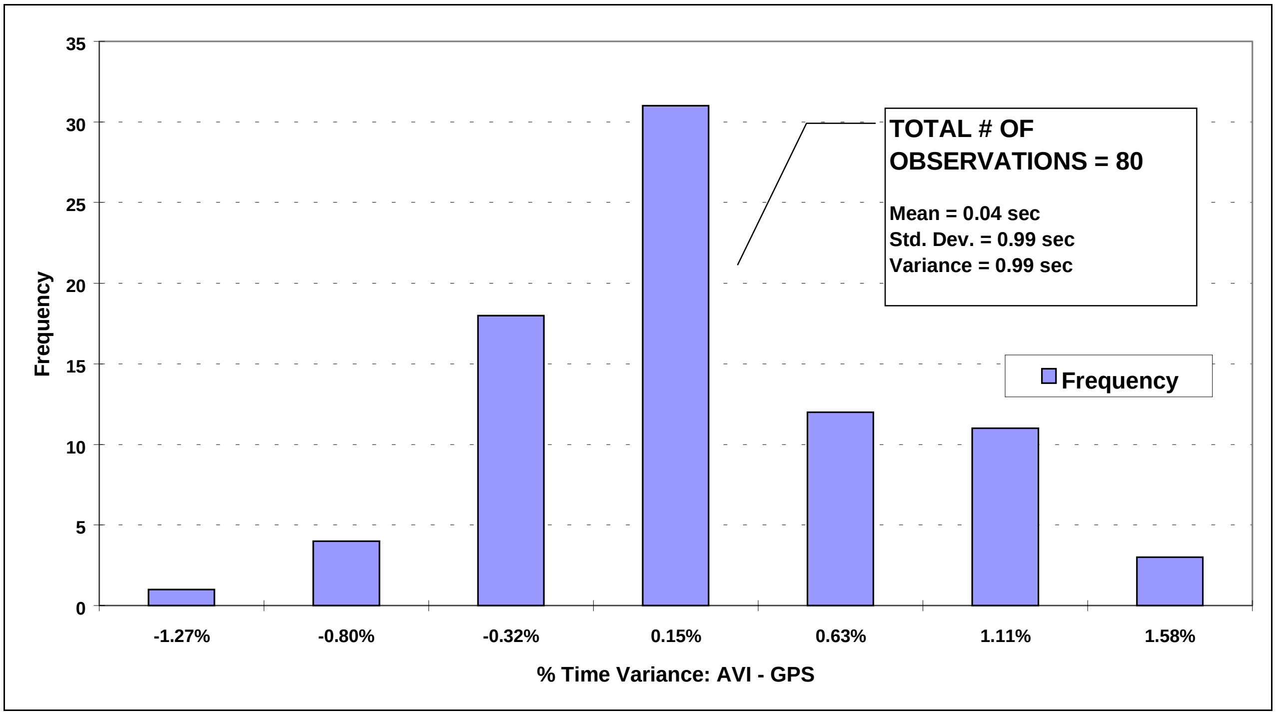

Figure 4.10 – AVI – GPS Travel Time Variance Histogram, I-35 – Filtered Data Set

A comparison of the values for mean, standard deviation and variance reported in Figures 4.9 and 4.10 are given in Table 4.12.

Table 4.12 – Statistical Data for Original and Modified GPS - AVI Travel Time Data Set

DATA SET	LARGEST DEVIATION (s)	MEAN (s)	STANDARD DEVIATION (s) (population)	VARIANCE
Original	5	0.10	1.13	1.27
Modified	2, -2	0.04	0.99	0.99

The results for the modified standard deviation and variance make intuitive sense given that the GPS units log the position and User Flag data to an output file at one second intervals. In a sense, two worst-case scenarios could result. The GPS unit could generate a position update entry just prior to the passage of an antenna and the pushing of the User Flag 'p' by the data collection team. This would result in the GPS-logged start time being one second late, as a full second would elapse before the GPS unit would log a new position update record containing the 'p.' In the event that the data collector 'anticipated' the next and final antenna on the link by pressing the User Flag 'p' slightly early, an arrival time might be recorded and logged a full second prior to the actual arrival time. In such a case, the GPS link time yields a value two seconds *less than* that of the AVI time, given that a second was lost at both link endpoints because of the late start and early finish unintentionally recorded by the data collector. In applying Equation 4.1, a value of 2 seconds is calculated for such a scenario. In order to generate a V_i value of –2, the opposite of what was just described would have to occur: an early entry at the first link AVI site and a late entry at the second and final link boundary.

Because of the limited set of arterial link observations recorded by the GPS and AVI equipment, accurate data is unavailable for the arterial links tested.

Given that the mean link travel time calculated by the AVI system for the test vehicle freeway runs was 166.1 seconds (ranging from a low of 136 sec. to a high of 348 sec.), a standard deviation of 1.13 seconds is acceptable for the application at hand. Even if the system were to deviate from the true travel time by the value of the standard deviation, the resulting error would be just 0.68%, a negligible value given the application. A worst-case scenario would pair the shortest link travel time recorded by the data collection team (136 sec.) with the largest absolute V_i (apart from human error), which was 2 sec. Such a case would yield a travel time error of 1.5%, still a marginal value. This margin of error translates into an error of +/- 0.9 mph for a trip made at 60 mph. By comparison, the use of spot speeds generated by inductance loop detectors to calculate travel times frequently results in time variances of between 5 and 10 mph (Ford).

4.4 Summary

In this chapter, a description of the functionality of San Antonio's AVI system is given. Next, the overall reliability of the San Antonio AVI system was assessed. Lastly, a controlled system reliability test was performed using a tag-equipped test vehicle.

Overall system reliability was measured by observing the number of AVI sites functional during a one-month period beginning on June 11, 1998 and ending on July 10, 1998. During that time, over 90% of the 53 readers were found to be functioning correctly for each day observed. This observation corresponded to about 3 readers down per day. A total of 6 sites experienced at least one day of down-time during that period, with the longest period of non-functionality for a single reader being 25 days. In the controlled reliability study, the freeway AVI readers sites tested showed a slightly higher capture rate than the arterial reader sites tested (86% vs. 75%). In addition, it was shown that the mounting configuration of AVI antennas appear to have an influence on tag capture rate. This observation was most notable at AVI site 44 on I-35 South, which was located in a weaving section. It was found that during congested conditions, through-traffic might be more likely to use the right-most lane which was not designed for AVI coverage. Such a combination of highway geometry and antenna configuration could result in a reduced number of tag-equipped vehicles being captured at that site. Thunderstorm activity was present during one morning of drive tests. During that time, it was found that the AVI system correctly recorded 94% (15 of 16) of the passes performed by the test vehicle. This result indicates that AVI reliability is not dependent upon dry/clear weather conditions. Lastly, AVI reliability was found to fluctuate for different test vehicle speeds. It was concluded with limited confidence that AVI reliability is independent of vehicle speed.

In the study of AVI accuracy, it was found that the AVI system is highly accurate in calculating travel times. For the experimental data set of 80 link travel times (filtered to remove entries affected by human error), the difference between AVI-calculated travel times and GPS-calculated travel times was found to be less than 2% in each instance. The mean difference between AVI- and GPS-calculated travel times was found to be 0.04 seconds, with a standard deviation of 0.99 seconds. The level of travel time accuracy generated by the AVI system was found to exceed those often reported for loop detectors.