Chapter 6 – Level of Aggregation Study

The objective of the probes in San Antonio is to provide accurate travel time information to ATIS users. Because of variability in travel times between multiple tag-equipped vehicles that complete a link within the same time period, San Antonio AVI travel time data are aggregated and averaged to provide users with more representative information. The data set collected during the San Antonio freeway and arterial drive tests provides a source of data suitable for a case study of the effects of different levels of travel time aggregation.

This chapter will discuss the current travel time algorithm used by the Transguide system to calculate aggregate travel time information for all AVI links. Next it will examine the variance in GPS test vehicle travel times vs. aggregate travel based on 2-min, 5-min and 15-min time windows. Finally, a root mean square error (RMSE) analysis and a correlation analysis will be performed on the GPS and aggregate travel time data. This analysis is conducted to observe how aggregated travel time averages relate quantitatively to the individual GPS probe vehicle's travel times during testing.

6.1 Description of San Antonio Rolling Average Algorithm

The 53 AVI antenna sites provide coverage of a total of 94 links in San Antonio. Travel times for each link are updated every five minutes by a rolling average algorithm, and are subsequently reported to the web-based Transguide traffic map (http://www.transguide.dot.state.tx.us/), Traveler Information Kiosk System and In-Vehicle Navigation System. By calculating a rolling average of travel times at five-minute intervals, Transguide officials can provide average travel time data which capture and average multiple vehicle-trips across each link, while still delivering this information with real-time timeliness.

The rolling average algorithm calculates link travel times by matching unique tag reads recorded by the AVI readers at the start and at the end of defined AVI links. For each link, the algorithm sums and averages the travel times of the trips completed by AVI-equipped vehicles during five-minute time windows. It then reports the resulting averaged travel times. Trips are filtered so that excessively high travel times are eliminated prior to calculating any link travel time average.

This filtering step effectively eliminates vehicles which have exited and re-entered the link, or which have taken an indirect route to proceed between link-bounding readers. Such an instance might arise on AVI-equipped freeways if a vehicle passes an AVI reader, and then proceeds to the nearest freeway exit to purchase gasoline or food, prior to arriving at the next AVI reader site. If the vehicle were to then return to the freeway and traverse the remainder of the AVI link, its time would be significantly higher than vehicles that did not exit the freeway. Such a travel time would inappropriately inflate the rolling average value calculated for the five-minute window during which that vehicle finished traversing the AVI link. Similar scenarios can be easily visualized on arterials for travelers who are shopping or eating at restaurants located between AVI readers. A complete and detailed description of the rolling average algorithm is found in Appendix A.

6.2 Qualitative Analysis of Probe Vehicle Travel Times vs. Aggregate Travel Times

To acquire a general understanding of how closely the test vehicle's freeway and arterial link travel times were correlated to aggregated travel times, several plots were created for both freeway and arterial runs. Three representative plots (2 freeway sections and 1 arterial section) are given below as Figures 6.1, 6.2 and 6.3. To provide a thorough comparison, three levels of aggregation were calculated (2-min, 5-min and 15-min aggregations) and plotted along with the test vehicle's link travel times. Aggregated travel time values were obtained using a Visual Basic program which processes AVI tag read archives to calculate average link travel times.

6.2.1 Qualitative Analysis – I-35 Freeway Sections

Figures 6.1 and 6.2 illustrate how the test vehicle's travel times compared to aggregate travel times of 2, 5 and 15 minutes for two different AVI links on I-35. Figure 6.1 shows data for June 11, 1998 between AVI sites 43 and 44 on I-35 North. This figure shows a moderate level of congestion during both the morning and evening peak hours. Figure 6.2 shows data plotted for the same date between AVI sites 45 and 44 on I-35 South. This figure illustrates significant AM-peak congestion.

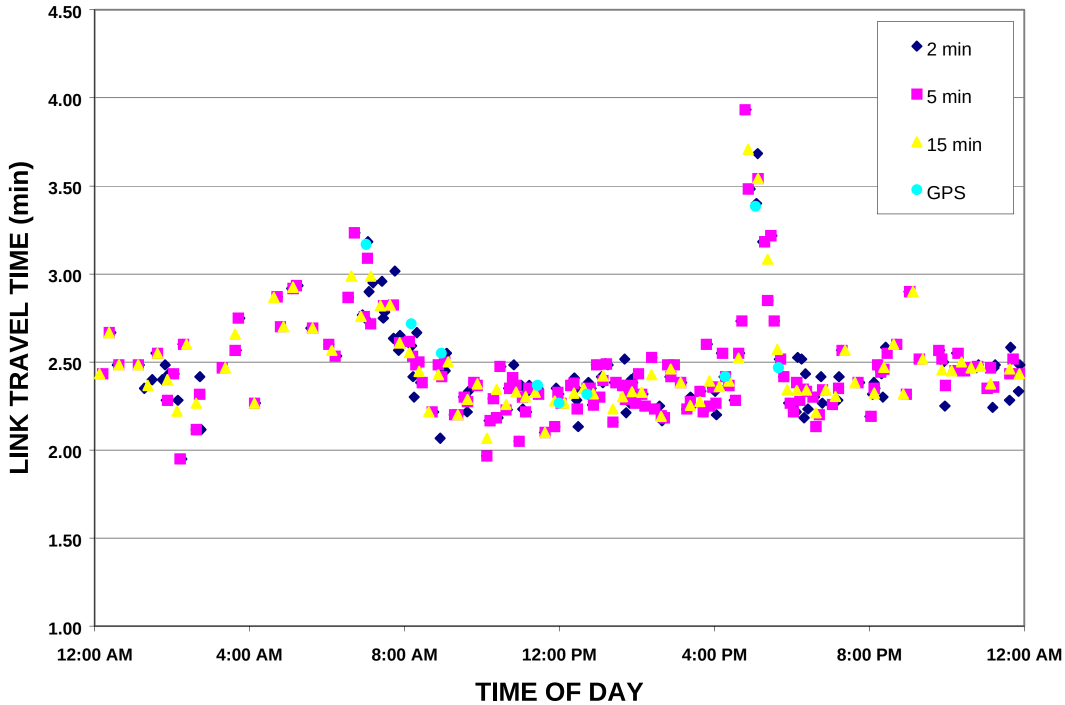

Figure 6.1 – Individual Probe Travel Time vs. 2-, 5- & 15-min Averages (I-35 North from AVI Site 43 to 44)

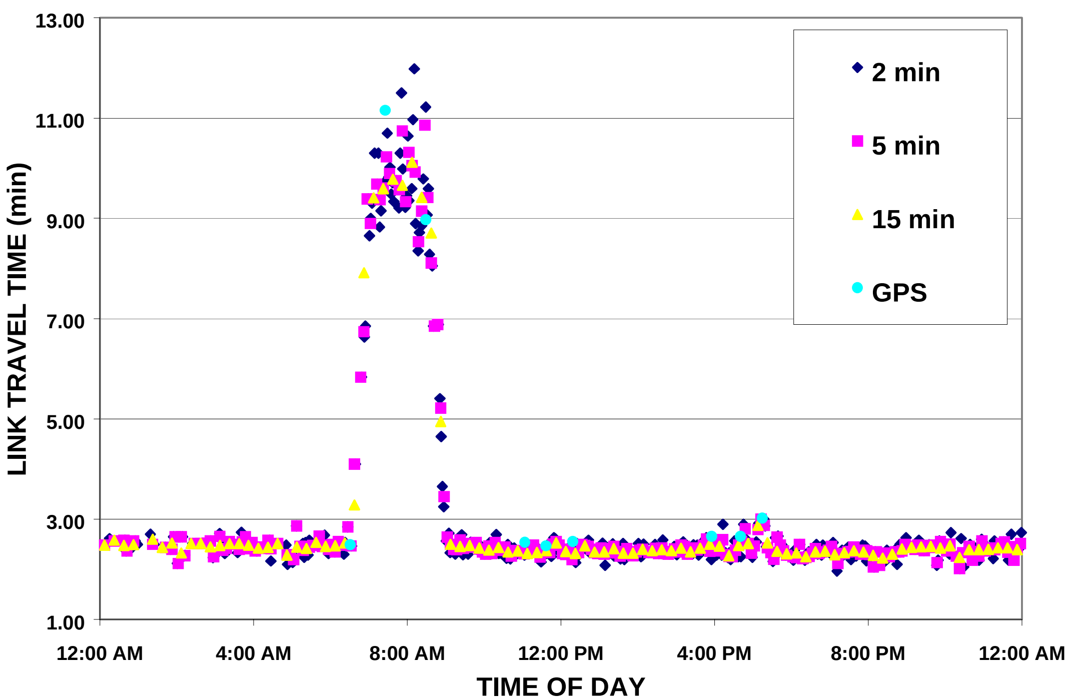

Figure 6.2 – Individual Probe Travel Time vs. 2-, 5- & 15-min Averages (I-35 South from AVI Site 45 to 44)

6.2.1.1 Discussion of Qualitative Analysis – I-35 Freeway Sections

From Figures 6.1 and 6.2, it is apparent that the AVI system effectively captures increased travel times during peak-hour congestion. In addition, the 2-min aggregation values (blue diamonds) tend to vary the greatest, amount while the 15-min aggregation values (yellow triangles) tend to vary the least. This makes intuitive sense, given that the larger sampling of travel times (15-min aggregation) should also tend to smooth out the increase in variation present in the measurements for a smaller sampling size (2-min aggregation).

A second qualitative observation can be made by examining how closely the test vehicle's travel times (represented by light blue circles) resemble the aggregated travel time values. Close observation reveals that a total of nine GPS trips were made on each link: 3 during the AM peak, three during the midday off-peak and three during the PM peak. As expected, the test vehicle's link travel times follow the aggregated travel time values plotted.

Of final note is the variance between the 2-min, 5-min and 15-min aggregation values during periods of congestion. In Figure 6.2, this variance is most apparent at approximately 8 am. During this time there was significant thunderstorm activity in San Antonio, and traffic flow became congested due to poor visibility and road conditions which caused several accidents on I-35. At the peak of the congestion, there is a distinct separation between blue, red and yellow points representing the increasing levels of aggregation. As expected, the 2-min aggregate values at the peak of congestion show the highest travel time values (max. of 11 min. 59 sec. at 8:11 am), while the 15-min aggregate values show the lowest peak (10 min 7 sec. at 8:07 am). This separation is noteworthy as it indicates that the time window chosen to perform rolling average travel time calculations on freeways can affect the accuracy of the data being provided to ATIS users.

6.2.2 Qualitative Analysis – Fredericksburg Rd. Arterial Section

Figure 6.3 illustrates individual test vehicle and aggregated travel times for the northbound Fredericksburg Rd. arterial link bounded by AVI sites 17 and 16. This northbound link from site 17 to 16 is a coordinated, signalized corridor encompassing five signalized intersections. As noted in Figure 6.3, the signalization of this route creates significant variations in travel time throughout the day. Travel times range from a low of 1 minute 18 seconds (2:55 am) to a high of 3 minutes 37 seconds (5:33 pm). As expected, the highest travel times occur during the AM and PM peaks.

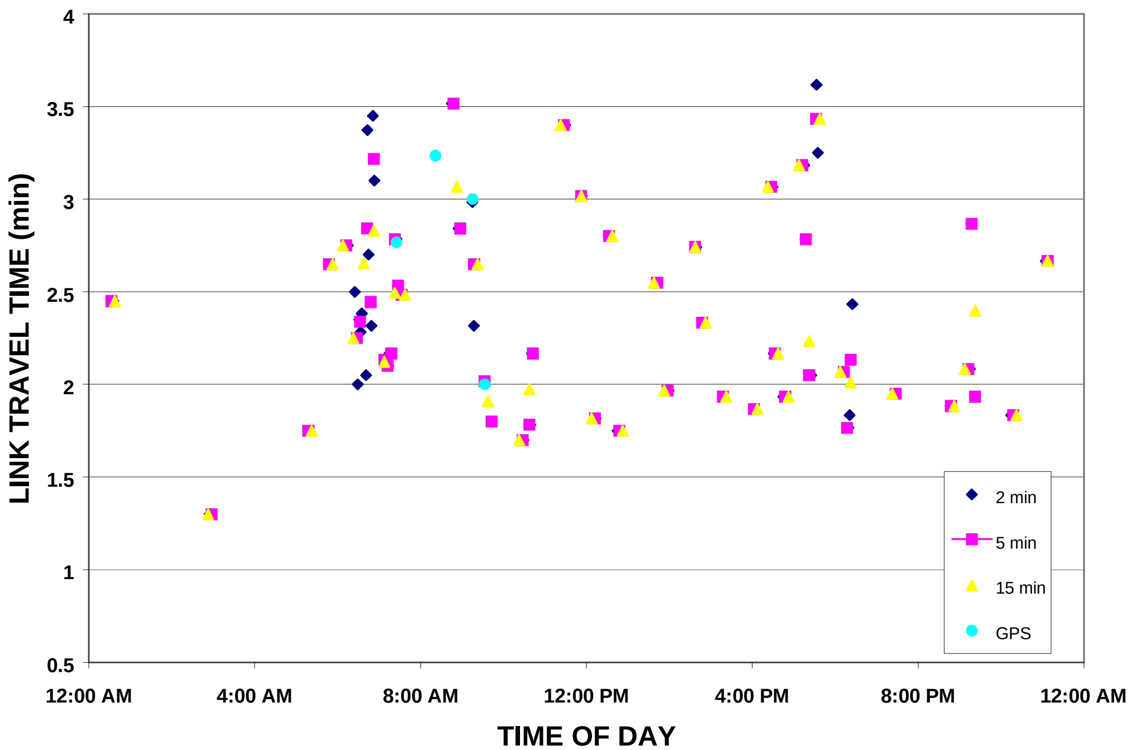

Figure 6.3 – Arterial Probe Vehicle Link Travel Time vs. 2-, 5- & 15-min Aggregate Travel Times Fredericksburg Rd. Northbound from AVI Site 17 to 16

6.2.2.1 Discussion of Qualitative Analysis – Fredericksburg Rd. Arterial Section

Because of Fredericksburg Rd.'s signalization, both test vehicle and aggregate travel times vary greatly throughout the day. The scattered nature of the plot in Figure 6.3 differs noticeably from the more uniform trends shown in Figures 6.1 and 6.2. Figures 6.4 and 6.5 demonstrate the varied nature of the aggregated values on Fredericksburg arterial vs. those on I-35. For comparative purposes, both plots in Figures 6.4 and 6.5 have been fit to the same y-axis scale (link travel times from 1.0 min to 4.0 min.), and point-to-point smoothing has been performed for the 15-min aggregate values.

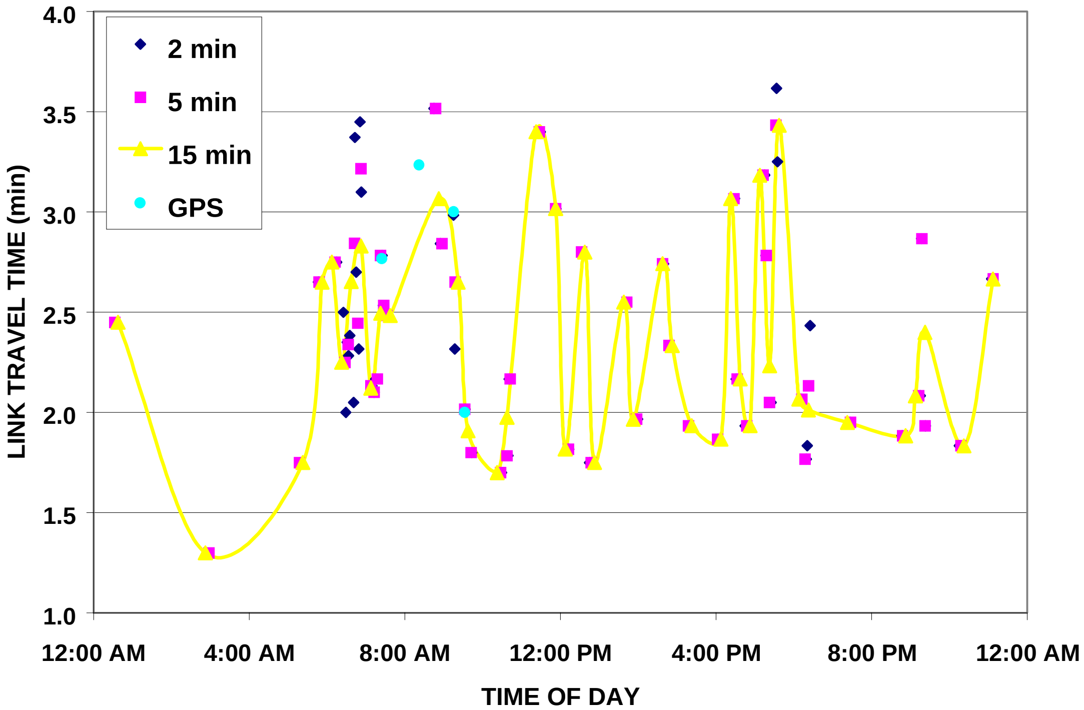

Figure 6.4 – Fredericksburg Rd. Arterial Section - 15-min Aggregation Point-to-Point Smoothing AVI Site 17 to 16 (Northbound)

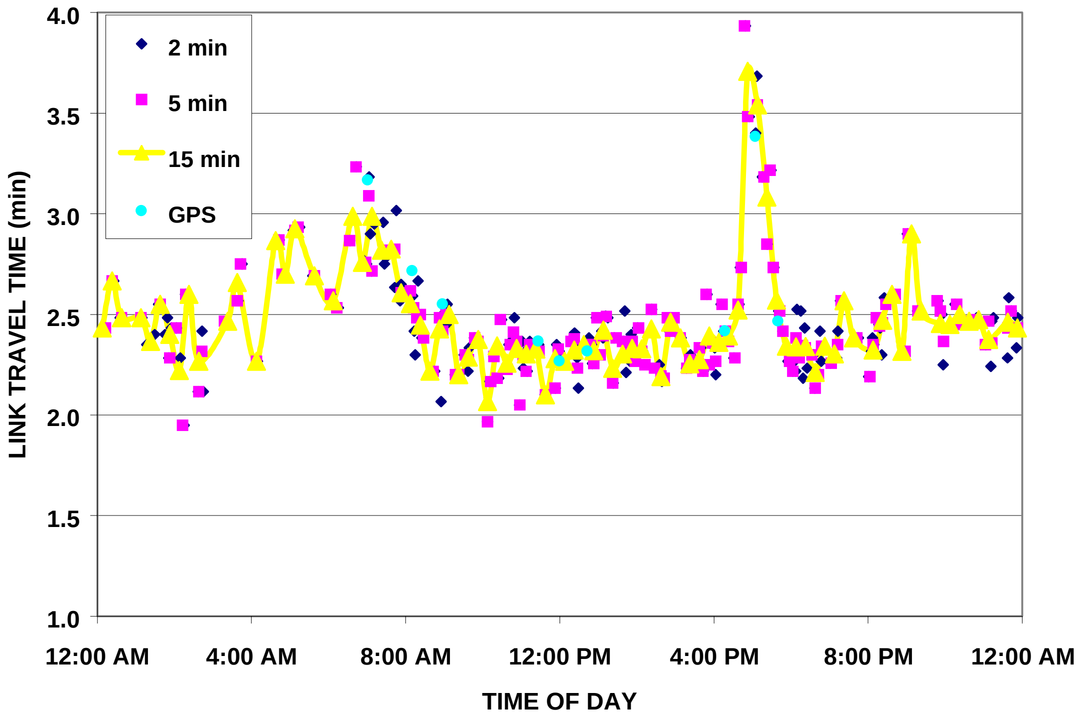

Figure 6.5 – I-35 Freeway Section - 15-min Aggregation Point-to-Point Smoothing AVI Site 43 to 44 (Northbound)

The point-to-point smoothing in Figure 6.4 oscillates throughout the day in large, irregular waves, while the same trendline in Figure 6.5 shows oscillation amplitudes that are of lower magnitude during different times of the day. While the trendline for the arterial section in Figure 6.4 experiences oscillations frequently greater than 0.5 minutes, the trendline for the freeway section in Figure 6.5 generally shows oscillations less than 0.5 minutes in difference. Additionally, the arterial section in Figure 6.4 shows consistently large oscillations throughout the day, while the freeway section in Figure 6.5 shows small to medium size oscillations during the AM peak and off-peak hours, with a large jump during the PM peak.

Because there were only three arterial runs shown in Figure 6.4, it is difficult to develop a general conclusion on how well the test vehicle link travel times correlate with the aggregate link travel times. As demonstrated by Figures 6.1 through 6.5, the nature of aggregate travel time variance can differ substantially between AVI-equipped freeways and arterials. This qualitative analysis develops a suitable platform from which the subsequent quantitative analysis can be performed.

6.3 Quantitative Analysis of Individual Probe vs. Aggregate Travel Times

As demonstrated in section 6.2, the level of aggregation of link travel time data influences the accuracy of real time data being provided to ATIS users. This section will first quantify the root mean square error (RMSE) that is observed between the test vehicle and the three levels of aggregation (LOA). Correlation analysis results will also be reported for the 3 LOA's. A discussion of the results will follow.

6.3.1 Root Mean Square Error (RMSE) Analysis of Test Vehicle and Aggregated Link Travel Times

A RMSE analysis was performed on the arterial and freeway data set described in Chapter 5. This analysis was performed to identify any trends in RMSE as the link travel time aggregation level was varied. This section addresses the same 2-min, 5-min and 15-min aggregation levels discussed in Section 6.2.

The RMSE analysis is used to evaluate the error between a series of numbers found in a pair of same-dimension vector arrays of dimension [1 x n]. For two distinct arrays X and Y of dimension [1 x n], the general form of the RMSE equation is found in Equation 6-1.

(Eqn. 6-1) $$\text{RMSE} = \frac{\left[\sum_{i=1}^{n}(x_i - y_i)^2\right]^{1/2}}{(n-1)}$$

for x_i = i^{th} element in array X

y_i = i^{th} element in array Y

n = no. elements in arrays X and Y

The specific form of the RMSE equation for calculating root mean square error between a set of test vehicle link travel times and a corresponding set of aggregated like travel times is given in Equation 6-2.

(Eqn. 6-2) $$\text{RMSE}_{jk} = \frac{\left[\sum_{i=1}^{n}(GPS_{ij} - AGGX_{ijk})^2\right]^{1/2}}{(Q_{jk}-1)}$$

for

GPS_{ij} = test vehicle link travel time for link j

$AGGX_{ijk}$ = aggregated link travel time

Q_{jk} = number of elements in {AGGX}

i = test run identifier

n = number of test runs for link j

j = link identifier

k = aggregation level

The general forms of the GPS and AGGX arrays are given below.

$$GPS = \begin{Bmatrix} 1 \\ 2 \\ . \\ . \\ . \\ . \\ . \\ . \\ n \end{Bmatrix} \qquad AGGX = \begin{Bmatrix} 1 \\ 2 \\ . \\ . \\ . \\ . \\ . \\ . \\ n \end{Bmatrix}$$

Since 9 test runs were performed for each freeway link, all GPS_j arrays are {1 x 9}, as are all *complete* $AGGX_{jk}$ arrays. Some $AGGX_{jk}$ arrays, however, are incomplete given that vehicle tag matches were not obtained by the AVI system. In such cases, corresponding values of the GPS_j values are removed such that the dimensions of the GPS_j and $AGGX_{jk}$ are equal. Freeway links are assigned link identification (ID) numbers. The link ID table for this experiment is shown below in Table 6.1. AVI antenna site locations are illustrated in Figure 6.6 for reference.

Table 6.1 – I-35 Freeway Link ID Table

$$\begin{Bmatrix} 1 & 42to43 \\ 2 & 43to44 \\ 3 & 44to45 \\ 4 & 45to44 \\ 5 & 44to43 \\ 6 & 43to42 \end{Bmatrix}$$

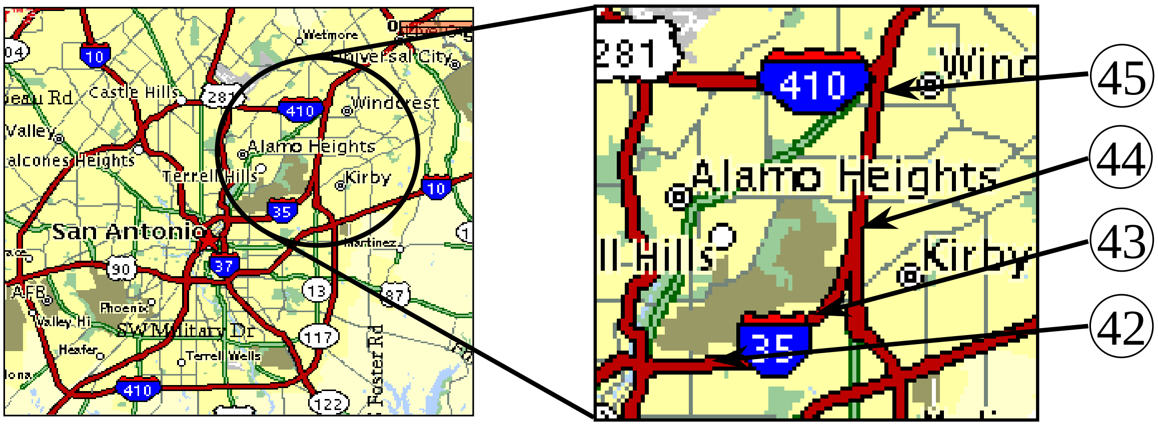

Figure 6.6 – AVI Antenna Site Locations for I-35 Freeway Link ID Table (source: http://www.mapquest.com/)

A sample calculation of a RMSE value for the I-35 link 2 (AVI sites 43 to 44) is given below. This sample equation compares test vehicle link travel times with 2-min aggregate link travel times.

Sample RMSE Calculation:

Level of Aggregation, k = 2-min Link ID, j = 2

$$GPS_2 = \begin{Bmatrix} 190 \\ 163 \\ 153 \\ 142 \\ 136 \\ 139 \\ 145 \\ 203 \\ 148 \end{Bmatrix} \qquad AGG2_2 = \begin{Bmatrix} 190 \\ 154 \\ 147 \\ 138 \\ 124 \\ 139 \\ n/a \\ 222 \\ 151 \end{Bmatrix}$$

Since $AGG2_{7,2}$ holds no data, it is removed from the set along with the 7^{th} element of GPS_2 (145).

The new sets for GPS_2 and $AGG2_2$ are given below:

$$GPS_{link2} = \begin{Bmatrix} 190 \\ 163 \\ 153 \\ 142 \\ 136 \\ 139 \\ 203 \\ 148 \end{Bmatrix} \qquad AGG2_2 = \begin{Bmatrix} 190 \\ 154 \\ 147 \\ 138 \\ 124 \\ 139 \\ 222 \\ 151 \end{Bmatrix}$$

For the above data:

$$RMSE_{2,2} = \frac{\left[\sum_{i=1}^{8} (GPS_i - AGG2_i)^2\right]^{1/2}}{(8-1)}$$

$RMSE_{2,2}$ =

$$\frac{\left[(190-190)^2 + (163-154)^2 + (153-147)^2 + (142-138)^2 + (136-124)^2 + (139-139)^2 + (203-222)^2 + (148-151)^2\right]^{1/2}}{(8-1)}$$

= 4 seconds

To better quantify the value for $RMSE_{2,2}$, it can be divided by the average recorded GPS link travel time for link 2 ($AVGTT_{2\text{-}min}$) to obtain the percent RMSE relative to the average for the given link (Note: all link 2 GPS travel times *prior to* reduction of the GPS_{link2} travel time set performed above are included in this average calculation).

The average of GPS_{link2}, $AVGTT_{2\text{-}min} = \dfrac{(190+163+153+142+136+139+145+203)}{8}$ = 158 sec.

$$PCTRMSE_{2,2} = 100\% \text{ x } \left[\frac{RMSE_{2,2}}{AVGTT_{2=\min}}\right] = 100\% \text{ x } \left\{\frac{4\text{ sec.}}{158\text{ sec.}}\right\} = 2.3\%$$

Hence, the RMSE for link 2, aggregation level 2 is 4 sec. or 2.3%.

RMSE analyses were performed for each of the six I-35 freeway AVI links driven and for each of the three levels of aggregation. Statistics for the data used in the RMSE calculations are found in Table 6.2.

Table 6.2 – Summary of Data Available for RMSE Analysis

LINK	LINK ID, *i*	# OF GPS RUNS PERFORMED	# OF ELEMENTS 2-MIN AGGREGATION	# OF ELEMENTS 5-MIN AGGREGATION	# OF ELEMENTS 15-MIN AGGREGATION
42 TO 43	1	9	7	9	9
43 TO 44	2	9	8	9	9
44 TO 45	3	9	7	9	9
45 TO 44	4	9	5	8	9
44 TO 43	5	9	6	9	9
43 TO 42	6	9	6	9	9
TOTAL		**54**	**39**	**53**	**54**

The results of these analyses are reported in Table 6.3.

Table 6.3 – I-35 Freeway Root Mean Square Error Analysis for 2-min, 5-min and 15-min Aggregated Travel Time Data

LINK	LINK ID, *i*	AVG TT 2-MIN AVG	AVG TT 5-MIN AVG	AVG TT 15-MIN AVG	RMS ERROR 2-MIN (s)	RMS ERROR 5-MIN (s)	RMS ERROR 15-MIN (s)	RMS ERROR 2-MIN (%)	RMS ERROR 5-MIN (%)	RMS ERROR 15-MIN (%)
42 TO 43	1	161	160	160	6	3	3	3.9%	1.8%	1.8%
43 TO 44	2	158	156	155	4	2	3	2.3%	1.4%	1.8%
44 TO 45	3	167	164	160	3	3	4	2.0%	1.8%	2.6%
45 TO 44	4	232	247	240	23	15	10	9.8%	6.2%	4.0%
44 TO 43	5	149	149	151	5	5	3	3.1%	3.6%	2.3%
43 TO 42	6	188	180	178	7	5	5	3.7%	2.5%	2.9%
AVERAGE					**8**	**6**	**5**	**4.1%**	**2.9%**	**2.6%**

6.3.1.1 Discussion of RMSE Analysis

As shown by the totals in Table 6.2, the *total average* RMSE is reduced for the set of 6 links observed as the aggregation level is increased. A graphical display of the %-RMSE for each link for the three aggregation levels shown in Table 6.3 is given below in Figure 6.7.

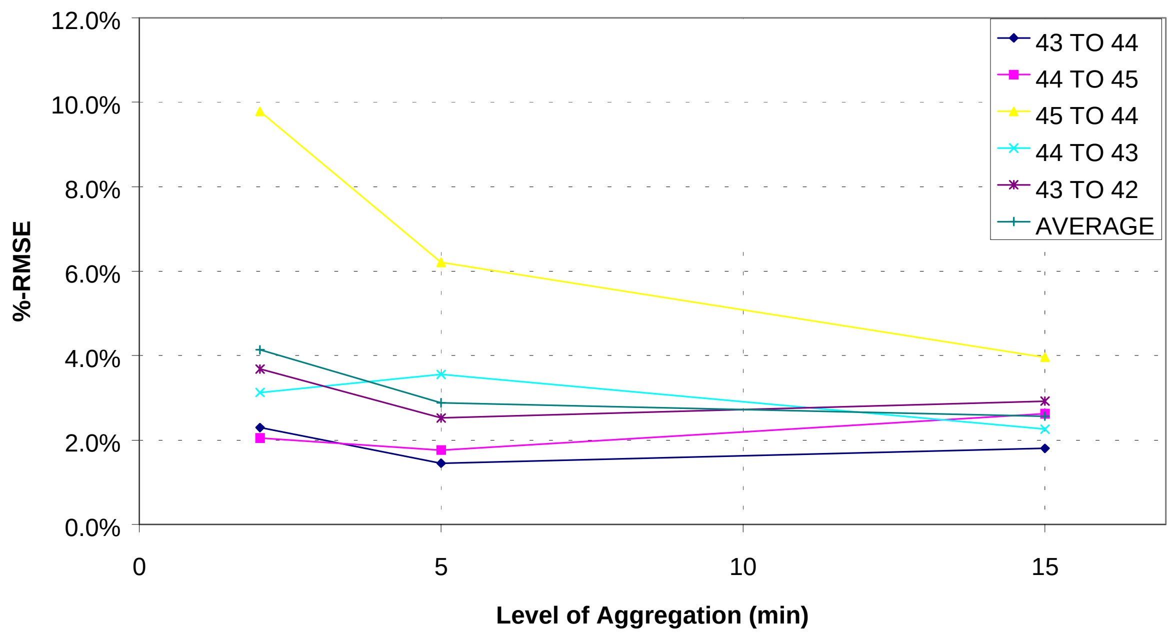

Figure 6.7 – Percent Root Mean Square Error vs. Level of Aggregation

Figure 6.7 illustrates the general trend of reduced %-RMSE as link travel time aggregation levels are increased from 2-minute levels to 5-minute levels. In such a case, all 6 links returned reduced RMSE values. However, as the LOA was increased from 5-min to 15-min, 3 of the 6 links returned slight *increases* in RMSE, while one showed no change. These results seem to indicate that an increase from a 2-minute LOA to a 5-minute LOA results in an improved RMSE value, while a subsequent increase to a 15-minute LOA returns mixed results.

On the whole, the RMSE values are quite low (less than 4%), with the exception of link 4, which is the southbound I-35 link from AVI Site 45 (north link boundary) to AVI Site 44 (south link boundary). As discussed and illustrated in Chapter 5 Section 5.1.2, this link contains a weaving section that causes recurring congestion, particularly during peak hour traffic. The relatively high RMSE values are in this case attributed to this weaving section which has been shown to significantly affect individual vehicle travel times across this link.

From a practical standpoint, transportation officials must develop a strategy to determine which LOA meets their accuracy needs, while not compromising their efforts to provide real-time data.

The results found in this analysis indicate that a 5-min LOA represents an improvement over the 2-min LOA for RMSE values calculated between individual vehicles and aggregated vehicle travel times. An increase in LOA from 5-min to 15-min, however, returned an improved RMSE value for only 2 of 6 links. This finding lends credit to the 5-minute rolling average travel time algorithm currently used in San Antonio to calculate travel times on AVI links.

6.3.2 Correlation Analysis of Test Vehicle and Aggregated Link Travel Times

In addition to the RMSE analysis, a correlation analysis was performed for the I-35 freeway AVI links. While the RMSE analysis captures the closeness of GPS and aggregated travel times, it fails to capture how changes in those travel times (increases and decreases) might correlate to one another. This section will analyze how GPS and aggregate travel times are correlated by freeway link, by time of day and by corridor direction.

6.3.2.1 Correlation Analysis by AVI Link

The 54 GPS freeway link runs performed on June 11, 1999, are plotted along with their respective 2-min, 5-min and 15-min AVI aggregate travel time values in Figure 6.8. A qualitative observation of Figure 6.8 reveals that AVI aggregate travel times follow the experimental travel times recorded by the GPS-equipped test vehicle for all link travel times plotted. The graph shows that as GPS link travel times increased, AVI aggregate travel times also increased. In addition, at lower link travel times, the AVI aggregate travel times appear to be more closely bunched around the GPS line of correlation. However, as travel times increased (owing to congestion), the AVI aggregate travel times diverged somewhat from the line of perfect correlation. In addition, the *amount of divergence* appears to increase as the magnitude of the travel times increase.

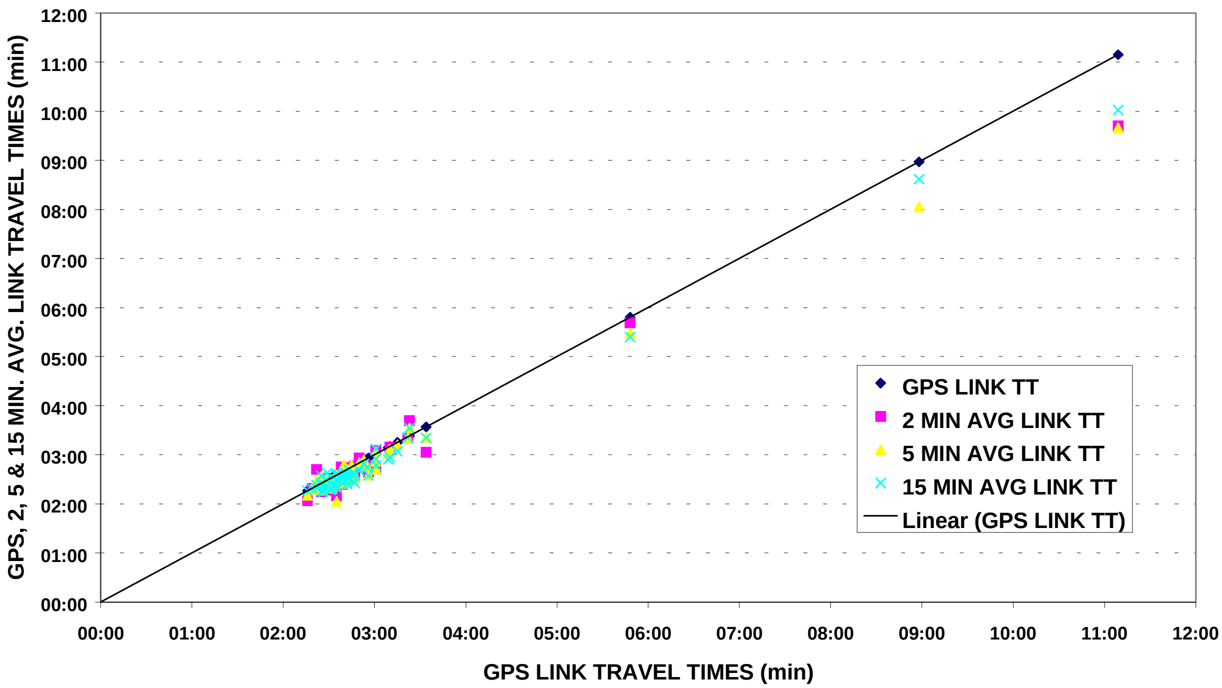

Figure 6.8 – Correlation Plot for Freeway GPS and Aggregate AVI Link Travel Times

A more detailed presentation of the correlation between GPS and aggregate link travel times is given in Table 6.4. This table returns correlation values for the set of nine runs performed across each of the six freeway links.

Table 6.4 – Freeway GPS/Aggregate AVI Correlation Coefficients By Link

LINK	CORRELATION COEFFICIENTS BY LINK		
	2-MIN AVG vs. GPS	5-MIN AVG vs. GPS	15-MIN AVG vs. GPS
42 TO 43	0.8918	0.9917	0.9871
43 TO 44	0.9770	0.9807	0.9550
44 TO 45	0.9409	0.9389	0.9254
45 TO 44	0.9995	0.9992	0.9982
44 TO 43	0.8962	0.5734	0.8121
43 TO 42	0.9904	0.9908	0.9921

As shown by Table 6.4, 11 out of 18 correlation values exceed a value of 0.95, and 16 of 18 exceed 0.85. The link bounded by AVI sites 44 and 43 returned the two lowest correlation coefficient of the sample. This link yielded a value of 0.5734 for the 5-min aggregation level and a value of 0.8121 for the 15-min aggregation level. To better understand these low values, Figures 6.9 and 6.10 are provided to identify more clearly where divergences occurred between the AVI and aggregate travel times.

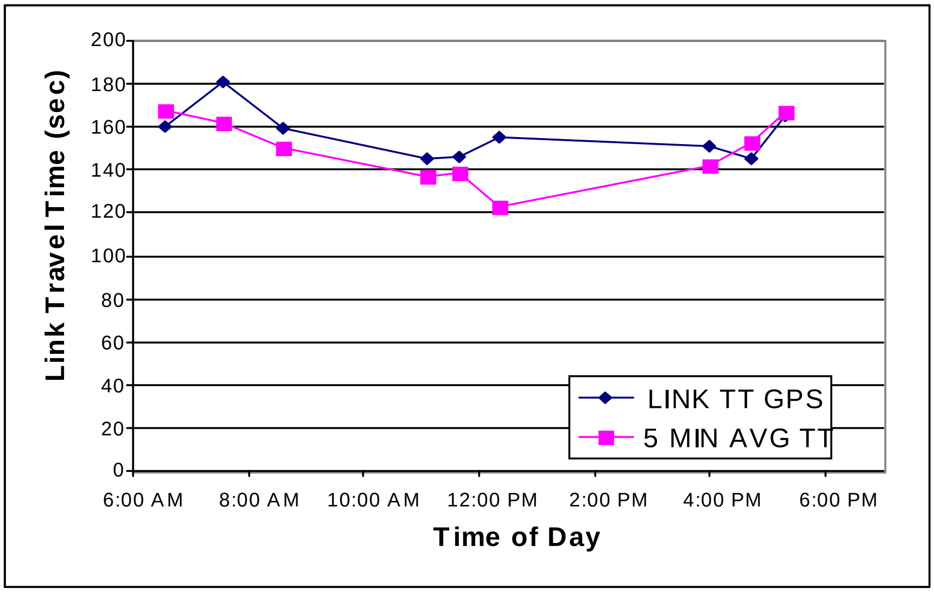

Figure 6.9 – GPS vs. 5-min Aggregate Link Travel Times, AVI 42 to 43

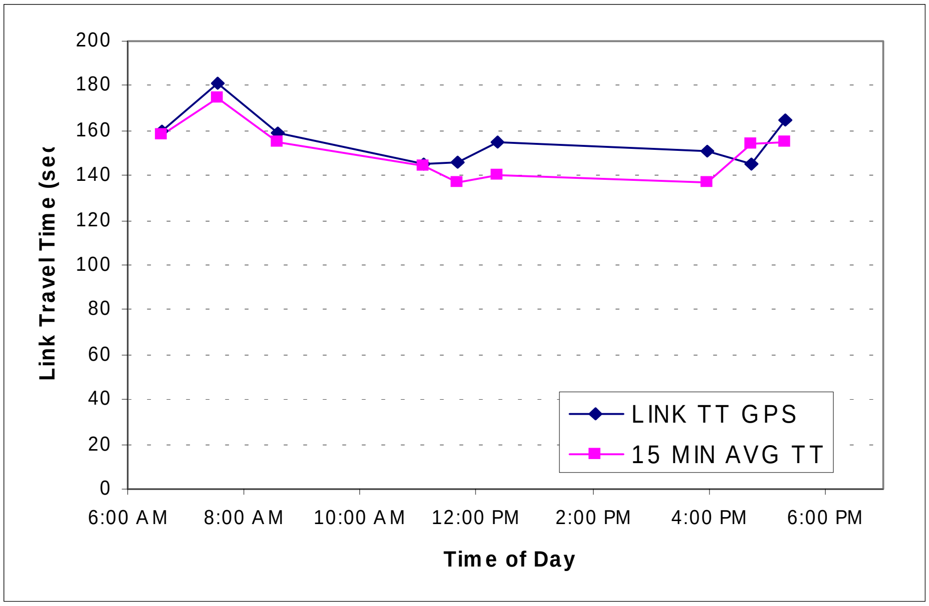

Figure 6.10 – GPS vs. 15-min Aggregate Link Travel Times, AVI 42 to 43

In Figure 6.9, noticeable divergences occur between the first two runs of the day, the 5th and 6th runs (spanning midday) and the 7th and 8th runs. Since the GPS and 5-min aggregate appear to behave independently of one another in those three portions of the plot, the low correlation coefficient reported is not surprising. In Figure 6.10 a similar circumstance is observed as the GPS link travel time values and the 15-min aggregate travel time values behave oppositely (GPS increases slightly while 15-min aggregation decreases) between the 4th and 5th points of each series, as well as the 7th and 8th points. By comparison, Figure 6.11 illustrates the trends of the GPS and aggregate travel time readings for the link and aggregation level returning a higher correlation coefficient (0.9982, AVI 45 to 44 , 15-min aggregation).

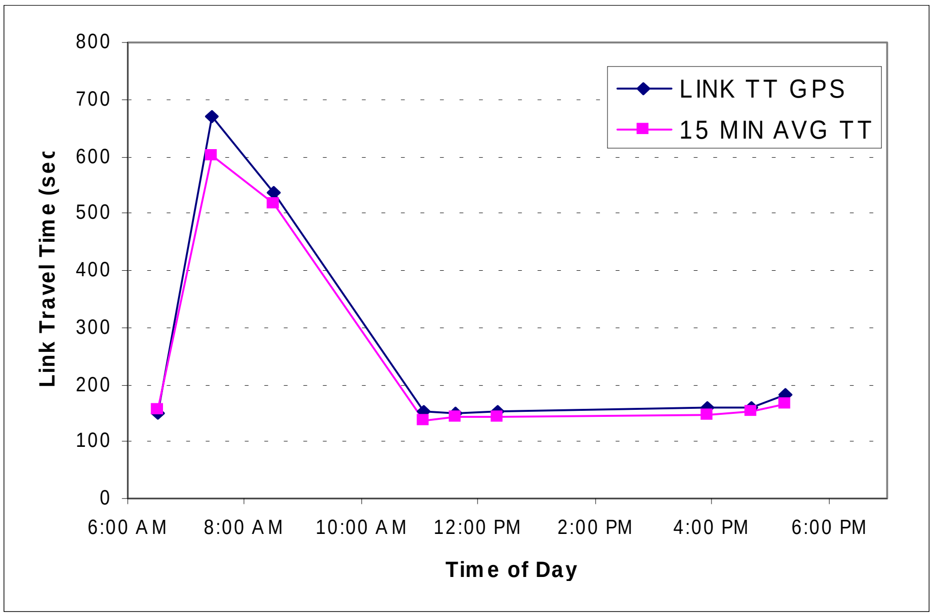

Figure 6.11 – GPS vs. 15-min Aggregate Link Travel Times, AVI 45 to 44

Figure 6.11 reveals a noticeable difference in the of between the GPS and aggregate travel times. Not only are the values extremely close at each run, they also show a high degree of correlation as they increase and decrease together in value.

6.3.2.2 Correlation Analysis by Time of Day

Figures 6.12, 6.13 and 6.14 show correlation plots broken down by time of day: AM, Midday and PM. Again, these plots tend to show a fairly close correlation between GPS link travel times and AVI aggregate travel times, with some diverenge occurring at higher GPS travel time values.

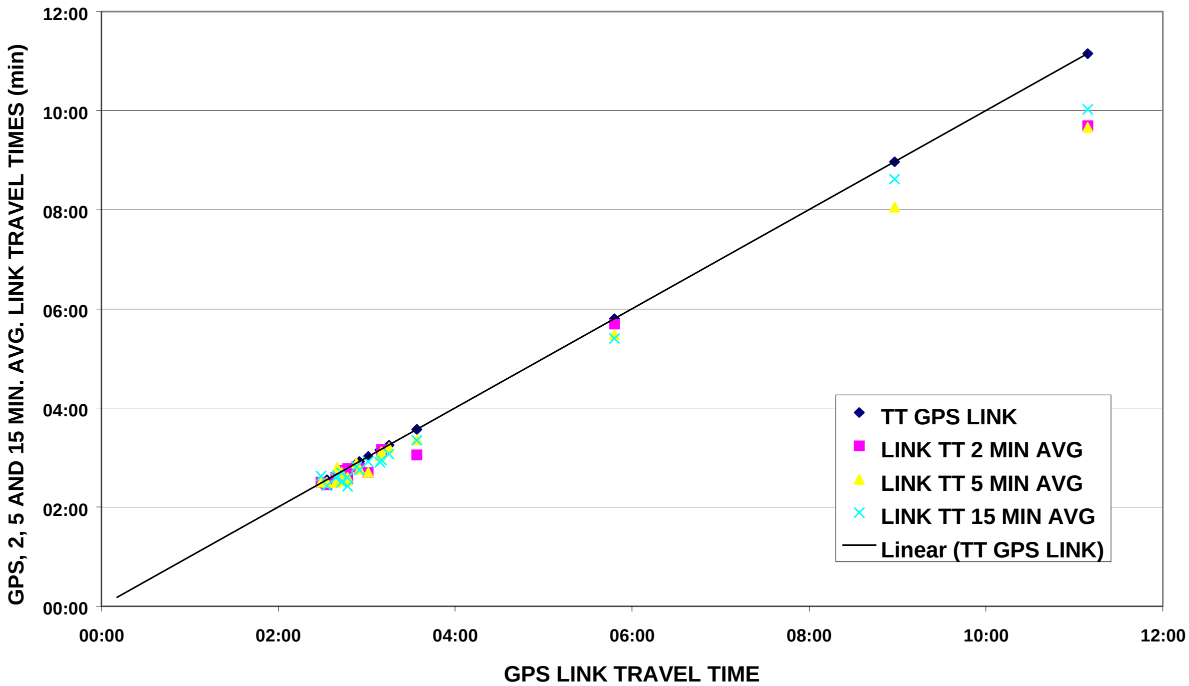

Figure 6.12 – AM Correlation Graph, GPS and Aggregate Travel Times

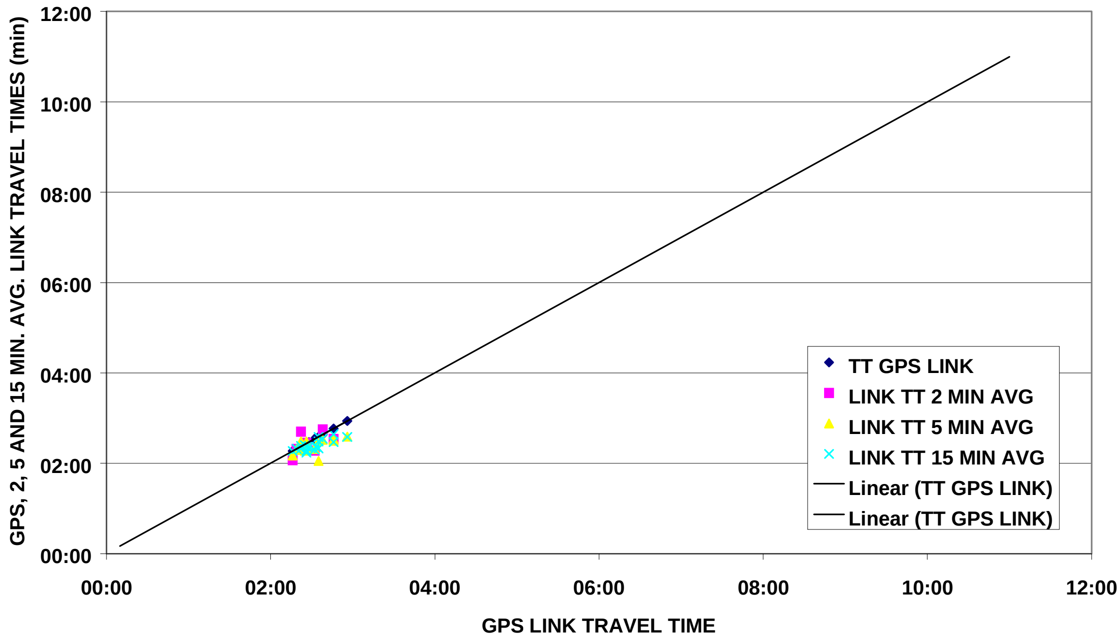

Figure 6.13 – Midday Correlation Graph, GPS and Aggregate Travel Times

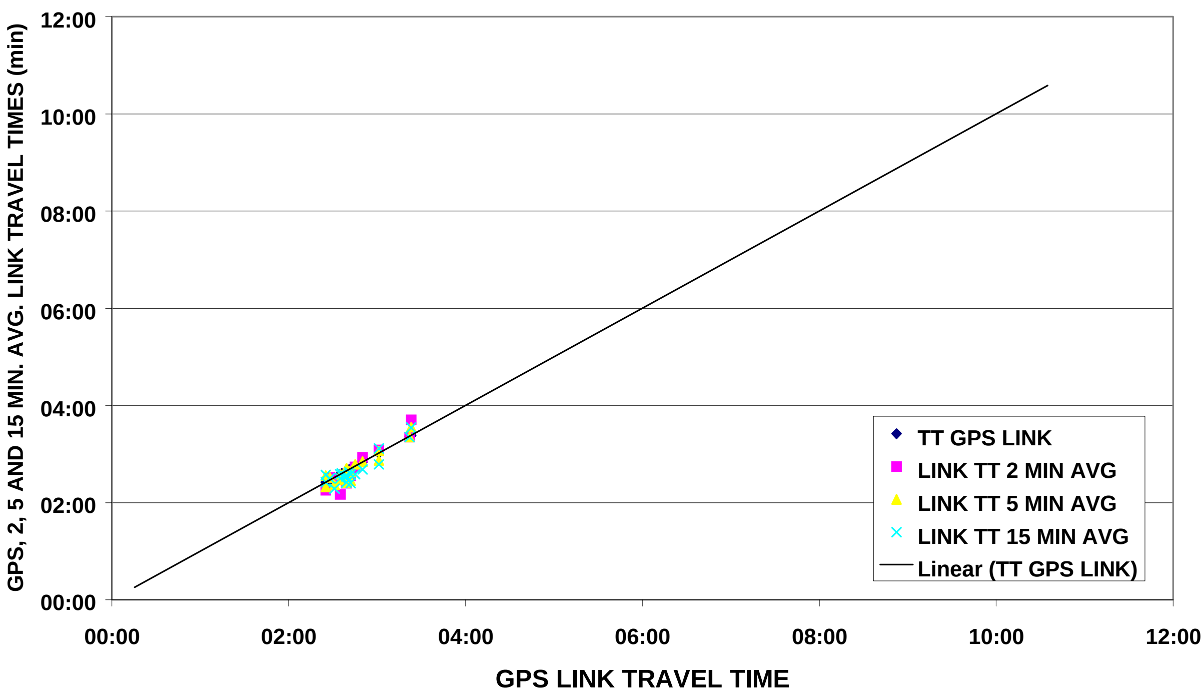

Figure 6.14 – PM Correlation Graph, GPS and Aggregate Travel Times

To better understand the qualitative observations, correlation coefficients were calculated and are reported in Table 6.5.

Table 6.5 – Freeway GPS/Aggregate AVI Correlation Coefficients By Time of Day

TIME OF DAY	CORRELATION COEFFICIENTS BY TIME OF DAY		
	2-MIN AVG vs. GPS	5-MIN AVG vs. GPS	15-MIN AVG vs. GPS
AM	0.9960	0.9982	0.9980
MIDDAY	0.6073	0.5628	0.7701
PM	0.9466	0.9420	0.9165

Upon observing the values reported in Table 6.5, it is obvious that the midday correlation values are significantly lower than the corresponding AM and PM values at each aggregation level. To better understand the poor correlation reported in Table 6.5, a correlation analysis was performed by link for the midday link travel times. The results are given in Table 6.6.

Table 6.6 – Midday Freeway GPS/Aggregate AVI Correlation Coefficients By Link

AVI LINK	2-MIN AVG VS. GPS	5-MIN AVG VS. GPS	15-MIN AVG VS. GPS
42 to 43	N/A	0.8660	0.1890
43 to 42	1.0000	0.9177	0.2250
43 to 44	0.8347	0.8030	0.8660
44 to 43	-1.0000	-0.9789	-0.1723
44 to 45	-0.9984	-0.5000	-0.5852
45 to 44	N/A	-1.0000	-0.3273

As revealed in Table 6.6, there is a significant amount of *negative correlation* in the set of midday link travel time correlation values. 2 of the 18 values are not available because of insufficient data, while 8 of the remaining 16 values are negative. The low midday correlation values reported in Table 6.5 are substantiated by the numerous negative correlation values shown in Table 6.6.

Although it is not precisely known why the correlation values are poor for midday link trips, two potential reasons are offered. The first suggestion is that there is a reduced level of market penetration during the midday period, resulting in fewer tags from which the AVI system can derive aggregate travel times. Because of the hypothesized reduction of samples from which to generate aggregate travel times, it would be more likely that scattered aggregations might be reported at midday. With such an inconsistency in aggregate travel times being reported, the poor correlation values would be expected. In order to examine this hypothesis, the average number of tag reads per aggregation window was computed for the AM, midday and PM periods. The results are given in Table 6.7.

Table 6.7 – Average Number of Tag Reads Per Aggregation Window

TIME OF DAY	2-MIN AVG # READS	5-MIN AVG # READS	15-MIN AVG # READS
AM	2.11	4.00	8.50
MIDDAY	1.28	2.72	7.94
PM	1.16	2.72	7.00

Contrary to what was anticipated, the average number of tag reads per aggregation level is lowest during the PM peak and *not* the midday off-peak. Hence the hypothesis that the low correlation during the midday off-peak is due to reduced tag reads is unfounded.

The second hypothesis is that, because of reduced volume during the midday off-peak, vehicle travel speeds than during denser traffic conditions. With more freedom to travel at a variety of speeds, drivers are thought to be traversing the AVI links at higher and more varied speeds. This greater variability in speeds translates into increased variability in travel times. Such a condition is thought to influence the correlation values in a negative manner, given that the GPS test vehicle was driven at relatively conservative speeds.

6.3.2.3 Correlation Analysis by Direction

As a third and final quantitative evaluation of GPS vs. aggregated AVI travel times, a correlation analysis by direction was performed. Correlation plots for northbound and southbound links were plotted and are illustrated below in Figures 6.15 and 6.16.

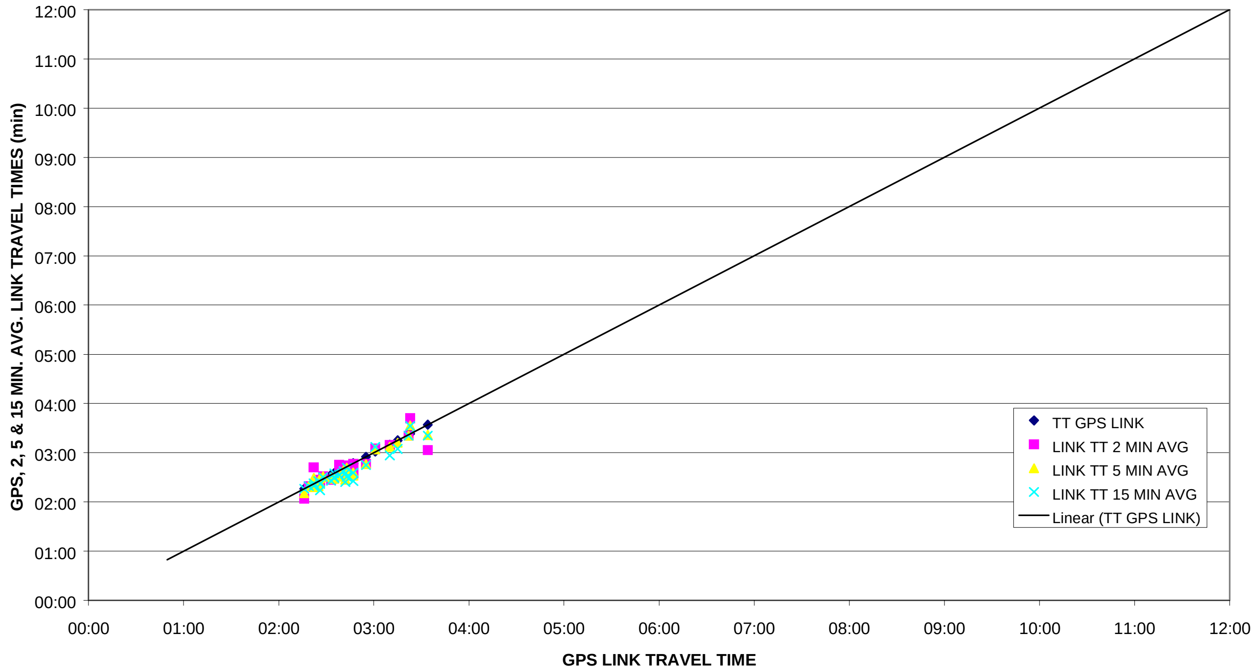

Figure 6.15 – Northbound Correlation Graph, GPS and Aggregate Travel Times

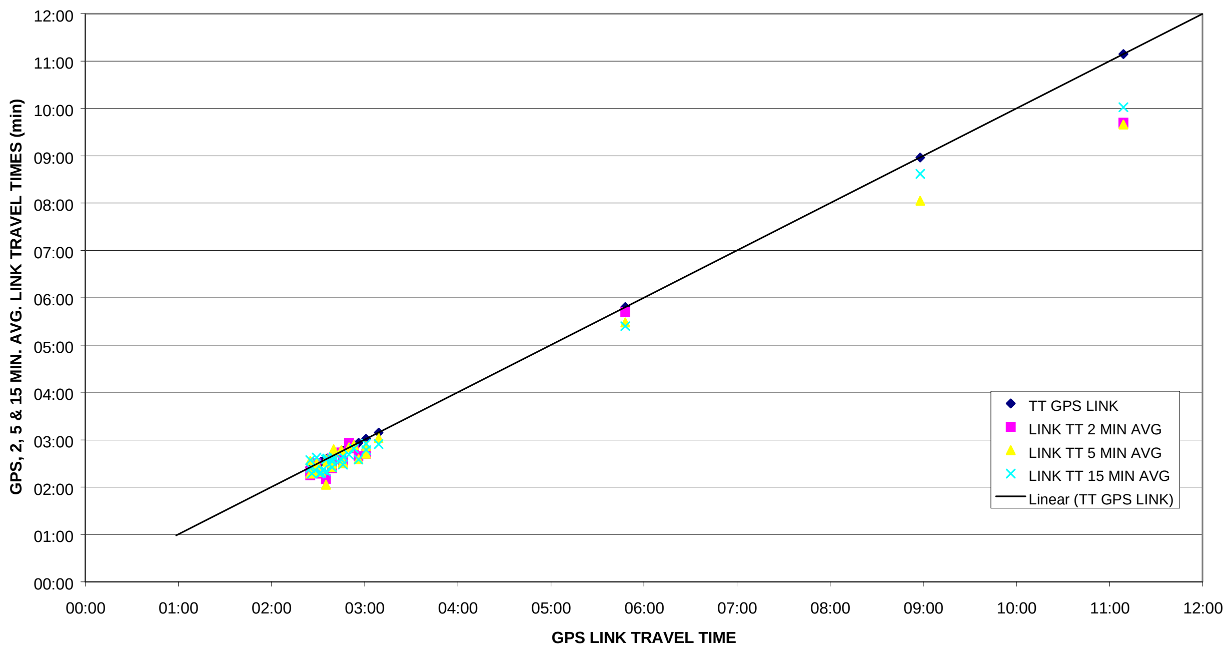

Figure 6.16 – Southbound Correlation Graph, GPS and Aggregate Travel Times

Again, a similar pattern is seen as described in sections 6.3.2.1 and 6.3.2.2 where the aggregate AVI link travel times closely surround the line of perfect correlation defined by the GPS vehicle's link travel times. As travel times increase, the correlation remains positive, but the deviation between GPS and aggregate link travel times increases. The quantitative values for the north- and southbound correlation analyses are given in Table 6.8.

Table 6.8 –Freeway GPS/Aggregate AVI Correlation Coefficients By Direction

DIRECTION	2-MIN AVG vs. GPS	5-MIN AVG vs. GPS	15-MIN AVG vs. GPS
NORTH	0.8874	0.9603	0.9422
SOUTH	0.9961	0.9958	0.9966

As demonstrated by the high correlation values, the correlation analysis by direction for the freeway corridor experimented here do not reveal any non-correlation between the GPS link travel times and the aggregate AVI travel times.

6.4 Summary

As observed by the numerous correlation plots in Section 6.3, 2-, 5- and 15-min aggregated AVI link travel times show an expected positive correlation to lines of perfect correlation defined by GPS test vehicle link travel times. A quantitative correlation analysis by link revealed a high correlation for all links at each level of aggregation with just one exception. The correlation analysis of the 5-min aggregated travel times for AVI link 44-43 returned a value of 0.5734, the lowest of all the link correlation coefficients regardless of aggregation level. Upon further investigation, it was noted that at several points there existed a negative correlation between pairs of GPS and 5-min aggregate values (Figure 6.7). This variation from the expected positive correlation can at present only be described as random error.

Results returned by the time-of-day correlation analysis showed that AM and PM aggregate link travel time values show a high correlation to GPS link travel times. Midday aggregate link travel times, however, returned lower correlation coefficients ranging from 0.56 to 0.77. Upon further investigation, it was found that, on a per-link basis, 8 of 18 midday correlation coefficients were *negative*. It was concluded that this anomaly was due to the increased freedom for drivers to traverse links at a different velocities in the reduced, midday traffic volumes. The increased variability of speeds resulted in an increased likelihood that other drivers might be traveling at significantly higher speeds than the GPS test vehicle, and vice versa. Such a scenario allows a greater possibility for negative correlation to occur. In some cases, the GPS vehicle may exceed the average link speed of other AVI-equipped vehicles, while at other times the opposite may be true. This facilitates the diverging and crossing tendencies of travel time plots as illustrated in Figures 6.7 and 6.8. In performing a broader correlation analysis by direction (northbound and southbound I-35), it was shown that there was a relatively high correlation between GPS and aggregate link travel times.

Although both RMSE analysis and correlation analysis are quantitative analysis tools, they reveal different characteristics of the relationship between single-vehicle link travel times and aggregate link travel times. The RMSE method revealed that 5-min aggregate travel times were preferable to 2-min and 15-min averages in achieving the most accurate link travel time estimation. This result supports the use of the 5-minute rolling average algorithm currently used by Transguide to calculate travel times on AVI links. The RMSE method also identified the higher variance in travel time estimation error during congested periods, as often occurred on the freeway link between AVI sites 45 and 44. The correlation analysis, meanwhile, identified that midday aggregate travel times do not show a high correlation to individual vehicle travel times. On a per-link basis, the correlation coefficients were even found to be negative in 8 of 18 cases. However, the correlation analysis generally revealed that single-vehicle link travel times show a high correlation to aggregate link travel times of 2-, 5- and 15-min aggregation levels on a per-link and directional basis, independently of congestion levels.