

Chapter 7 – Conclusions and Final Recommendations

The main purpose of this thesis was to perform a field evaluation of travel time estimates derived from the Automated Vehicle Identification system in San Antonio, TX. It should be noted that this study does not involve any simulation modeling of AVI systems, although its results can be used for such a purpose. This field study appears to be the first of its kind in evaluating an in-place, full-scale AVI system. To do so, GPS instrumentation was selected as a suitable benchmark for measuring AVI system performance. Next, an analysis of the reliability and accuracy of travel times derived from the AVI system was undertaken. Third, a study of the level of market penetration of AVI tags in San Antonio was performed. Finally, two quantitative analyses were executed to determine the relationship between individual probe vehicle travel times and three levels of aggregated travel times. This chapter draws conclusions from the previous four chapters to generate a field evaluation of the AVI system in San Antonio.

7.1 Reliability and Accuracy Study

As mentioned in the literature review, accurate travel time information is very beneficial for ATIS applications. Because of this, it is important to evaluate the reliability and accuracy of AVI antennas.

The first step of this study was to identify a suitable benchmark with which to measure AVI performance. Based on its ability to provide real-time location, speed and time data, GPS was tested and found to be a reliable benchmark (Chapter 3). The accurate GPS units allowed for the independent tracking of a tag-equipped test vehicle, which was used to assess the reliability and accuracy of San Antonio's AVI system.

The reliability study of the AVI system (Chapter 4) was divided into two parts: overall system reliability, and controlled reliability for individual antenna sites. In assessing the overall system reliability, one month of AVI reader data was acquired and analyzed. The analysis revealed that, for the period observed, San Antonio's 53-site AVI system maintained better than 90% operability during the entire time. The average number of sites down per day was slightly less than 3 (indicating a 94.5% functionality), and the maximum number of sites down never

exceeded 5 (90.6% functionality). The reliability assessment for individual antenna sites was primarily concerned with variations between facility type (freeway vs. arterial) and levels of congestion. The freeway and arterials chosen provided some level of recurring congestion given that the freeway section included a weaving section and given that the arterial was signalized. The analysis by facility type showed the freeway antenna sites to be more reliable than the arterial sites tested. The freeway antenna sites correctly captured the test vehicle's tag 86% of the time, while the arterial sites only reached a 75% capture rate. Combined, the freeway and arterial antenna sites netted a capture rate of 84%, which exceeds the 80% design capture rate for San Antonio's AVI system. For varied test vehicle speed intervals ranging from 0 to 65 mph, the tag capture for all antennas varied from 67 % (16–25 mph) to 100 % (0-15 mph). There did not appear to be a clear trend in tag capture rate as the probe vehicle's speed varied, hence the conclusion of this study is that tag capture rate is independent of vehicle speed. Because of limited observations at lower speeds, however, this conclusion has limited confidence (see 4.4 Summary).

Several additional observations were made during the reliability study. During thunderstorm activity, the AVI freeway sites correctly recorded 15 of 16 possible tag reads (94%). This data suggests that AVI performance is also independent of rainy weather. Lastly, it was noted that the weaving section in the vicinity of AVI site 44 on I-35 south caused possible poor performance of that site. Because only 2 of the 3 lanes at site 44 have designed coverage, through-traffic was easily missed as it moved to the outside lane to circumvent congestion caused by weaving. For this reason, it is recommended that the combination of antenna and highway geometry be considered when designing the antenna layout of an AVI system.

A study of the accuracy of the time measurements of the AVI system showed that AVI travel times for test vehicles varied by approximately one second from the travel times recorded manually with the GPS units. When compared to the total link travel times, the discrepancy proved to be negligible at less than 2% error for all trips evaluated. This level of accuracy is deemed suitable for travel time calculation.

7.2 Level of Market Penetration Study

A LMP study was undertaken in Chapter 5 to determine factors affecting the number of tag-equipped vehicles on San Antonio's roads. This study also established a reference parameter to associate with the results found in Chapter 6 of this thesis.

Daily tag read counts for arterial and freeway AVI antenna sites were taken over a period of several months. When plotted against time, the number of daily tag reads was shown to rise steadily during the time period evaluated for both freeways and arterials. Such a trend seems to indicate that tag distribution efforts in San Antonio are being reflected by an increase in the number of tag-equipped vehicles on the road. It was also noted that, given the abundance of Amtech toll markets surrounding the San Antonio region, out-of-town tags contribute significantly to the total number of tag reads recorded in San Antonio (> 50 %). This result indicates that out-of-town tags that are compatible with the hometown AVI system can be very beneficial in providing additional probes from which to gather information. Such a background level of market penetration should be considered when calculating tag distribution requirements for a new AVI system.

In this study, two definitions for LMP were presented: Definition 1 LMP, which is a theoretical LMP calculated by dividing the total number of tags distributed by the total number of registered vehicles; and Definition 2 LMP, which is calculated by dividing the number of tag-equipped vehicles observed on the road by the total traffic volume observed. As shown, Definition 2 is the more accurate indicator of the actual field LMP. The data collected indicates that the actual number of unique San Antonio tags read by the AVI system lagged far behind the number of tags distributed. Because of this trend as well as the significant influence of out-of-town tag-equipped traffic, it was necessary to count both actual tag-equipped vehicles and total traffic to obtain a reasonable LMP for San Antonio. Such an analysis was performed on a major highway in southeast San Antonio by acquiring tag reads from an AVI site and traffic volume from a nearby loop detector station. The results indicated that the field LMP ranged as high as 8% during the early morning hours, while dropping to approximately 0.5% from the morning rush hour peak to well past the evening rush hour peak. The high LMP during the early morning is

attributed to a large percentage of truck traffic (trucks are often equipped with toll tags). It should be noted that the LMP study included out-of-town vehicles equipped with Amtech tags.

7.3 Level of Aggregation Study

A final evaluation was performed to compare test vehicle travel times with aggregate travel times derived from other tag-equipped vehicles. This analysis was performed to determine if aggregate travel times could accurately reflect individual vehicle travel times. Additionally, three levels of aggregation were investigated to see if one outperformed the others.

A qualitative assessment was first performed by plotting the test vehicle travel times vs. travel time aggregations of 2-, 5- and 15-minutes. The plots revealed that the individual test vehicle generally had similar travel times to the aggregated values derived from other tag-equipped vehicles. To quantify the apparent similarity, a RMSE analysis was performed along with a correlation analysis.

The RMSE analysis showed that, with one exception, the test vehicle link travel times for all freeway links was very close (< 4%) to the 2-, 5- and 15-minute aggregated travel times. The one exception was link 45 to 44 on I-35 south, which includes a weaving section that experiences recurring congestion (see description, 4.2.2.2.3 Geometric Configurations). It is concluded that the recurring congestion in this area led to the slightly higher RMSE values for that link. When plotted, the results of the RMSE analysis indicated that the 5-minute level of aggregation provided noticeably better results than the 2-minute level of aggregation, and slightly better results than the 15-minute level of aggregation. This result bodes well for the San Antonio program, as a 5-minute rolling average algorithm is currently used to calculate travel times on AVI links.

The correlation analysis of test vehicle link travel time and aggregate link travel times for all freeway links illustrated that test vehicle travel times vary more when travel times are increased. Nonetheless, the quantitative results show that a high degree of correlation was maintained between the test vehicle and the aggregate vehicle travel times when evaluated by link. The only exception to this finding was for the 5- and 15-minute levels of aggregation for I-35 south

between AVI sites 44 and 43. The correlation coefficients were the two lowest (0.5734 and 0.8121 respectively) of the entire study. Further analysis appeared to indicate that these poor results were the result of random error. When analyzed by time-of-day, the AM and PM correlation coefficients were very high (> 0.90) while the midday correlation coefficients were significantly lower (< 0.80). It is hypothesized that the increase in congestion during AM and PM peak hours tends to force all vehicles to travel at similar speeds. During the off-peak midday period, however, the reduced traffic allows for greater differences in travel times. This varied midday traffic is reasoned to be the cause of the lower correlation values during the midday drive tests. A final study of correlation analysis by direction appeared to yield little difference between northbound and southbound corridors of I-35 (all values > 0.88).

7.4 Recommendations for Further Research

The conclusion of this research both answers past questions and generates new ones. A first suggestion for further research is to pursue the possibility of unencrypting the archived, encrypted tag data so as to ascertain the LMP for San Antonio tags only. Because of tag encryption, there remains some uncertainty in the LMP brought about by Transguide's tag distribution efforts *alone*. The results of Transguide's efforts could be better quantified through a more precise LMP measurement (excluding all out-of town tags) only through an unencryption process.

In addition, the LMP efforts presented here create a suitable platform from which to model an AVI system. Sensitivity analyses could be performed using varying levels of hometown and out-of-town market penetration to determine the tag distribution level required to obtain adequate travel time data for ATIS purposes

Because of limited data from AVI-equipped arterials, much of this thesis focused on evaluating AVI performance on freeways only. A more complete arterial data set would allow for a better comparison of AVI time accuracy and a comparison of level of aggregation, RMSE and correlation values with those found for freeways. This level of aggregation study is of particular interest given that it is known that travel times vary significantly more on signalized arterials than on freeways.

Lastly, the AVI data gathered for this thesis could be used to evaluate AVI travel times vs. loop-derived travel times. San Antonio is somewhat unique in that its traffic management program uses traffic data derived from both loop detectors and AVI. Follow-up research to this thesis for the purpose of comparing the accuracy of deriving travel times from loops and AVI is already under way.