ACCURACY OF VEHICLE PROBE ESTIMATES OF LINK TRAVEL TIME AND INSTANTANEOUS SPEED

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ABSTRACT

The deployment of Advanced Traveler Information Systems (ATIS) created a need for adequate real-time dynamic data to support such systems. The deployment of larger numbers of vehicle probes, which automatically transmit when drivers start their trip (O-D) and traverse the various links (link travel times), is expected to provide a considerable amount of these real-time data. Unfortunately, few studies have analyzed actual probe data in order to evaluate their true accuracy and reliability.

This paper presents some limited field tests that evaluated vehicle probe link travel time and instantaneous speed estimates, and compares them directly to Freeway Traffic Management System (FTMS) loop detector data.

The study concluded that the vehicle probe link travel time estimates were consistent with the travel times measured by a human observer (error within 6 seconds). It was also found that freeway loop detector travel time estimates and vehicle probe travel times were highly correlated (correlation coefficient of 83%). Finally, the vehicle probe speed estimates were compared to odometer speed measurements for a variety of network and driver characteristic configurations. The vehicle probe speed estimates were found to be consistently within 10 km/hr of the actual speed measurements.

1. INTRODUCTION

Much of the recent research into Route Guidance Systems (RGS) has focused on estimating the system and user benefits for systems that receive and utilize real-time or dynamic traffic information (1,2). These studies assume that reliable and accurate sources of real-time information are available. However, much less research has investigated how reliable current sources of real-time data might be. Van Aerde *et al*. (3) examined using simulation, how reliable vehicle probes were, for various levels of market penetration, as sources of link travel time data and Origin-Destination (O-D) data. Alternatively, this paper attempts to investigate the reliability and accuracy of vehicle probe link travel time and instantaneous speed estimates utilizing a limited study of some actual field data. The need for a good estimate of link travel time arises because these link travel times are utilized in the minimum path selection, while the need for accurate instantaneous speed estimates arises because it is required in order to predict the vehicle emissions.

Initially, the test networks that were utilized in the field evaluations are presented in Section 2. Three comparison tests are then presented next in this paper. The first test, that is presented in Section 3, compares the link travel time estimates from vehicle probes to manually measured link travel time estimates using a stop watch for nine test runs. In the second test, which is presented in Section 4, link travel time estimates from vehicle probes are compared to travel time estimates based on standard dual loop detector speed measurements. The objective of the second test is to evaluate the consistency between probe and FTMS data sources of real-time data. The third test, which is presented in Section 5, compares instantaneous vehicle probe speed estimates to direct odometer speed measurements in order to evaluate the quality of the instantaneous vehicle probe speed estimates. Finally, Section 6 provides a summary and conclusions of the paper.

2. NETWORK DESCRIPTIONS

Five test networks in Orlando, Florida were selected for conducting a series of probe field tests. The objective of these field tests was to attempt to evaluate the accuracy of probe data under typical traffic and network conditions. While the analysis presented in this paper is far from exhaustive, it does sample five of the main traffic network configurations under typical traffic conditions.

The first of these five networks was a major arterial corridor along Colonial Drive. Colonial Drive is a typical four lane divided east/west signalized arterial. The Colonial Drive test network, that consisted of 36 links, extended from Alafaya Trail in the east to Tampa Avenue in the west. This test corridor extended over approximately 21 kilometers (13 miles) and was composed of a mixture of urban and sub-urban links.

The second test network was composed of a downtown grid network that formed a closed loop of 33 links and extended over approximately 5 kilometers (3 miles). The links were typically shorter than the links of the Colonial Drive network.

The third network traversed approximately 14 kilometers (8.8 miles) along an unsignalized urban highway (Alafaya Trail). The Alafaya Trail network allowed for the field testing of probe data under a variety of different driving characteristics. The forth network was a typical subdivision network that was composed of six stop signs and four yield signs. This subdivision network extended over approximately 12 kilometers (7.5 miles).

The final test network was composed of a 16 kilometer (10 miles) detectorized section of the I-4 freeway. I-4 serves as a major route that travels across the center of Florida from the south-west (Tampa) to the north-east (Daytona) passing by Disney World. The detectorized portion of the I-4 freeway was located in the vicinity of the downtown of Orlando, extending from 33rd street to the south-west and ending downstream of Maitland Boulevard to the north-east, as illustrated in Figure 1.

There was a total of 24 loop detector stations located along I-4 numbered from 1 to 25, with no data being provided for station 10. The spacing of the detector stations ranged from approximately 0.40 to 0.90 kilometers (0.25-0.54 miles). There were no major terrain variations along the detectorized section of the I-4 freeway, as Orlando is rather flat. However, at many interchanges with arterials the freeway was elevated. The entire detectorized section of I-4 was composed of three lanes in each direction.

3. TEST 1: A COMPARISON OF LINK TRAVEL TIME ESTIMATES FROM MANUAL COUNTS AND VEHICLE PROBES

In order to evaluate the accuracy of vehicle probe link travel time estimates along signalized links, the link travel times on the first network (Colonial Drive) and the second network (downtown network) were measured by a human observer using a stop watch and compared to the travel times that were logged automatically by the vehicle probes.

3.1 Study Description

In this study the probed vehicle was driven along a major signalized arterial twice (Colonial Drive). The first eastbound and westbound trip was conducted in the late morning/early afternoon (between 10:00 a.m. and 12:30 p.m.). The second trip was conducted in the early evening during the p.m. peak (between 4:00 and 6:30 p.m.).

The probed vehicle was also driven five times along the downtown network. Three of these trips were conducted in the late morning (between 11:00 and 12:00 p.m.), while the remaining two were conducted in the evening during the p.m. peak (between 5:00 and 6:00 p.m.).

The main objective, behind varying the trip start times, was to capture the normal variations in demands during a typical day. Thus, these test runs attempted to capture both the spatial and temporal variations of traffic conditions in an urban network. These spatial variations were captured by utilizing an arterial and downtown network while the temporal variations were captured by varying the study start time.

The probe data for the specified trips were collected and were compared to the observed measured link and trip travel times. The observed link travel times were measured as the time difference required in traveling from the centerline of the upstream cross street to the centerline of the downstream cross street.

3.2 Evaluation of Trip Travel Times

In order to evaluate the link travel times of the constituent links of the various test trips, an estimate of the trip travel time was estimated as the sum of the component link travel times. Any missing link travel times were given their nominal travel times (free-speed travel times). The difference in the trip travel times from the measured trip durations ranged from -23% to -4%. The average error was approximately -12% with a standard deviation of approximately 7%. Thus the 95 percentile confidence limits, assuming a normal distribution of the trip travel time estimates, ranged between -26% and +1%. It is noteworthy that the vehicle probes underestimated the trip duration for all of the nine test runs. This was most probably caused because the use of free-speed travel times for any missing links underestimated the actual travel time on these links.

A further analysis of the results indicated that the trip travel time error decreased as the average link travel time increased. Because the probe information was restricted to sending a maximum of three link travel times each minute, it was speculated that this restriction was the probable cause for this discrepancy. As a result of this restriction, when probed vehicles traversed more than three links each minute, only the last three link travel times were transmitted to the Traffic Management Center (TMC). A total of 33% of the downtown links experienced a travel time less than 20 seconds and thus resulted in the missing of a portion of these links. In order to further investigate this speculation, the number of missing links as a function of the link travel time was analyzed. It was found that for the downtown network with an average link travel time of 31 seconds the number of links missed was 20% while for the Colonial Drive network the average link travel time was 55 seconds and the number of links missing was only 6%.

3.3 Evaluation of Link Travel Time Estimates

Important components of the trip travel time are the link travel times of the component links. In this section of the paper the accuracy of the vehicle probe estimation for individual link travel times is compared to the actual measured link travel times in order to validate the probe link travel time estimation.

The nine test trips indicated that the average link travel time error did not exceed four seconds. It must be noted that the percentage average error (average error/average travel time) decreased as the average link travel time increased. For the downtown network, the average error ranged from 2.5 to 3.5 seconds, while the average absolute error ranged from 3 to 4.4 seconds and the Root Mean Squared (RMS) error ranged from 3 to 6 seconds. It must be noted that the Least Significant Bit (LSB) of the vehicle probe travel time estimate was 6 seconds. Thus, for the downtown network the margin of error was within the resolution of the probe travel time estimate.

For the Colonial Drive network, the average error was minor ranging from 2 to 3 seconds. However, the absolute and RMS errors were more significant ranging from 4 to 15 and 5 to 27 seconds, respectively. In order to determine the reason for the high absolute and RMS errors, Table 1 illustrates the probe estimated link travel time, the observed link travel time and the corresponding difference in the link travel time estimates. It can be noted from Table 1 that the error was generally small except for the highlighted cells. Furthermore, it is evident from the highlighted cells that for each large positive difference in the link travel time estimate, a corresponding equal negative difference was present. This phenomena was caused due to the inconsistencies in including the delay at an intersection to the upstream versus the downstream link for the automated probe estimates, while the manually observed link travel times always considered the intersection delay to be part of the upstream link. The inconsistency could have resulted from the GPS and map matching navigation system that was used by the probe vehicles which, due to location errors, could dislocate the start of a link when no turning movement occurred. The occurrence of a turning movement would allow the GPS to re-adjust the vehicle location. This explains why this error occurred along the Colonial Drive linear network rather than the grid network.

Thus, it can be concluded that although at first glance one may conclude that the probe link travel time estimates are not very accurate, a further analysis indicates that the inconsistency in the link travel time estimates, which canceled each other out in a route based analysis, was caused due to the assignment of delay at the intersection to upstream versus downstream links.

4. TEST 2: A COMPARISON OF LINK TRAVEL TIME ESTIMATES FROM STANDARD LOOP DETECTORS AND VEHICLE PROBES

In the previous section of this paper the probe vehicle estimates of signalized link travel times were evaluated by comparing manual stop watch measurements of the link travel times to automated probe data. In this section an attempt is made to compare probe link travel time estimates to freeway link travel time estimates based on speed counts from standard loop detectors. The objective is to evaluate the constancy of probe data with respect to standard loop detector data as accurate sources of real-time information.

4.1 Qualitative Comparison

The dual loop detector stations along I-4 measure the flow, speed and occupancy of traffic every 30 seconds. A weighted average five minute speed estimate was subsequently calculated for each station from these 30 second data samples. Based on the five minute speed estimates, the travel times along a 1.6 km link (1 mile) located at station 12 were calculated. The resulting vehicle probe and loop detector travel time estimates at station 12 for Monday 22/2/1993 are illustrated in Figure 2. It appears that the probe and loop detector travel time estimates are highly consistent. However, it should be noted that the number of probe observations was relatively small (6 observations).

It should be noted that the loop detector travel time estimate was zero from time zero to time 7.75 because of a failure in the loop detectors. It is also interesting to note that the travel time on the link at station 12 ranged from approximately 80 seconds during the off-peak conditions to approximately 900 seconds during the peak period. Figure 2 verifies that the probe travel time estimates were generally found to increase in a fashion consistent with the loop detector data during the peak period to reflect the level of congestion that was experienced.

4.2 Statistical Comparison

In order to systematically attempt to quantify the similarity in probe and loop detector link travel time estimates, a regression analysis was conducted on the data at station 12 over a 6 day period during February 1993. The analysis included a total of 34 probe link travel time observations.

Initially, a regression was conducted on the entire range of observations, allowing the regression analysis to select the appropriate y-axis intercept (REG 1). The regression analysis estimated the coefficient of determination (R^2) to be 0.77. Figure 3a demonstrates the observed data points over the 6 day period. The x-axis represents the link travel time estimated by the vehicle probe while the y-axis represents the loop detector link travel time estimate. A perfect correlation of link travel time estimates would result in a line of unit slope that passes through the origin. The existence of an intercept would suggest a potential constant systematic error between the two sources of link travel time estimates, while a slope other than unity would reflect the potential for a variable systematic difference between the two sources in the estimation of the link travel times.

The regression line (REG 1) was estimated to have an intercept of 24 seconds with a standard error of 8.7 seconds that resulted in 95% confidence limits that did not include the graph's origin. Thus, based on the first regression results there appeared to be a statistically significant constant link travel time error. The slope of the first regression line was estimated to be 0.8 with a standard error of 0.08 that resulted in 95% confidence limits that did not contain the unit slope. The existence of an extreme point was considered as one of the possible causes that resulted in the regression line having a statistically significant intercept and not having a unit slope.

A second regression was conducted on the data in which the intercept was set a priori to zero (REG 2). The line generated from the regression analysis is illustrated in Figure 3a. In this regression the coefficient of determination was reduced to 0.72, as opposed to 0.77 in the initial regression (REG 1). The slope increased from 0.8, in the first regression, to 0.97 and the unit slope fell within the 95% confidence limit ranges.

The extreme point was then removed from the analysis and a regression was conducted on the remaining 33 observations. In the initial regression (REG 3), the intercept was estimated to be −2.7 seconds with a standard error of 12 seconds as illustrated in Figure 3b. Thus it was found that the origin fell well within the 95% confidence limits. Because the intercept was found to not be statistically insignificant at the 95% confidence level, the regression was repeated by setting the intercept to zero as illustrated in Figure 3b (REG 4). The final regression analysis estimated a coefficient of determination of 0.68. The slope was estimated to be 1.13. However, the lower bound 95% confidence limit was slightly greater than unity (1.01). This final regression suggested that loop detector and probe link travel time estimates were highly correlated (correlation coefficient of 0.83).

5. TEST 3: A COMPARISON OF INSTANTANEOUS LINK SPEED ESTIMATES FROM THE VEHICLE ODOMETER AND VEHICLE PROBES

The test runs presented in this section involved a probe vehicle that was equipped with a device that recorded the odometer speed readings each deci-second. This section evaluates the accuracy of these standard instantaneous probe vehicle speed estimates by comparing to the odometer speed estimates that were generally not available for the rest of the vehicle fleet. The objective is to evaluate the instantaneous probe speed estimates that are utilized in estimating vehicle emissions.

5.1 Study and Driving Characteristics Description

The study conducted in this portion of the paper involved driving a probed vehicle along six test drives on January 28, 1993. The location of the various test drives was varied in order to capture the spatial variations in traffic conditions. In addition, the driving characteristics of the different test runs were varied in order to capture different driver behaviors. A summary of the test runs conducted in the study presented in this section is demonstrated in Table 2.

In test run 3-1 the probed vehicle (equipped with a TravTek route guidance system) was driven twice along the Alafaya Trail test network. In the first drive, the vehicle ran at a constant speed of approximately 80 km/hr (50 mph). In the second drive, the vehicle ran at a constant speed of approximately 48 km/hr (30 mph). Alternatively, test run 3-2 involved driving the probed vehicle along the same route at various acceleration/deceleration cycles.

Test run 3-3 involved driving the probed vehicle along the subdivision test network for a typical driver behavior. Test runs 3-4 and 3-6 involved driving the probed vehicle under a typical driver behavior along the Colonial Drive test network. Finally, in test run 3-5 the probed vehicle was driven along the downtown test network.

5.2 Data Sources

The probed vehicle that conducted the above test runs was equipped with four video cameras in order to collect very detailed driver behavior data. These data included, the driver's eye movements, control usage, lane tracking and the odometer speed. Other special data was collected which included, 2-axis acceleration, steering wheel position, and brake light status. The camera car speed estimates, based on the odometer readings, measured each deci-second were aggregated on a second by second basis and used as the base to evaluate the probe speed estimates.

The probe vehicle gathered information about the link speeds, traveled distance, vehicle location, link travel times, vehicle maneuver and other information. The standard vehicle speed estimates were computed using a gauge attached to the vehicle brakes. In order to evaluate the accuracy of these standard probe speed estimates, these speeds were compared to the odometer speed estimates.

5.3 Vehicle Speed Comparison

In this section, the raw probe speed estimates are evaluated. Subsequently, some adjustments are made to the raw probe speed estimates in order to deem them more accurate. These adjusted probe speed estimates are evaluated for each trip. Finally, the overall average speed estimates are compared.

a. Raw Probe Estimates

The variation in the odometer speed estimate each minute for the entire simulation period is illustrated in Figure 4 (labeled as camera estimate). As discussed earlier, the test run 3-1 involved driving twice along Alafaya Trail at a constant speed. The decrease in speed in the vicinity of time 4:52 is a result of reversing and maneuvering the vehicle in order to repeat the trip at a lower speed.

Figure 4 also demonstrates the variation in the raw probe speed estimates (labeled as probe estimate). It is evident from Figure 4 that these speed estimates demonstrated unrealistically large variations in the vehicle speed. For example, the speed varied from 60 mph to 170 mph in a one second interval and then dropped to 60 mph as indicated in the figure.

b. Adjusted Probe Estimates

In order to discern realistic speed variations from unrealistic speed variations, the maximum possible acceleration rates for an average passenger vehicle were estimated as illustrated in Table 3. Based on these values realistic average acceleration and deceleration rates were estimated to be half the maximum values. The speed variations were constrained to vary in a manner that did not exceed these average values. This limit on the maximum allowable variations in the probe speed estimates resulted in more realistic speed estimates as illustrated in Figure 4 (shown as adjusted(1) probe).

However, it was found that the adjusted probe speed estimates tended to be higher than the odometer estimates as illustrated in Figure 4. A scaling factor for the first portion of the test trip (from 4:47 to 4:51 p.m.) was estimated to be 0.89 another scaling factor for the reverse trip (from 4:53 to 5:00 p.m.) was estimated to be 0.88. The adjusted probe speed estimates for all the test runs were then scaled based on an average scaling factor of 0.88 in order to generate a further adjusted speed estimate which is labeled as “adjusted(2) probe.” However, this final adjusted probe speed estimate tended to lag behind the camera car estimate by a few seconds.

c. Overall Comparison

In order to quantify the accuracy of the vehicle probe speed estimates, the Root Mean Square (RMS) error for each test run relative to the odometer speed estimates was calculated. The RMS error was estimated as the squared difference in speed estimates, from the odometer speed estimate each second. For cases in which a probe estimate was not available the previous second's probe estimate was utilized as the best estimate of the probe speed.

Figure 5 illustrates the RMS errors and the average odometer speed estimate for each of the test runs. It is evident from Figure 5 that the RMS errors for the various scenarios for test run 3-5 was not large. However, as test run 3-5 involved driving the TravTek vehicle in a downtown network the vehicle experienced several stops at traffic signals and as a result the average speed was fairly low (10 mph). Thus a high normalized RMS error for test run 3-5 arose as a result of the low average speed rather than as a result of high RMS error. It can be noted from Figure 5 that the RMS error for the various speed scenarios was similar for the various test runs. Specifically, the RMS error for the raw probe estimates ranged from 7 mph to 10 mph, the RMS error for the initial adjusted probe estimates ranged from 5 mph to 7 mph, and the RMS error for the final adjusted probe speed estimates ranged from 3 mph to 6 mph.

6. SUMMARY AND CONCLUSIONS

This paper presented some preliminary investigations of the accuracy of probe data for different network configurations. It was found that on freeway links the vehicle probe link travel time estimates were consistent with the measured travel times (error within 6 seconds). The study also demonstrated that by limiting the number of reported link travel time estimates to only three each minute, a considerable number of links could be skipped depending on the link travel time. Furthermore, it was found that GPS and map matching navigation could result in some error in identifying the exact location of the vehicle if few turning movements are made.

Link travel time estimates, based on speed measurements of standard dual loop detectors, were compared to the vehicle probe link travel time estimates. It was found that the two sources of real-time data were highly correlated (correlation coefficient of 83%). This demonstrated that on freeways standard dual loop detectors could serve as reliable and accurate sources of real-time data.

Finally, the standard vehicle probe instantaneous speed estimates were compared to special odometer speed measurements for a variety of network and driver characteristic configurations. It was concluded, based on this limited comparison, that some type of trimming of peaks would be required to be applied to the probe data in order to prevent unrealistic large speed variations. It was also found that the probe speed estimates would be required to be reduced by approximately 10%. Following the above adjustments the speed estimates were found to be within 10 km/hr of the actual speed estimates.

Although these results are specific to the study presented in this paper, it is felt that two conclusions can be generalized. The first, is that standard dual loops can serve as reasonably accurate sources of real-time data. The second conclusion, is that the link travel time information provided from vehicle probes is reasonably accurate and thus with large market penetrations of RGS vehicles a considerable amount of reasonably accurate data will be available.

REFERENCES

1. Rakha H., Van Aerde M., Case E.R. and Ugge A. (1989), "Evaluating the Benefits and Interactions of Route Guidance and Traffic Control Strategies Using Simulation," Proceedings of the IEEE Vehicle Navigation and Information Systems Conference, Toronto, September, pp. 296-303.
2. Rilett L.R. (1992), “Modelling of TravTek’s Dynamic Route Guidance Logic Using the INTEGRATION Model,” Ph.D. Thesis, Queen’s University.
3. Van Aerde M., B. Hellinga, L. Yu, and H. Rakha (1993), "Vehicle Probes as Real-Time ATMS Sources of Dynamic O-D and Travel Time Data,"Conference on Advance Traffic Management Systems (ATMS), St. Petersburg, Florida, October.

Table 1: Observed and probe link travel times along Colonial Drive

Link number	probe link travel time (1)	Observed link travel time (2)	Observed-TMC (2-1)
186	78	79	1
187	66	68	2
188	90	90	0
189	120	125	5
190	42	40	-2
191	6	15	9
193	12	13	1
195	42	44	2
196	66	71	5
197	72	73	1
198	186	188	2
199	60	61	1
200	60	65	5
201	36	40	4
202	30	35	5
203	6	85	79
204	108	27	-75
205	24	25	1
206	54	58	4
207	12	16	4
208	30	37	7
209	30	30	0
210	12	16	4
211	12	78	66
212	84	24	-60
213	30	54	24
214	42	22	-20
215	18	16	-2
216	36	82	46
217	72	26	-46
219	24	27	3
220	6	9	3
221	36	37	1
222	108	111	3
223	6	6	0
224	missing	50	50

Table 2: The test 3 summary

Test	Description	Approximate Length (km)	Travel time (minutes)
3-1	2 constant speed runs along Alafaya Trail network	14.0	15.68
3-2	Acceleration/deceleration run along Alafaya Trail network	5.0	7.50
3-3	Normal driving in subdivision network	11.9	18.08
3-4	Normal driving along Colonial Drive network	21.8	28.25
3-5	Normal driving in downtown network	5.3	15.27
3-6	Normal driving along Colonial Drive network	21.1	32.00

Table 3: Estimation of average vehicle acceleration/deceleration rates

Acceleration:
initial speed= 0 mph
final speed = 60 mph
time to change speed = 9.8 seconds
$\Rightarrow$ maximum acceleration = $\frac{(60-0)}{9.8} = 6\,\text{mph/sec}$
$\Rightarrow$ average acceleration = 3 mph/sec
Deceleration:
initial speed = 80 mph
final speed = 0 mph
distance to change speed = 304 feet
$\Rightarrow$ maximum deceleration = $\frac{(80^2-0^2)}{2\times 304}\times\frac{5280}{3600} = 15.4\,\text{mph/sec}$
$\Rightarrow$ average deceleration= 7 mph/sec

(Source: Road & Track, June 1987, Honda Accord, pp.32)

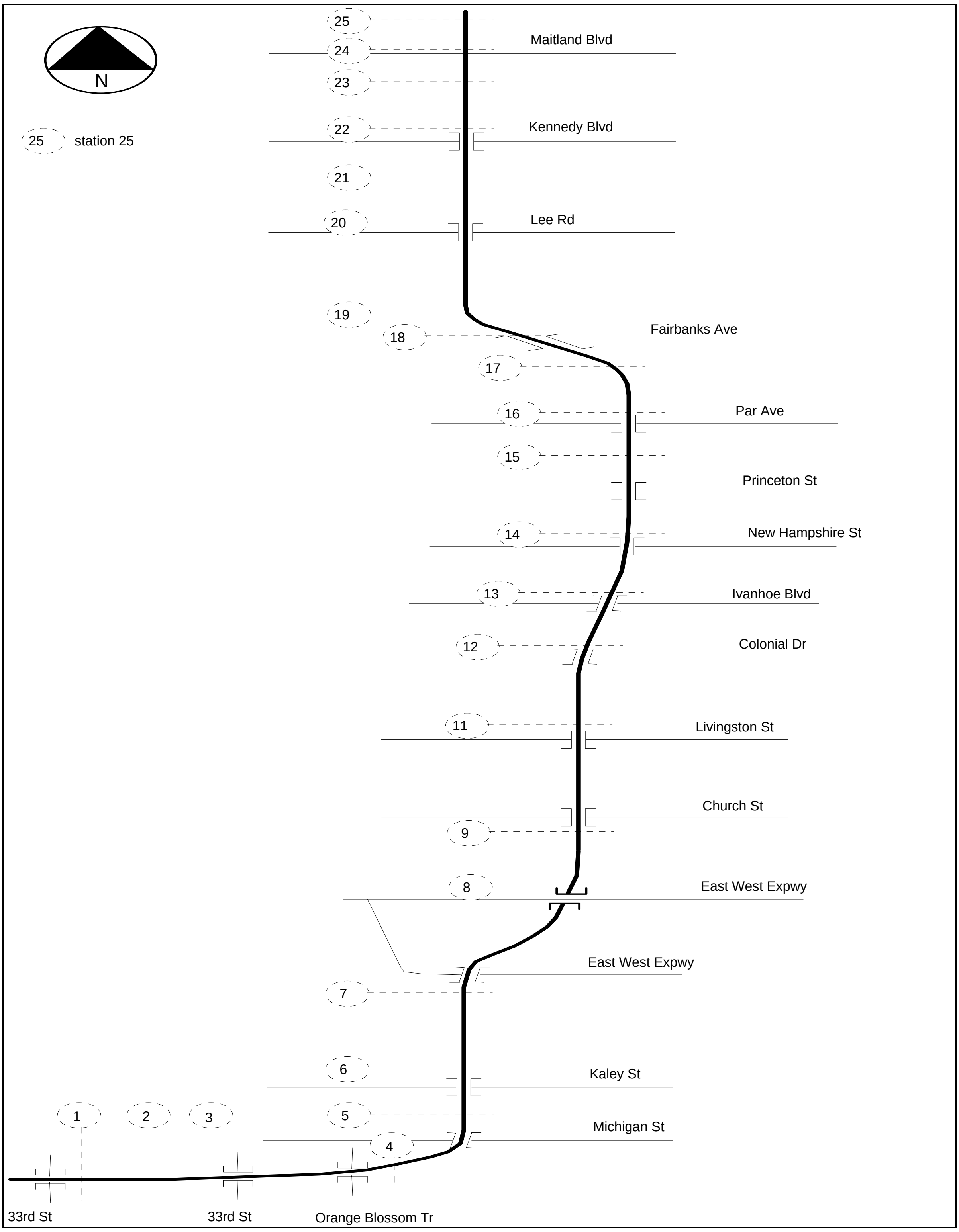

Figure 1: I-4 test network layout

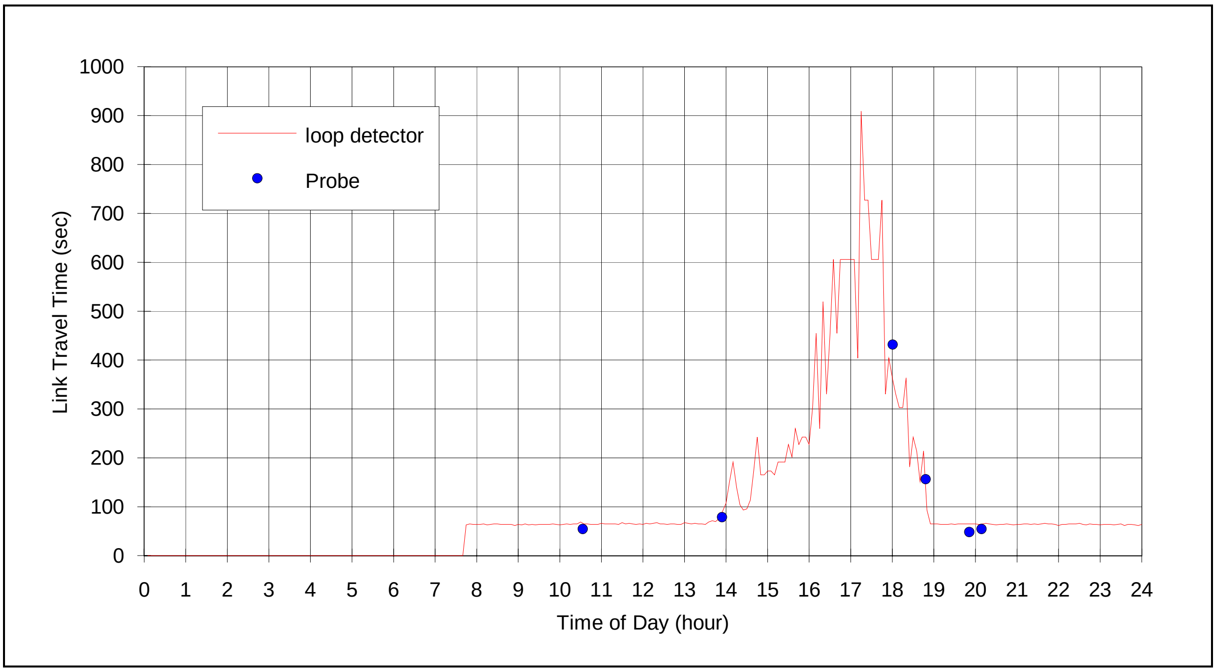

Figure 2: Probe and loop detector eastbound link travel time estimates at station 12

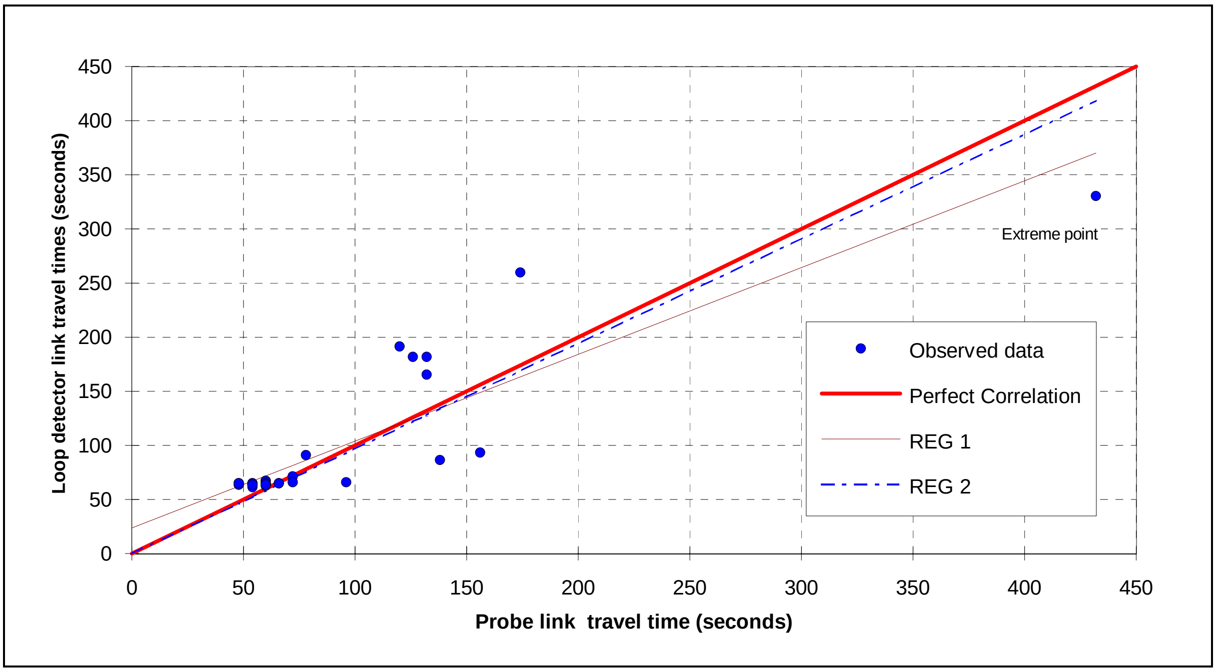

Figure 3a: Regression analysis of probe and loop detector link travel times (34 observations)

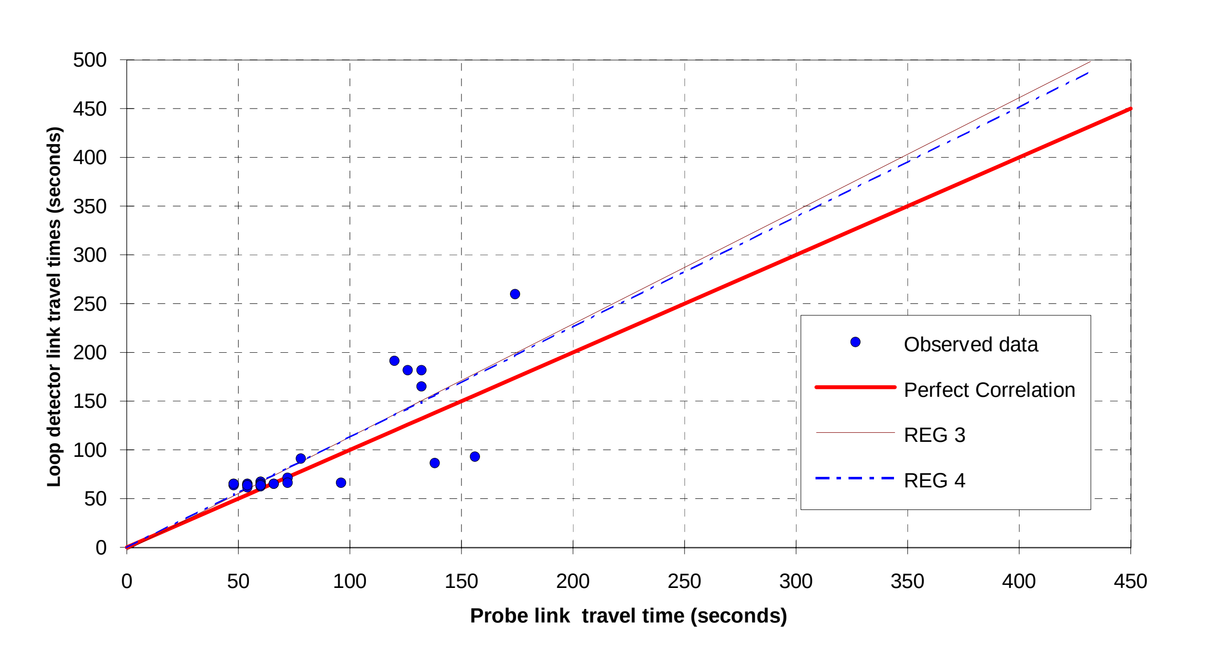

Figure 3b: Regression analysis of probe and loop detectore link travel times (33 observations)

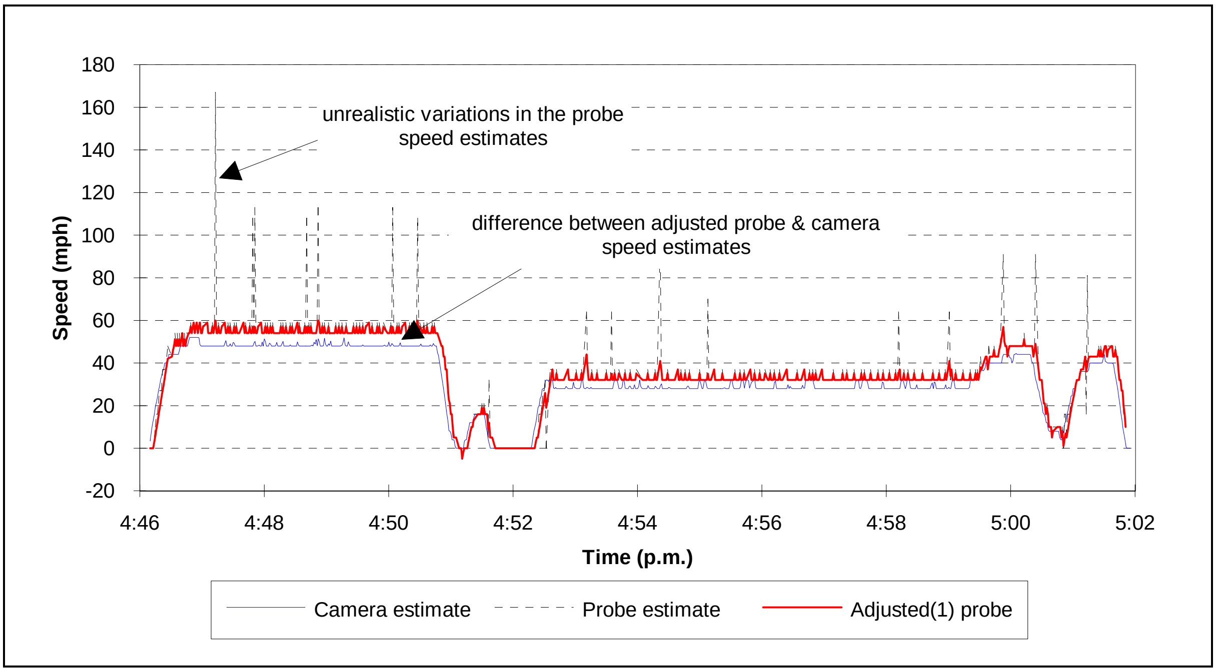

Figure 4: Variation in Speed estimates for test run 3-1

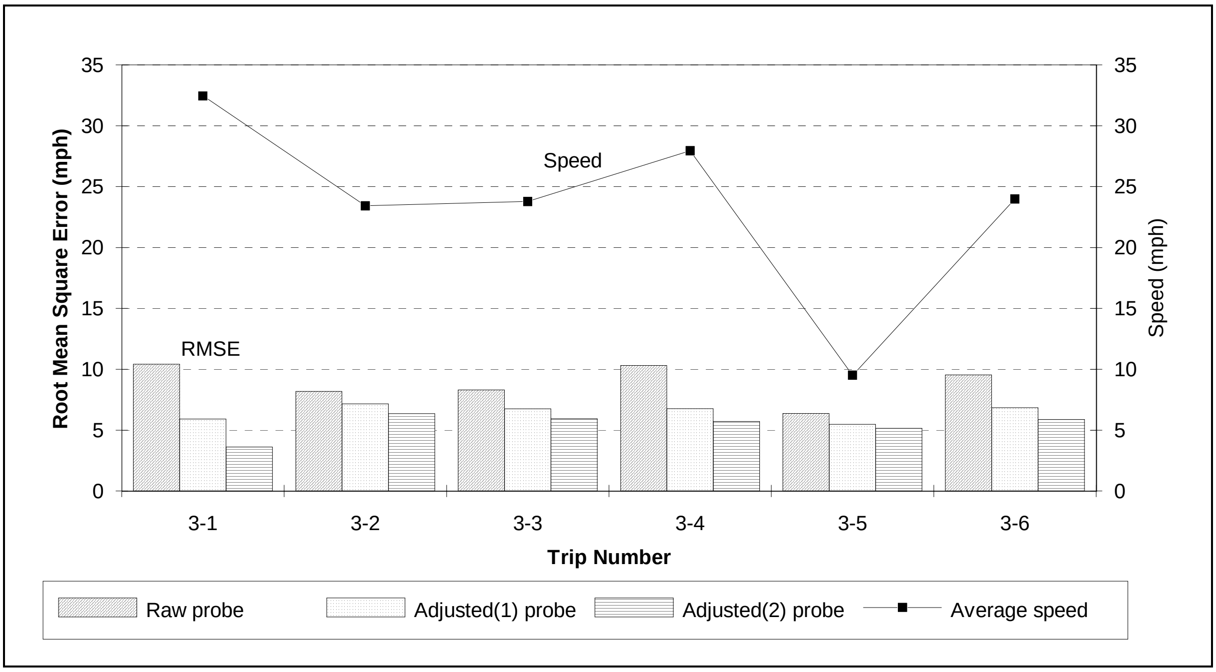

Figure 5: RMS speed error and odometer speed estimates