TECHNICAL MEMORANDUM

To: Vehicle Probe Project Team

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Subject: ***I-95 Vehicle Probe Project – Historical Speed Analysis White Paper***

EXECUTIVE SUMMARY

In this analysis the performance of historic and free-flow speed data were compared to the performance of real-time data delivered in the I-95 Vehicle Probe Project (VPP). The same validation methodology was used to calculate the error as compared to ground truth data sampled by the Bluetooth traffic monitoring equipment in the state of Delaware during November 2010. The average absolute speed error (AASE) and speed error bias were calculated for each data set consistent with the methodology in the validation program.

Table E-1 provides summary results of the AASE real-time speed data, historical speed data, reference speed data and an assumed free-flow speed of 55 miles per hour (mph). The AASE is measured against the standard error of the mean (SEM) band, consistent with the I-95 validation methodology. In all four speed categories, real-time data outperformed historic data. However, historic data met the I-95 contract requirements for accuracy (<10 mph) in all but the 0-30 mph speed bin. In this lowest speed bin representing severe congestion the AASE for historical data was 18.5 mph, over four times greater than the AASE of real-time data. Reference speed and 55 mph free-flow speed had nearly double the error of historical speed in this lower speed bin.

Table E-1. Summary of Historic Speed Data Performance Analysis

	Comparison of AASE Performance against SEM Band All Freeway Data - 24 Hours a Day*				
SPEED BIN	**Real-Time Data**	**Historical Speed**	**Reference Speed**	**55 MPH****	**Hours**
0-30	3.9	18.5	37.2	32.7	37.9
30-45	6.2	8.4	18.2	14.3	43.7
45-60	1.6	3.1	2.0	1.0	438.5
60+	2.0	3.7	2.3	7.8	1001.2
ALL	2.1	4.0	3.6	6.8	1521.3

* Data taken from Nov 2010 VPP validation ** Only daytime data

The results indicate that historical data can predict all but the most severe congestion with reasonable accuracy. Secondly, the VPP validation methodology can only distinguish performance of non-real-time data only in the lower two speed bins. The contrast in performance in the 0-30 mph speed bin reveals the value in the real-time data versus historical versus a free-flow or reference speed.

OBJECTIVE

The objective of this investigation is to assess how historical data performs relative to real-time data within the context of the I-95 Vehicle Probe Project (VPP). In this analysis real-time speed data, historical speed data, and assumed free-flow speeds are compared to ground-truth speed and travel time collected using Bluetooth traffic monitoring technology on specific segments of freeway in Delaware. The analysis of each data set is consistent with the methodology incorporated as part of the I-95 VPP validation program.

The performance of real-time as compared to historical and/or free-flow data provides insight into several issues that have been raised and discussed with respect to the VPP. Within the VPP data feed, historical data is used whenever there is insufficient real-time data upon which to report conditions. In this situation, the degree to which historical data is a reliable estimate of real-time conditions is of interest. Secondly, this comparison provides evidence of whether the VPP validation methodology that uses four distinct speed bins can distinguish between historical and real-time traffic data. Lastly, if the real-time data significantly outperforms historical data, it is an indication that the VPP does provide real-time monitoring and is not simply a reflection of expected conditions.

METHODOLOGY

Based on the VPP validation methodology, performance is assessed in four speed ranges (0-30 miles per hour (mph), 30-45 mph, 45-60 mph, >60 mph), representative of severe congestion to free-flow conditions. Historical speed data and assumed free-flow speeds are scored in the same manner that real-time VPP data is scored in the monthly VPP validation process. The accuracy of each range is tested against contract specification of 10 mph average absolute speed error. All data for this investigation was taken from the VPP validation program in which ground truth data is sampled using Bluetooth Traffic Monitoring (BTM) technology.

The study utilized a sample VPP validation data set recorded in Delaware during November 2010. Bluetooth sensor deployments in Delaware started on November 3, 2010 and ended on November 17, 2010. Travel time data was sampled from nine freeway segments totaling over 14 miles. The roadways highlighted red in Figure 1 illustrate the freeway roadway segments over which Bluetooth sensors were deployed and data collected. (1)

In addition to reporting real-time speed and travel time, each record also contains historical speed and a reference speed. The historical speed (referred to as *average* speed in reference three) reflects an average for that time of day and day week. The reference speed reflects free-flow speed for the segment. Full details on these data items are available in reference three. (3) The historical speed used in this analysis is the historical speed reported in the I-95 VPP project. The reference speed is also analyzed, along with other assumed free-flow speeds of 65, 60, and 55 mph.

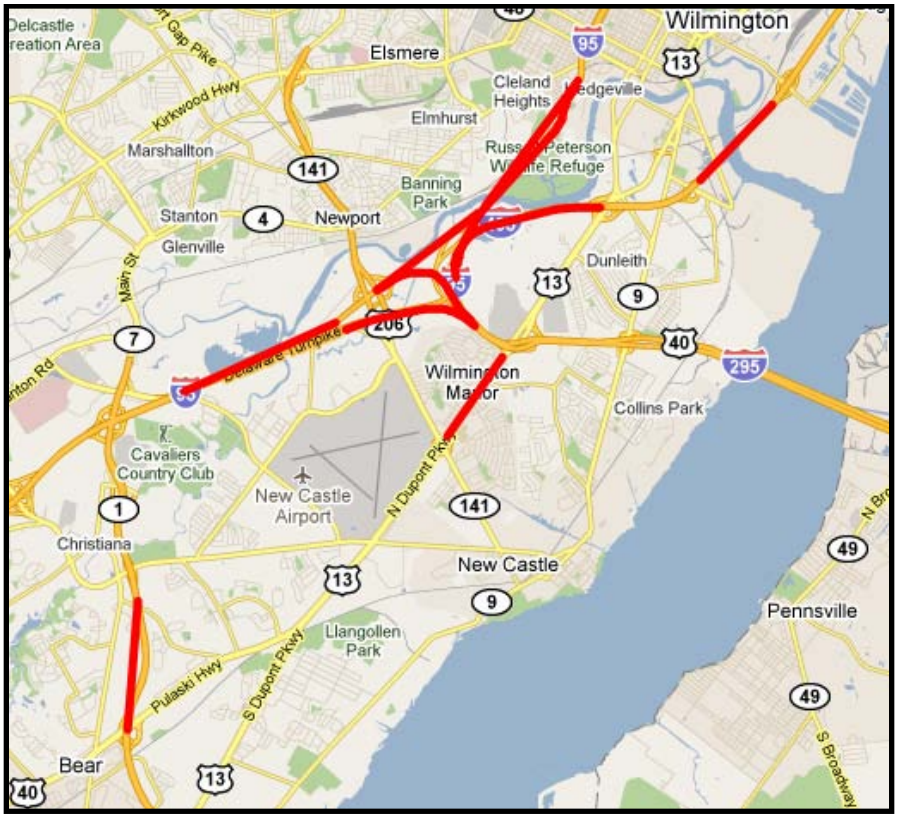

Figure 1. Freeway road segments sampled in Delaware in November 2010

I-95 VALIDATION METHODOLOGY

Bluetooth Traffic Monitoring (BTM) technology provides a rich data source for evaluation of the VPP data, but still some uncertainty exist with the definition of the ground truth vehicle speeds and travel times. There are significant speed and travel time variations depending on vehicle, driver and roadway characteristics. For this reason in addition to reporting the mean travel time and speed calculated from the Bluetooth data, a confidence band is defined that represents the uncertainty existing in data. (2)

Error statistics are calculated with respect to the mean and the standard error of the mean (SEM). The SEM is a band defined by a 1.96 standard error (SE) from the mean (1.96 SE) band. SEM is calculated as the standard deviation of Bluetooth sampled data divided by the square root of the number of Bluetooth data points taken for a given time, and accounts for the uncertainty in the true mean speed of traffic.

A statistical analysis of the data is performed in four speed ranges: 0 to 30 mph, 30 to 45 mph, 45 to 60 mph and greater than 60 mph, in conformance with the VPP validation methodology. The error metrics were calculated with respect to the SEM band and mean for each of these speed ranges. Two basic measures of error are used to evaluate the accuracy of the VPP

historical speeds. The two measures are: 1) the speed error bias (SEB) 2) average absolute speed error (AASE). The confidence band and statistical analysis that are used in this study are detailed in reference two.

RESULTS

To assess the performance of historical speed, SEB and AASE were calculated for both historical and real-time speed data. The results are shown in Tables 1 through 3. Table 1 provides the results averaged over the entire data set. Table 2 includes only data from daytime hours of 5am to 10pm. Table 3 includes only data from nighttime hours from 10pm-5am.

Table 1. Data quality measures for freeway segments in Delaware (All Data)

SPEED BIN	Data Quality Measures (All Data)								No. of Obs.
	Historical Speed				Real-Time Speed				
	1.96 SE Band		Mean		1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	18.5	18.5	20.2	20.2	3.0	3.9	3.7	5.3	455
30-45	7.2	8.4	8.8	10.5	4.3	6.2	5.7	8.3	524
45-60	-1.9	3.1	-1.8	5.1	0.6	1.6	1.4	3.4	5262
60+	-3.7	3.7	-6.3	6.4	-1.8	2.0	-3.7	4.5	12014
ALL	-2.3	4.0	-3.9	6.5	-0.8	2.1	-1.8	4.3	18255

Table 2. Data quality measures for freeway segments (5am-10pm)

SPEED BIN	Data Quality Measures (5am-10pm)								No. of Obs.
	Historical Speed				Real-Time Speed				
	1.96 SE Band		Mean		1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	18.1	18.1	19.7	19.7	2.4	3.2	3.0	4.6	440
30-45	6.6	8.0	7.7	9.8	3.7	5.9	4.6	7.6	426
45-60	-2.4	3.4	-2.5	5.2	0.6	1.6	1.4	3.4	4329
60+	-4.0	4.0	-6.6	6.7	-1.8	2.1	-3.6	4.5	10221
ALL	-2.6	4.3	-4.3	6.7	-0.9	2.1	-1.8	4.3	15416

Table 3. Data quality measures for freeway segments (10pm-5am)

SPEED BIN	Data Quality Measures (10pm-5am)								No. of Obs.
	Historical Speed				Real-Time Speed				
	1.96 SE Band		Mean		1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	28.9	28.9	32.2	32.2	22.3	23.1	25.4	26.4	15
30-45	10.0	10.0	13.6	13.6	7.3	7.8	10.7	11.4	98
45-60	0.5	1.8	1.0	4.3	0.6	1.4	1.4	3.7	933
60+	-2.1	2.1	-4.8	5.0	-1.6	1.6	-4.0	4.5	1793
ALL	-0.7	2.4	-2.0	5.3	-0.4	1.9	-1.5	4.6	2839

Note that in the initial analysis, the results in Table 1 and Table 3 indicated unusually high error values which revealed an inconsistency in the historical data archive. Within the vehicle probe archive historical speeds are recorded as zero during nighttime hours (10pm-5am). Although these are not valid historical speeds, the absence of historical data is consistent with the algorithm that generates the VPP data. If insufficient data is available to estimate real-time speed during nighttime hours from 10pm to 5 am, reference speed is reported. If insufficient data is available during the daytime hours of 5am to 10pm, historical speed is reported.

Consistent with the VPP reporting algorithm, reference speed was used instead of zero historical speed during nighttime hours. Whenever the historical speed was reported as zero, it was replaced by reference speed provided in VPP data.

Appendix A repeats the analysis using reference speed data as reported in the VPP data feed for all hours of the day. Appendix B repeats the analysis using constant free-flow speed values of 50, 55 and 60 mph. The performance of reference speed (as detailed in Appendix A) and assumed constant free-flow speeds (as detailed in Appendix B) were worse than that of historical speed in the lower speed bins. Appendix C repeats the analysis of historical speed for four freeway segments in Virginia, with similar results.

CONCLUSIONS

The performance of historical data when compared to real-time data differs primarily during congested periods. The results from the two higher speed bins reflect primarily free-flow conditions, and in these bins, historical data performs well using the VPP validation methodology, and the results AASE error is within contract specification of the VPP contract. However, during congested periods, the differences in performance between historical and real-time data are evident. For speeds less than 30 mph the validation error for historical data is large, reflecting severe, non-recurring congestion that would not be predicted by archived data records. During the daytime for the 30-45 mph speed category, the errors are usually less than 10 mph, which is within contract specifications, but still performs poorly in comparison to the real-time data. The results of this investigation indicate that when historic data is used during periods of low data-density, it may mask severe congestion. The validation methodology is able to discriminate between historic data and real-time data only during non-recurring and severe

congestion. The results from Delaware were consistent with the results from Virginia shown in Appendix C.

The analysis of reference speed and constant free-flow speeds showed similar patterns. Not only was the performance in the lower two speed bins significantly worse than real-time data, but it was also significantly worse than historical data. This suggests that in the absence of real-time data, historical traffic data as reported in the VPP data feed provides a better estimate of prevailing conditions than an assumed free-flow traffic condition. In the upper two speed bins the AASE as measured against the SEM band for reference speed and constant free-flow speeds generally performed within the 10 mph contract specification (with the exception of the 50 mph free-flow speed in the 60+ band).

REFERENCE

(1) Ali Haghani, Masoud Hamedi, and Kaveh Farokhi Sadabadi, "I-95 Corridor Coalition Vehicle Probe Project: Validation of INRIX Data, Monthly Report, Delaware", December 2010.

(2) Ali Haghani, Masoud Hamedi, and Kaveh Farokhi Sadabadi, "I-95 Corridor Coalition Vehicle Probe Project", University of Maryland, College Park, January 2009.

(3) I-95 Vehicle Probe Project : I95 Interface Guide, Version 3.3, June 20, 2010

APPENDIX A

Tables A-1 and A-2 present the results of the performance of reference speed when evaluated using the I-95 validation methodology. The reference speed is reported in the I-95 data feed, and reflects the 85th percentile speed for the segment, which is indicative of free-flow speed. See reference three (3) for additional details. Table A-1 and Table A-2 show the results for all data and 10pm-5am respectively.

Table A-1. Data quality measures for freeway segments (comparing Bluetooth speed with reference speed) (All Data)

Comparing Bluetooth Speed with Reference Speed (All Data)					
SPEED BIN	Data Quality Measures				No. of Obs.
	1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	37.2	37.2	38.9	38.9	455
30-45	18.2	18.2	20.4	20.4	524
45-60	0.6	2	1.3	4	5262
60+	-2.3	2.3	-4.6	4.8	12014
ALL	0.1	3.6	-1.1	5.9	18255

Table A-2. Data quality measures for freeway segments (comparing Bluetooth speed with reference speed) (10pm-5am)

Comparing Bluetooth Speed with Reference Speed (10pm-5am)					
SPEED BIN	Data Quality Measures				No. of Obs.
	1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	28.9	28.9	32.2	32.2	15
30-45	10	10	13.6	13.6	98
45-60	0.5	1.8	1.1	4.3	933
60+	-2.1	2.1	-4.8	5	1793
ALL	-0.2	2.9	-1.6	5.8	2839

As expected for free-flow speeds, the errors are large in the lower two speed bins. In higher speed bins the errors are small, well within contract specifications of 10 mph.

APPENDIX B:

Tables B-1 through B-6 present the performance results of an assumed free-flow speed of 50, 55 and 60 mph. This analysis is similar to that performed in appendix A, but with an assumed constant free-flow speed. The results are similar to that of reference speed presented in appendix A.

Table B-1. Data quality measures for freeway segments with using 50mph as historical speed (5am-10pm)

Comparing Bluetooth Speed with 50mph as Historical Speed (5am-10pm)					
SPEED BIN	Data Quality Measures for				No. of Obs.
	1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	27.7	27.7	29.3	29.3	440
30-45	9.3	9.3	11.2	11.2	426
45-60	-3.6	3.7	-5.8	6.0	4329
60+	-12.8	12.8	-16.1	16.1	10221
ALL	-8.5	10.6	-11.1	13.5	15416

Table B-2. Data quality measures for freeway segments with using 50mph as historical speed (10pm-5am)

Comparing Bluetooth Speed with 50mph as Historical Speed (10pm-5am)					
SPEED BIN	Data Quality Measures for				No. of Obs.
	1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	22.9	22.9	26.2	26.2	15
30-45	4.1	4.1	7.6	7.6	98
45-60	-2.8	3.0	-5.3	6.0	933
60+	-10.9	10.9	-15.4	15.4	1793
ALL	-7.6	8.2	-11.1	12.1	2839

Table B-3. Data quality measures for freeway segments with using 55mph as historical speed (5am-10pm)

Comparing Bluetooth Speed with 55mph as Historical Speed (5am-10pm)					
SPEED BIN	Data Quality Measures for				No. of Obs.
	1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	32.7	32.7	34.3	34.3	440
30-45	14.3	14.3	16.2	16.2	426
45-60	-0.1	1.0	-0.8	2.8	4329
60+	-7.8	7.8	-11.1	11.1	10221
ALL	-3.9	6.8	-6.1	9.5	15416

Table B-4. Data quality measures for freeway segments with using 55mph as historical speed (10pm-5am)

Comparing Bluetooth Speed with 55mph as Historical Speed (10pm-5am)					
SPEED BIN	Data Quality Measures for				No. of Obs.
	1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	27.9	27.9	31.2	31.2	15
30-45	9.0	9.0	12.6	12.6	98
45-60	0.4	1.1	-0.3	3.3	933
60+	-6.1	6.1	-10.4	10.4	1793
ALL	-3.3	4.7	-6.1	8.3	2839

Table B-5. Data quality measures for freeway segments with using 60mph as historical speed (5am-10pm)

Comparing Bluetooth Speed with 60mph as Historical Speed (5am-10pm)					
SPEED BIN	Data Quality Measures for				No. of Obs.
	1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	37.7	37.7	39.3	39.3	440
30-45	19.3	19.3	21.2	21.2	426
45-60	2.3	2.3	4.2	4.2	4329
60+	-3.3	3.3	-6.1	6.1	10221
ALL	0.1	4.4	-1.1	6.9	15416

Table B-6. Data quality measures for freeway segments with using 60mph as historical speed (10pm-5am)

Comparing Bluetooth Speed with 60mph as Historical Speed (10pm-5am)					
SPEED BIN	Data Quality Measures for				No. of Obs.
	1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	32.9	32.9	36.2	36.2	15
30-45	14.0	14.0	17.6	17.6	98
45-60	2.4	2.4	4.7	4.7	933
60+	-2.2	2.2	-5.4	5.4	1793
ALL	0.1	2.8	-1.1	5.8	2839

APPENDIX C:

The analysis of historical speed was performed on four freeway segments in Virginia similar to that conducted for the Delaware freeway segment. The results are shown in the three following tables, and are similar to that obtained in Delaware. As with Delaware, the historical speed for night hours was recorded as zero, so reference speed was substituted during these time frames.

Table C-1. Historical speed data quality measures for four freeway segments in Virginia (All Data)

Comparing Bluetooth Speed with historical speed					
SPEED BIN	Data Quality Measures for				No. of Obs.
	1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	36.2	36.2	38.7	38.7	72
30-45	8.3	8.9	11.3	12.0	141
45-60	-0.1	3.2	1.0	5.2	578
60+	-2.6	2.6	-4.5	4.7	7264
ALL	-1.8	3.0	-3.4	5.2	8055

Table C-2. Historical speed data quality measures for four freeway segments in Virginia (5am-10pm)

Comparing Bluetooth Speed with historical speed (5am-10pm)					
SPEED BIN	Data Quality Measures for				No. of Obs.
	1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	32.9	32.9	35.6	35.6	50
30-45	8.5	9.1	10.3	11.1	132
45-60	-0.2	3.4	0.3	5.0	512
60+	-3.1	3.1	-5.2	5.3	5536
ALL	-2.4	3.5	-4.1	5.6	6230

Table C-3. Historical speed data quality measures for four freeway segments in Virginia (10pm-5am)

Comparing Bluetooth Speed with historical speed (10pm-5am)					
SPEED BIN	Data Quality Measures for				No. of Obs.
	1.96 SE Band		Mean		
	Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
0-30	43.6	43.6	45.6	45.6	22
30-45	5.0	5.0	26.3	26.3	9
45-60	1.5	1.5	6.5	6.5	66
60+	-0.8	0.8	-2.3	2.9	1728
ALL	-0.1	1.4	-1.3	3.6	1825