I-95 Corridor Coalition

I-95 Corridor Coalition Vehicle Probe Project: Validation of INRIX Data July-September 2008

Final Report

I-95 CORRIDOR COALITION

January 2009

I-95 CORRIDOR COALITION VEHICLE PROBE PROJECT: VALIDATION OF INRIX DATA JULY-SEPTEMBER 2008

Final Report

Prepared for:

I-95 Corridor Coalition

Sponsored by:

I-95 Corridor Coalition

Prepared by:

Ali Haghani, Masoud Hamedi, Kaveh Farokhi Sadabadi
University of Maryland, College Park

Acknowledgements:

The research team would like to express its gratitude for the assistance it received from the state highway officials in Delaware, Maryland, New Jersey, and Virginia during the course of this study. Their effort was instrumental during the data collection phase of the project. This report would not have been completed without their help.

January 2009

Executive Summary

Introduction

The I-95 Corridor Coalition is facilitating a groundbreaking Vehicle Probe Project (VPP) involving the public and private sectors as well as academia to collect and evaluate real-time travel time and speed data for approximately 1,500 miles of freeways and 1,000 miles of arterials in New Jersey, Pennsylvania, Delaware, Maryland, Virginia and North Carolina as shown in Figure 1.

The primary source of the INRIX data is GPS equipped fleet vehicles. These data are supplemented by sensor- and detector-based data in some states. These data will facilitate traffic management, traveler information and planning activities for both local and long distance travelers. The VPP began with the release of a Request for Proposals in May 2007 and contract award to INRIX, Inc. in January 2008. In July 2008, INRIX activated the data feed for the network illustrated in Figure 1. Data collection for the initial evaluation activities were conducted between July and October 2008.

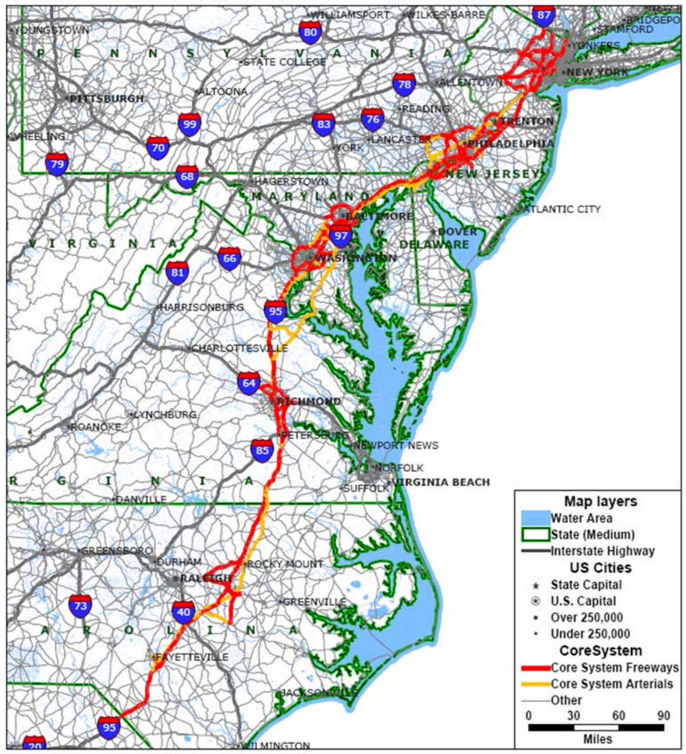

Figure 1 – Coverage Area

This report summarizes the methodology and results of the initial evaluation as well as discusses outstanding questions and issues on how to appropriately assess data quality and planned steps to move forward.

Evaluation Methodology

The University of Maryland is responsible for evaluating the quality of the VPP data at a level of detail that will determine its use for applications previously described. The evaluation was conducted by comparing INRIX GPS data to ground truth data collected on approximately 92 miles of representative roadway segments within the four states of Maryland, Virginia (northern), Delaware and New Jersey. This summary addresses the accuracy assessment of freeway segments and is based on the requirements established by the contract. The verification of data will be ongoing and will include an expanded data set over time. The evaluation had three basic stages: 1) collect ground truth data, 2) establish the statistical measures for comparison of INRIX GPS data to ground truth, and 3) compare the data to ground truth and draw conclusions.

Collect Ground Truth Data

Traditionally, floating car methods (a method in which an instrumented vehicle travels with the traffic stream, in a manner that is intended to replicate the speeds and travel times of the majority of the vehicles in the stream) are used to collect ground truth data. However, this very costly method produces a sparse amount of data not well suited to the requirements of this project. As a result, a new data collection methodology was developed that receives anonymous emissions from Bluetooth equipped accessories (cell phones, car radios, PDAs, PCs, etc.) in passing vehicles that have been activated in the discovery mode. Bluetooth protocol uses an electronic identifier, or tag, in each device called a Media Access Control address (MAC address). In order to collect ground truth data, pairs of Bluetooth receivers were deployed temporarily along the roadside as presented in Figure 2. Bluetooth devices observed by consecutive receivers served as the basis to sample the travel time of the traffic stream between the two detectors. This technique captures the travel times for approximately 5 percent of the vehicles within the traffic stream. The Bluetooth technique proved to be an extremely cost-effective and accurate measurement tool.

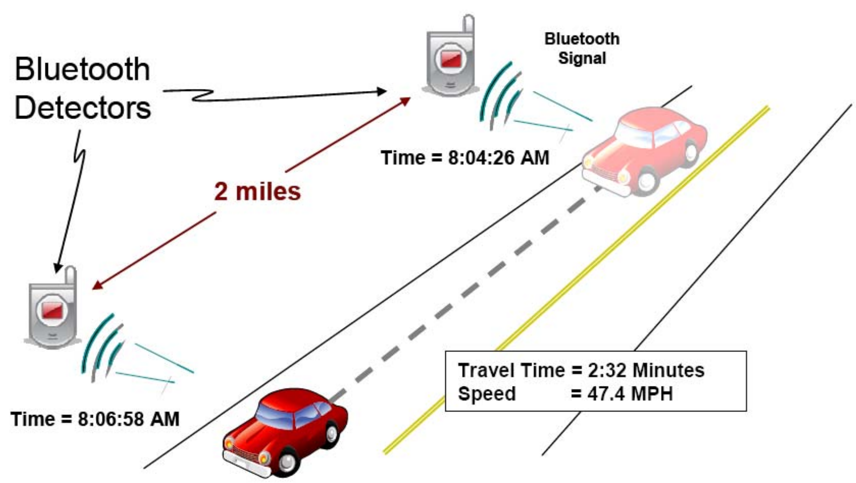

Figure 2 – Bluetooth Data Collection Method

Because the Bluetooth technology is a new technology, the verification of its accuracy was considered an important initial step of the evaluation. In Maryland and Virginia, a limited number of floating car data collection activities was performed by Motion Maps, LLC during morning and afternoon rush hours. Bluetooth sensors were deployed at the same time that the floating car runs were made with the objective of providing a comparison of the ability of the Bluetooth technology to provide ground truth travel times and speeds. A total of nine days of floating car testing was carried out in Maryland and Northern Virginia.

The results of these comparisons confirmed the accuracy of the Bluetooth technology and its use as a method for field measurement of travel times.

Establish Statistical Measures for Comparison

While the Bluetooth technology provides a rich data source for evaluation of the INRIX GPS, there is still some uncertainty associated with the definition of the ground truth vehicle speeds and travel times that existed when the measurements were made. On any roadway section there are significant speed and travel time variations depending on driver, vehicle and roadway characteristics. For this reason, in addition to reporting the mean travel time and speed calculated from the Bluetooth data, a confidence band was defined that represents the uncertainty existing in the definition of the ground truth speeds and travel times. A number of statistical measures were evaluated to define the width of this uncertainty band, and all these measures are described and reported in the full report. The uncertainty measure presented in the summary is termed the standard error of the mean (SEM).[1] The SEM is commonly used to represent the uncertainty associated with a given measurement because it is a straightforward calculation that is sensitive to both the variability and volume of data being used as the basis for the calculations. An example of the SEM band is shown in Figure 3. As shown, the band narrows to represent a higher confidence of the Bluetooth data and widens when there is less confidence in the Bluetooth data. In essence, the SEM band is a surrogate for the 95 percent confidence interval of ground truth.

[1] Standard Error of the Mean (SEM) is calculated as the standard deviation (S) of the calculated error (the difference between the Bluetooth data and the INRIX GPS) divided by the square root of the number of Bluetooth data points (N) taken for a given time. In other words, $SEM = S/(N)^{½}$

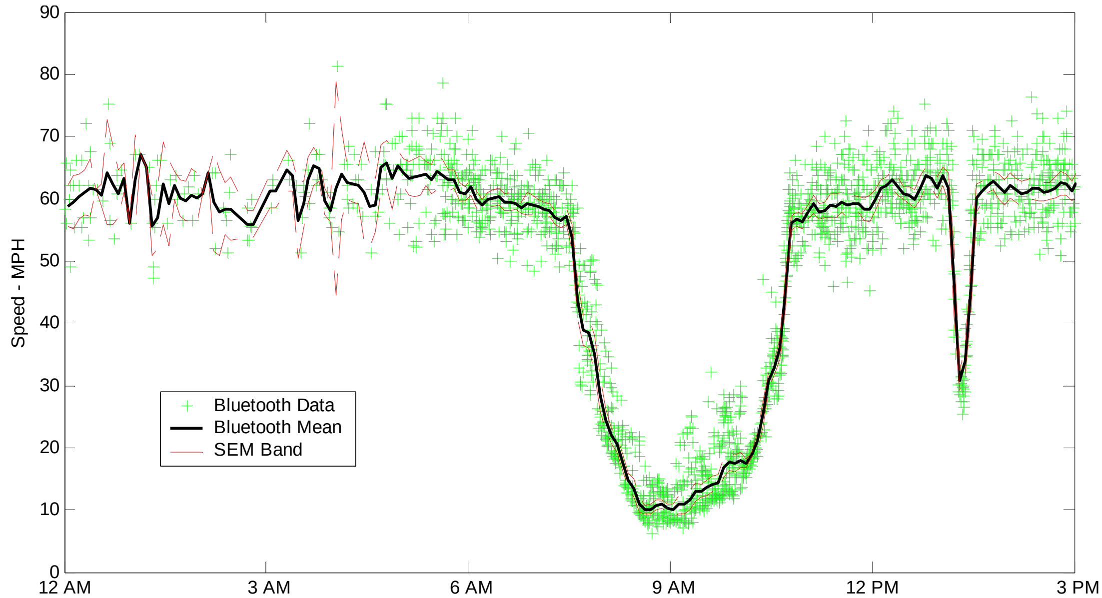

Figure 3 - Example of Standard Error of the Mean (SEM) Band

A statistical analysis of the data was conducted for four defined speed ranges: 0 to 30 mph, 30 to 45 mph, 45 to 60 mph and greater than 60 mph as defined in the contract. The ground truth SEM band and mean were calculated for these ranges as were the two basic measures of error used to evaluate the accuracy of the INRIX GPS data. The two measures are: 1) average absolute speed error (AASE)[2] – compares INRIX GPS data to ground truth – and 2) the speed error bias (SEB)[3] to identify bias (consistent differences) between INRIX GPS data and ground truth. The allowable maximum for the AASE and SEB is 10 mph and 5 mph, respectively.

Compare Data to Ground Truth and Draw Conclusions

This evaluation focused primarily on the accuracy of data collected along the freeways in the corridor. Data were objectively determined to fall within the SEM band and subjectively reviewed to determine the degree by which sudden slowdowns in traffic flow due to either congestion or incidents were identified and correctly captured. It is concluded that the INRIX travel time and speed data across the system and by individual state generally satisfies the accuracy specifications of the contract (average absolute speed error less than 10 mph and speed error bias less than 5 mph). It was also observed that quality of the INRIX travel time and speed data improves with increase in speed. Further, a subjective

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[2] The average absolute speed error (AASE) is calculated in the following manner. For each INRIX data point, find the difference between the data point and the Bluetooth data at the same time. Take the absolute value of the difference. Take the average of these absolute differences. In this way, positive errors and negative errors do not cancel each other.

[3] The speed error bias is calculated using the same procedure as the absolute speed error, except that the absolute value is not taken. Thus if there is a consistent positive or negative error, it would appear in the result of the calculation.

review established that INRIX positively identified the majority of congestion events defined as traffic slowing to 40mph or less for more than 15 minutes. This result confirms that the INRIX GPS data provides an accurate overall picture of traffic conditions for limited access roadways within the Corridor.

Table 1 presents the evaluation results by individual state and a composite of all states. The average absolute speed error (AASE) and speed error bias (SEB) are presented for comparison to both the Bluetooth ground truth SEM band and the mean for each of the four speed ranges previously defined. The following conclusions are drawn:

- In Northern Virginia, all data quality specifications are satisfied for all speed ranges using both the SEM band and mean.
- The average absolute speed error specification, that compares the INRIX GPS to the Bluetooth ground truth, is satisfied in comparison with the SEM band for data collected in all states at all speed ranges.
- The speed error bias specification, used to identify bias and consistent differences in the data, is satisfied in comparison with the SEM band for data collected in all states at all speed ranges with two exceptions in the 0-30mph speed range and one exception in the 30-45mph speed range.

Table 1
Evaluation Results

State	Average Absolute Speed Error (less than 10mph)		Speed Error Bias (less than 5mph)		Hours of data collection
	Comparison with SEM Band	Comparison with Mean	Comparison with SEM Band	Comparison with Mean	
Virginia					
0-30 MPH	4.10	5.30	2.20	2.60	16.7
30-45 MPH	5.70	7.40	1.40	1.70	24.3
45-60 MPH	2.90	5.20	0.20	0.90	87.2
> 60 MPH	2.20	4.30	-1.60	-2.80	101.7
All Speeds	2.97	5.04	-0.32	-0.53	229.8
Maryland					
0-30 MPH	7.80	11.70	7.20	10.60	2.4
30-45 MPH	6.70	10.70	4.00	6.10	5.8
45-60 MPH	3.30	6.20	-0.70	-0.20	30.8
> 60 MPH	1.80	4.00	-1.30	-2.20	108.2
All Speeds	2.40	4.85	-0.83	-1.25	147.2
Delaware					
0-30 MPH	6.50	10.90	-0.20	2.50	3.0
30-45 MPH	8.50	11.80	-1.90	-0.10	9.0
45-60 MPH	1.20	3.60	-0.10	0.00	74.4
> 60 MPH	2.50	5.50	-2.40	-4.90	112.4
All Speeds	2.35	5.16	-1.48	-2.74	198.8
New Jersey					
0-30 MPH	9.50	12.50	8.30	10.90	6.6
30-45 MPH	8.30	11.60	5.30	7.60	14.0
45-60 MPH	2.40	4.80	0.70	1.90	132.9
> 60 MPH	1.90	4.20	-1.60	-3.10	854.3
All Speeds	2.10	4.44	-1.14	-2.20	1007.8
All States					
0-30 MPH	5.90	8.10	3.80	5.20	28.7
30-45 MPH	6.90	9.60	2.20	3.40	53.0
45-60 MPH	2.30	4.70	0.20	1.00	325.3
> 60 MPH	2.30	4.30	-1.70	-3.20	1176.5
All Speeds	2.52	4.63	-1.08	-1.96	1583.5

Outstanding Questions and Issues

The evaluation discussed in this document represents the results of analyses of data collected from a snapshot in time and at the early stages of this major data collection effort. There are a number of issues for consideration as the evaluation process continues, including but not limited to:

- Specific issues related to false alarms and other short-duration, deviations of INRIX GPS data from the Bluetooth data.
- Mapping and geospatial accuracy issues.
- Temporal distribution and penetration rate of both Bluetooth and GPS data.
- Measurement of data lag[4] remains an issue to be resolved.
- Travel time variability and its impact on both the Bluetooth and GPS data.
- Outlier filtering and its impact on the ground truth data.

The project team will continue to research and identify countermeasures to either eliminate or reduce the severity of the effects of these issues.

Moving Forward

These data were collected within the first five months of the project and revealed a great deal about the vehicle probe data characteristics, the nature of GPS data, and mapping and geo-coding issues facing the industry in general. To date, the project team has gleaned much insight, but the work has just begun. Observations and lessons learned include:

- The density of GPS-based data used as the basis of the INRIX GPS feed continues to grow and thus improving the accuracy of the VP data over time.
- GPS data may not be a single-source replacement for traditional data collection methods. A blend or fusion of traditional traffic data and GPS-based VP data can and should be used when available. Further, historical data may be used under certain circumstances and during times when GPS-based data is not available.
- The fundamental accuracy and technical limitations of VP data presented here must be understood to properly design data applications for travel times on message signs, 511 and web sites in addition to operational uses such as incident detection.
- The evaluation process and efforts related to developing applications must continue in parallel in order to utilize the VPP data to its fullest extent. Methods to better quantify the quality of the VPP data will continue to be developed.

[4] The difference between the time the traffic flow is perturbed as a result of an incident and the time that the change in speed is reported in the traffic data.

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1 Introduction and Background

This report summarizes the results of the University of Maryland (UMD) research team's efforts over the summer of 2008 to validate the travel speed information that is provided since July 1, 2008 by INRIX to I-95 Corridor Coalition member states.

In this period the validation effort was concentrated on four states: Maryland, Virginia (Northern parts only), Delaware and New Jersey. In Maryland and Virginia, in conjunction with the Bluetooth sensor deployments, a limited number of drive tests were performed by Motion Maps, LLC. These drive tests were conducted to provide alternative "ground truth" for verification purposes. The data collected through these drive tests was analyzed by the UMD team and was compared with the data gathered from the Bluetooth sensors as well as the data provided by INRIX. The results of these analyses and comparisons are included in this report.

In this report we first establish the validity of the Bluetooth sensor data collection method as a viable technology that can be used to gather "ground truth" traffic speeds and travel times. Then, we provide the results of the effort that was performed to validate the data provided by INRIX. These results are obtained by comparing the data collected through Bluetooth sensor deployments in the states of Delaware, Maryland, Virginia, and New Jersey with the data provided by INRIX during the times and at the same locations where the Bluetooth data was collected.

The rest of this report is organized as follows. Section 2 describes the overall data collection effort and provides a thorough description of the Bluetooth technology as applied in the "ground truth" travel time and speed measurements. Also, the concept of the floating car method and its advantages and disadvantages are discussed in the same section. Section 2 also describes the procedure that was followed in selecting appropriate validation segments and the number of those segments in each state. The results of the analysis performed on the drive test data and comparisons between this data and Bluetooth sensor data are reported in Section 3. Section 4 provides the details of the methodology adopted in preparation and analyses of the collected Bluetooth sensor data and in comparing that data with the data provided by INRIX . Sections 5 through 8 present the results of the validation in the states of Delaware, Maryland, New Jersey and Virginia respectively and summarize the observations that the UMD research team has made regarding the quality of the data provided by INRIX since its data has become available to the I-95 corridor coalition members. Each section includes typical summary tables and charts for selected traffic message channel (TMC) segments resulting from the validation efforts.

Section 9 provides a collective perspective of the data quality in all four states. The data quality measures reported in this Section can be viewed as the overall measures of the data quality provided to the I-95 corridor coalition. Section 10 presents the conclusions of the validation effort.

This report has five appendixes that provide the detailed tables and charts for all TMC segments for which Bluetooth sensor data was collected and compared with the corresponding INRIX data. Appendixes A, B, C, and D provide the results for the states of Delaware, Maryland, New Jersey and Virginia respectively. These appendixes also present the results of evaluations for the freeway segments shorter than one mile in each respective state. Appendix E presents evaluation results for all states combined for the freeway segments shorter than one mile.

This report is also accompanied by a CD-ROM. This CD includes over 4000 graphs that are generated for the 90 TMC segments considered in the validation effort. These segments are grouped into four main folders where each folder contains the TMC segments of a state. In each state folder there are several folders each named after one TMC segment in that state. Inside each TMC folder graphs are grouped into four different sub folders each representing a different scenario under which data belonging to that TMC has been analyzed. Figure 1.1 shows the directory structure with the expanded subfolders of a sample TMC 103-04103 in the state of Delaware.

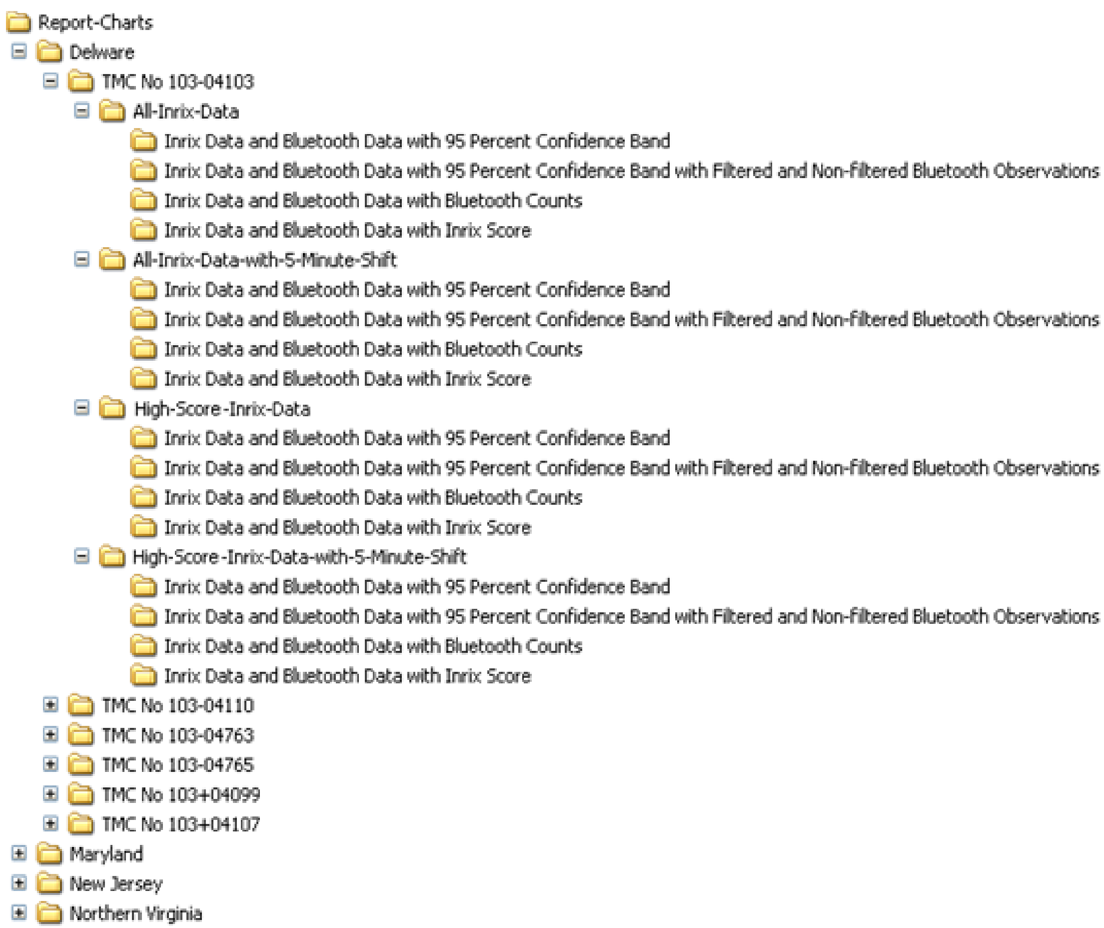


Figure 1.1
Illustration of the folder structure for organizing the graphs

The first folder, “All-INRIX-Data”, contains graphs related to analysis performed with all reported INRIX data. The second folder, “All-INRIX-Data-with-5-Minute-Shift”, has to do with the case in which all INRIX data are included in the analysis but they are compared with five minute delay with the Bluetooth data. The third folder, “High-Score-INRIX-Data”, contains graphs that are obtained using high score INRIX data alone. The last folder, “High-Score-INRIX-Data-with-5-Minute-Shift”, holds the set of graphs that are generated using high score INRIX data after they are delayed for 5 minutes.

Also, graphs inside each scenario folder are again organized into four different folders each containing a different set of graphs belonging to different days of data collection on that segment. The first folder presents the Bluetooth and INRIX data with the 95% Bluetooth mean speed confidence interval band. In the actual graph names, days are identified with [MMDD] which represents two digit month and day numbers. For instance September 25 is shown as 0925. (Note that any date reference is to calendar year 2008). The second folder contains the same information however it also includes the cloud of individual Bluetooth observations in which both filtered and non- filtered observation are displayed. The next folder contains daily graphs that present both INRIX and Bluetooth speeds as well as the number of Bluetooth counts in each 5 minute interval. Finally, the last folder incorporates the daily graphs that show the scores variation along with the INRIX and Bluetooth speeds. The graphs are in the Graphics Interchange Format (GIF) which can be viewed using any standard picture viewer software. Figure 1.2 presents the files in each of the directories and the organization of files in those directories.

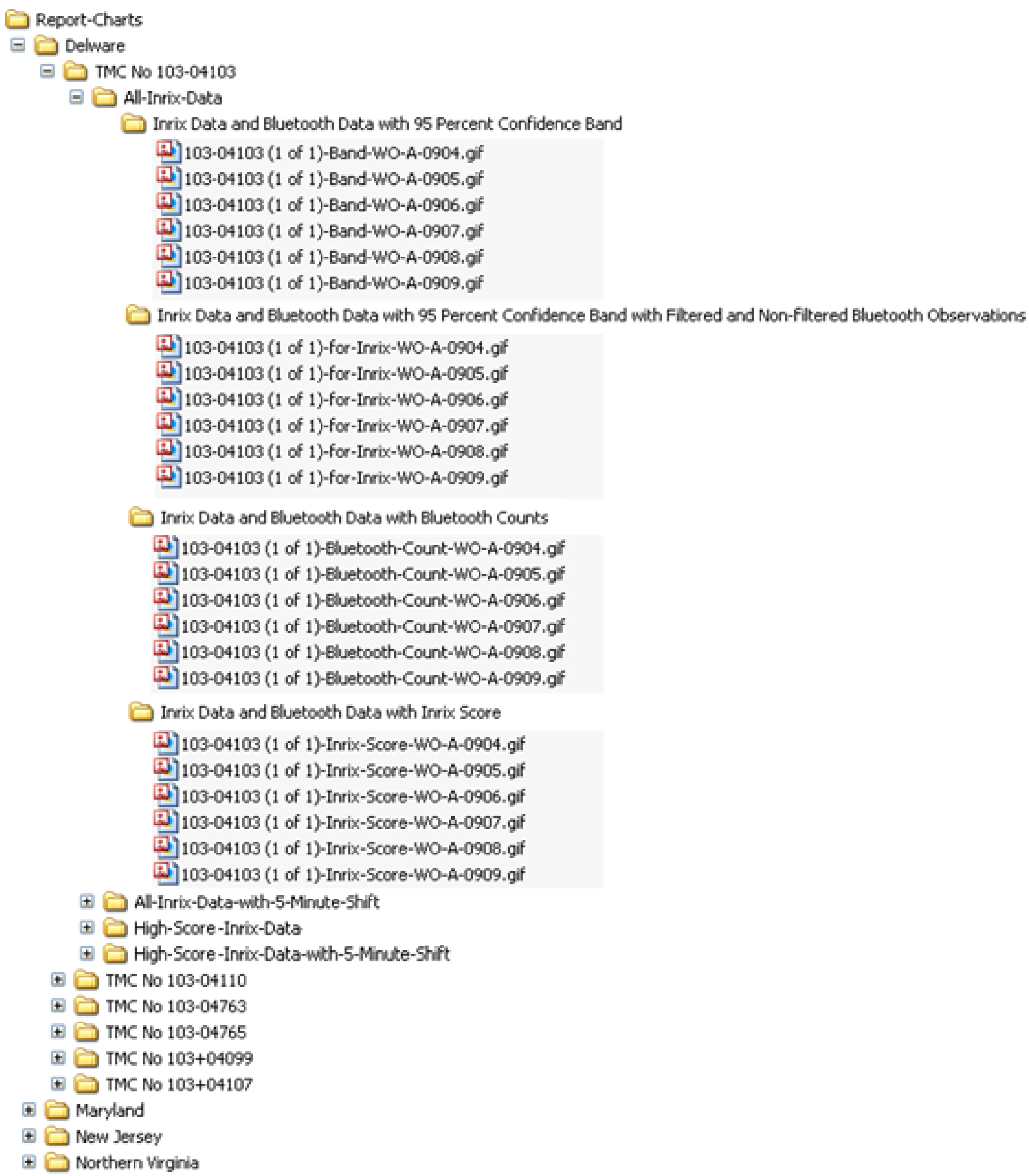


Figure 1.2
The graph files in individual directories in the CD-ROM

2 Data Collection Effort

2.1 *Bluetooth Technology*

The University of Maryland (UMD) has developed a technology to monitor vehicle travel times and speeds on highways based on signals available from the point-to-point networking protocol commonly referred to as Bluetooth. The majority of consumer electronic devices produced today come equipped with Bluetooth wireless capability to communicate with other devices that are enabled with this technology and are in close proximity. For example, many digital cameras use Bluetooth for uploading pictures to a laptop or desktop computer. Bluetooth technology is also the primary means that enables hands-free use of cell phones. Bluetooth enabled devices can communicate with other Bluetooth enabled devices anywhere from one meter to about 100 meters. This variability in the communications capability depends on the power rating of the Bluetooth sub-systems in the devices.

The Bluetooth protocol uses an electronic identifier, or tag, in each device called a Machine Access Control address, or MAC address for short. The MAC address serves as an electronic nickname so that electronic devices can keep track of who's who during data communications. It is these MAC addresses that are used as the basis for obtaining traffic information. The concept for deriving traffic information in this manner is illustrated in Figure 2.1.

2.1.1 Privacy Concerns

The anonymous nature of this technique is due to the use of MAC addresses as identifiers. MAC addresses are not directly associated with any specific user account (as is the case with cell phone geo-location techniques) or any specific vehicle (as is the case with deriving travel time from automated toll tags). The MAC address of a cell phone, camera, or other electronic devices, though unique, is not linked to a specific person through any type of central database, thus minimizing privacy concerns. Additionally, users concerned with privacy can set options in their device (referred to as 'Discovery Mode' or 'Visibility') so that the device is not detectable.

2.1.2 Concept of Operation

The UMD has developed a portable Bluetooth monitoring system consisting of several detectors and a central processing unit. These detectors are deployed on a freeway in proximity to the roadway at the base of a sign post or guard rail post. These units are the size of a large briefcase or small carry on. A photo of the device and a sample placement next to a sign post are shown in Figure 2.2.

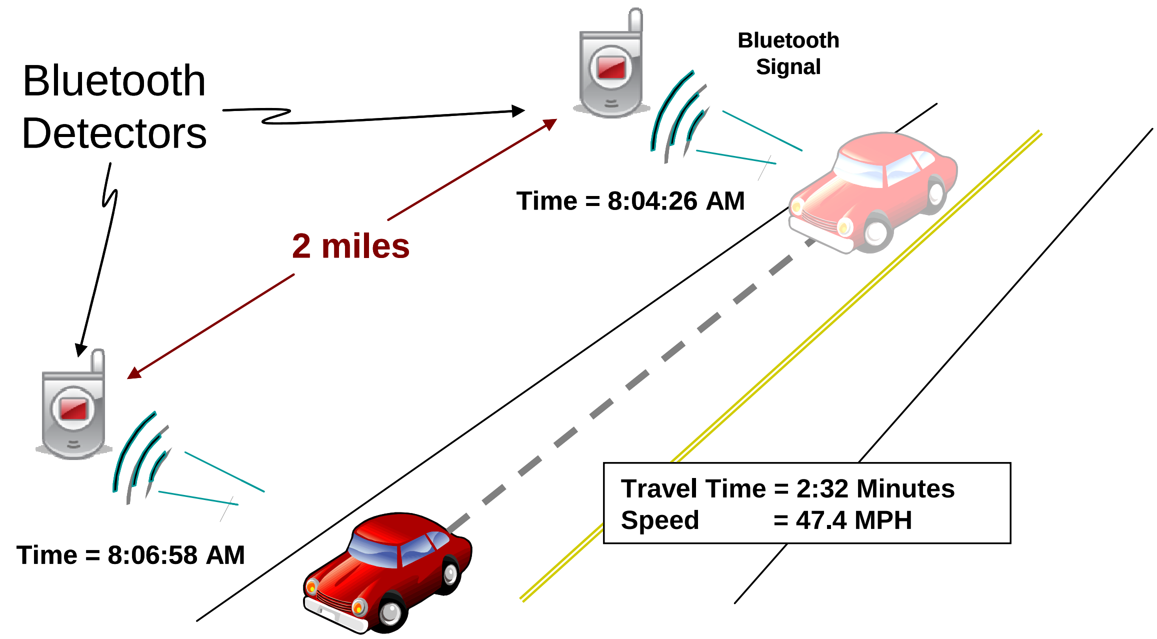


Figure 2.1
Bluetooth traffic monitoring operation concept

Figure 2.2
The Bluetooth detector deployed during data collection

2.1.3 Sample Data

Internal UMD studies have indicated that approximately one automobile in 20 contains some type of Bluetooth device that can be detected at the present time. This is referred to as the penetration rate. It is expected that in the near future this penetration rate will increase substantially as the number of Bluetooth technology enabled devices increases. Not every Bluetooth device is detected at every station so the number of matched detections (a device detected at two consecutive detectors) is generally lower than the penetration rate. Normally, a majority of the detected devices are seen at multiple stations when several Bluetooth sensors are deployed along a stretch of highway. When the MAC address of a device is matched between two consecutive sensors, the difference in time between the detections at the two sensors represent the travel time of the vehicle carrying the device. The matched MAC addresses for all devices that are detected between two consecutive sensors can be used to develop a sample of travel time for that particular segment of the roadway. Figure 2.3 shows data from a segment of Interstate I-95 between Washington, DC and Baltimore, Maryland between 6:30 AM and 12:45 PM. Each data point represents the travel time from a matched detection at each end of the segment. Figure 2.3 depicts the impact on travel time as a result of an incident that began around 10 AM and was cleared at approximately 10:50 AM. Traffic returned to normal flow around 11:15 AM.

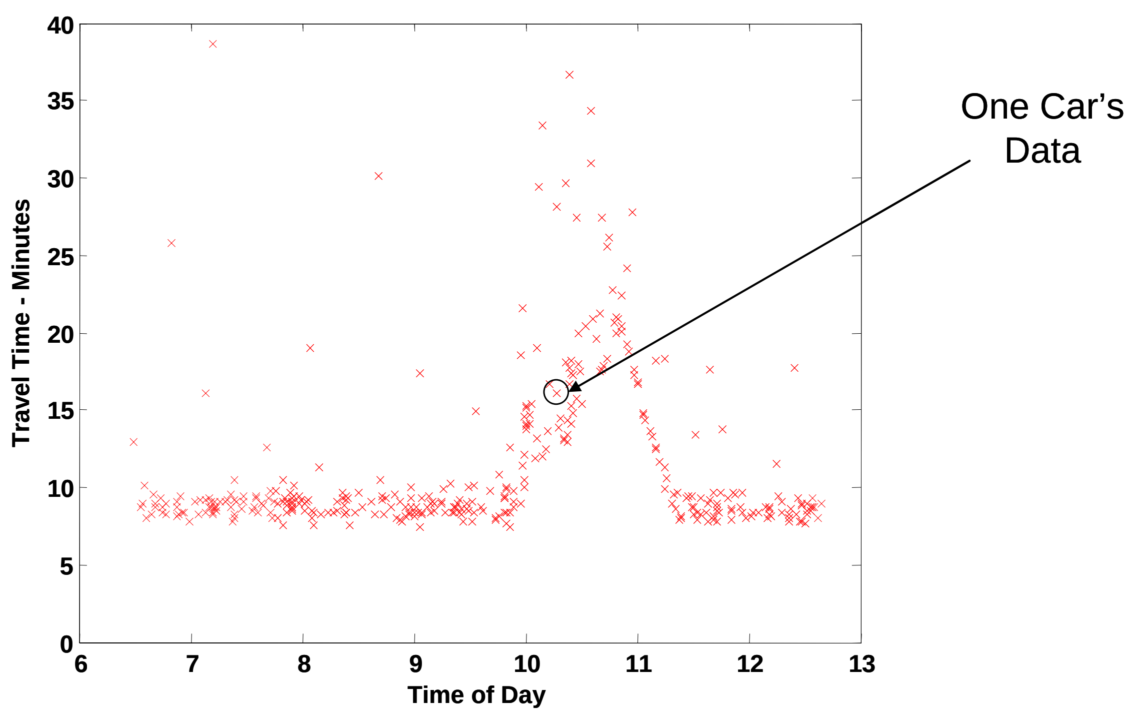


Figure 2.3
Sample Bluetooth data

It should be noted that in slow traffic, a vehicle can be detected multiple times by a single sensor and therefore, potentially there could be several possible matches for the same MAC address between two consecutive Bluetooth sensors. Internal UMD studies have indicated that the most accurate match representing the travel time for the vehicle traveling between the two sensors is the first times that the MAC address is detected at each of the sensors. In other words, the most accurate travel time is the difference in time when the vehicle was first detected at the first sensor and when it was first detected at the second sensor.

2.1.4 Conclusion

Bluetooth Traffic Monitoring provides an opportunity to collect high quality, high density travel time data by sampling a portion of the traveling vehicles' actual travel times from the traffic stream. By matching MAC addresses at two different locations, not only is accurate travel time measured, but also privacy concerns typically associated with other probe systems are minimized. This method has proved to be much more cost efficient than the floating car method that is described in the next section given the volume of data collected.

2.2 *Floating Car*

In Maryland and Northern Virginia drive tests were performed during morning and afternoon rush hours where Bluetooth sensors were simultaneously deployed. These drive tests were conducted with primary intention of providing a basis for comparison with Bluetooth technology to ensure that the new technology is accurately providing the "ground truth" travel times and speeds.

The actual drive tests were performed by Motion Maps, LLC. During these drive tests a second by second log of the vehicle locations were recorded using a global positioning system (GPS) device that was carried in the vehicle.

In total, nine days of drive testing was carried out in Maryland and Northern Virginia. Figure 2.4 presents a schematic map of the corridors around the capital beltway in Washington, D.C. both on the Northern Virginia side and the Maryland side on which drive tests were performed. Later on, as shown in Figure 2.5, corridors around the Baltimore city and the northeastern Maryland area were subject to drive testing.

2.3 *Test Segment Selection*

In general, five criteria were considered in selecting the test segments.

1. safety of both general traffic and the deployment team during and after installation of the sensors
2. priority for freeway segments longer than one mile
3. large daily fluctuations in the speed reported by INRIX
4. local concerns and input from state agency officials
5. size of each state's highway network in the overall validation network

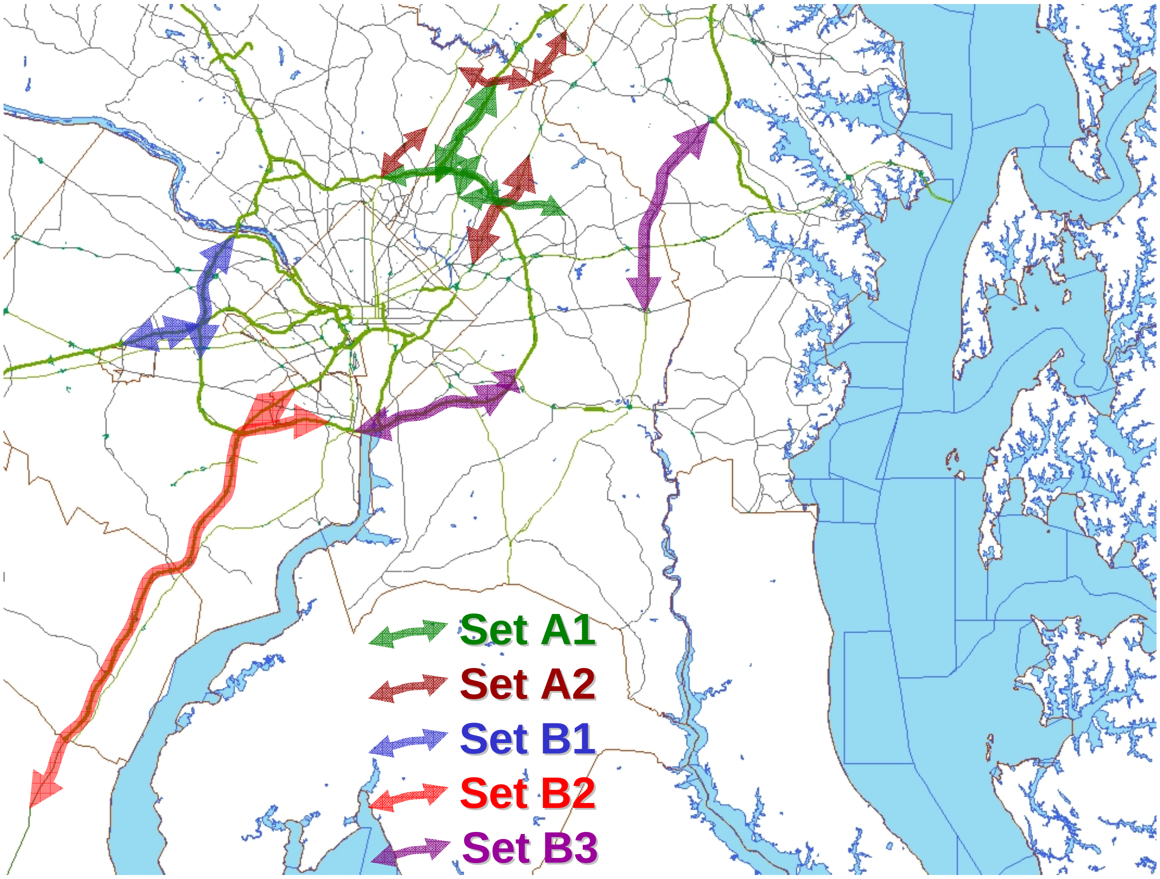


Figure 2.4
Schematic map of the drive test corridors in Northern Virginia and Capital Beltway area in Maryland (courtesy of Motion Maps, LLC)

Throughout the selection process the main consideration was to pick segments that had enough shoulder area for the deployment team to be able to access the deployment locations and do the deployments in a safe manner. It should be noted that every possible measure was taken to prevent the sensors from becoming a hazard for drivers.

As it was explained before, the Bluetooth technology can pick up signals anywhere within a 300 feet radius around the sensor. This implies that in the resulting travel time samples obtained using this technology one might expect to see errors caused by a maximum of 600 feet error in the length traveled (L). It can be shown that the maximum error in the speed estimates resulting from local inaccuracies in readings at each sensor is a function of the coverage radius of the sensor (R), the average speed of the traffic (S), error in travel time estimate $(\Delta T_{\min})$, and the actual travel time between a pair of sensors (T).

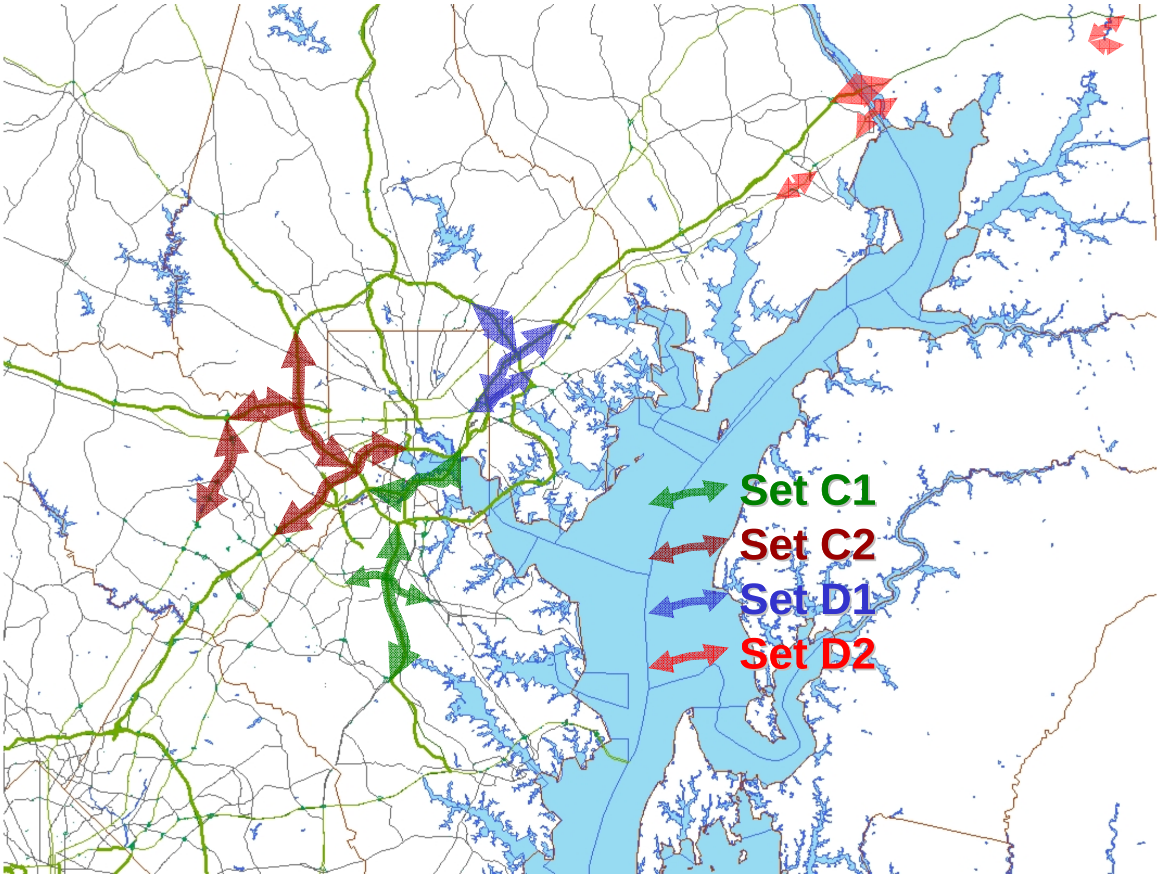


Figure 2.5
Schematic map of the drive test corridors in the Baltimore area and northeast Maryland (courtesy of Motion Maps, LLC)

$$L = S \times T \tag{2-1}$$

$$L + \Delta L = (S + \Delta S) \times (T + \Delta T) \tag{2-2}$$

$$\Delta L = S \times \Delta T + \Delta S \times T + \Delta S \times \Delta T \tag{2-3}$$

Equations (2-1) and (2-2) show the relationship between the traveled length and the average speed and travel time when accurate and inaccurate values for each of these parameters are used respectively. Equation (2-3) is derived by subtracting equation (2-1) from equation (2-2).

Equation (2-3) can be rearranged to obtain the statement for error in speed estimate shown in Equation (2-4).

$$\Delta S = \frac{\Delta L - S \times \Delta T}{T + \Delta T} \tag{2-4}$$

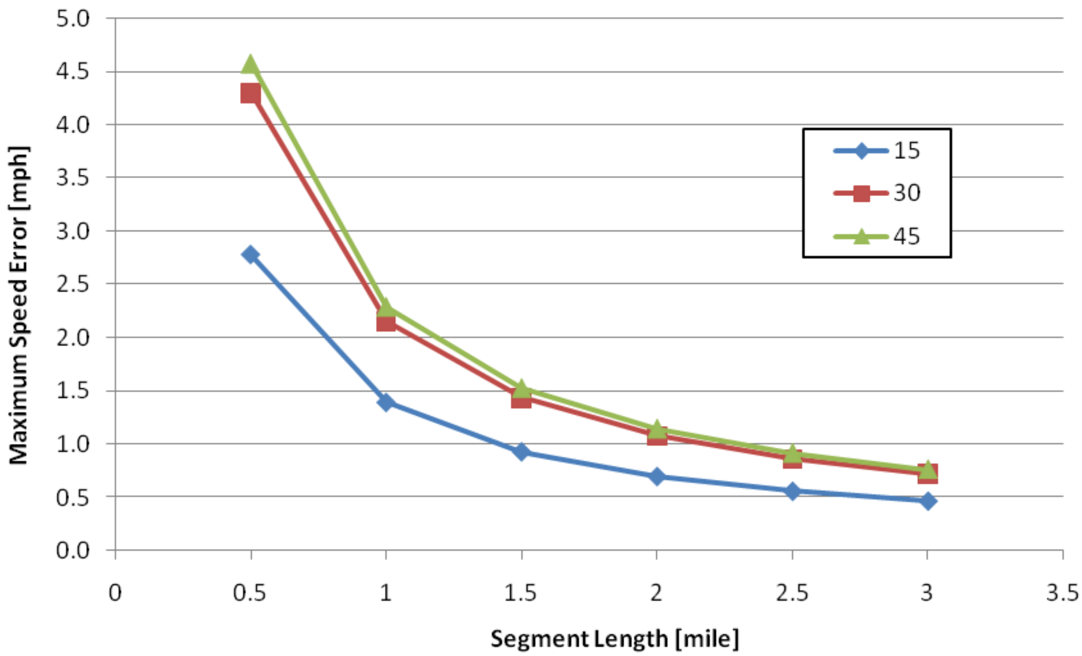
By setting the distance error at its maximum possible level, $(\Delta L_{\max} = 2R = 600\ ft)$, and the smallest possible time error equal to the scan period of the sensor $(\Delta T_{\min} = 5 \sec)$, an upper bound for the error in speed estimate can be obtained. Equations (2-5) and (2-6) can be directly used to estimate the maximum error in speed estimate.

$$\Delta S \le \frac{\Delta L_{\max} - S \times \Delta T_{\min}}{T + \Delta T_{\min}} \tag{2-5}$$

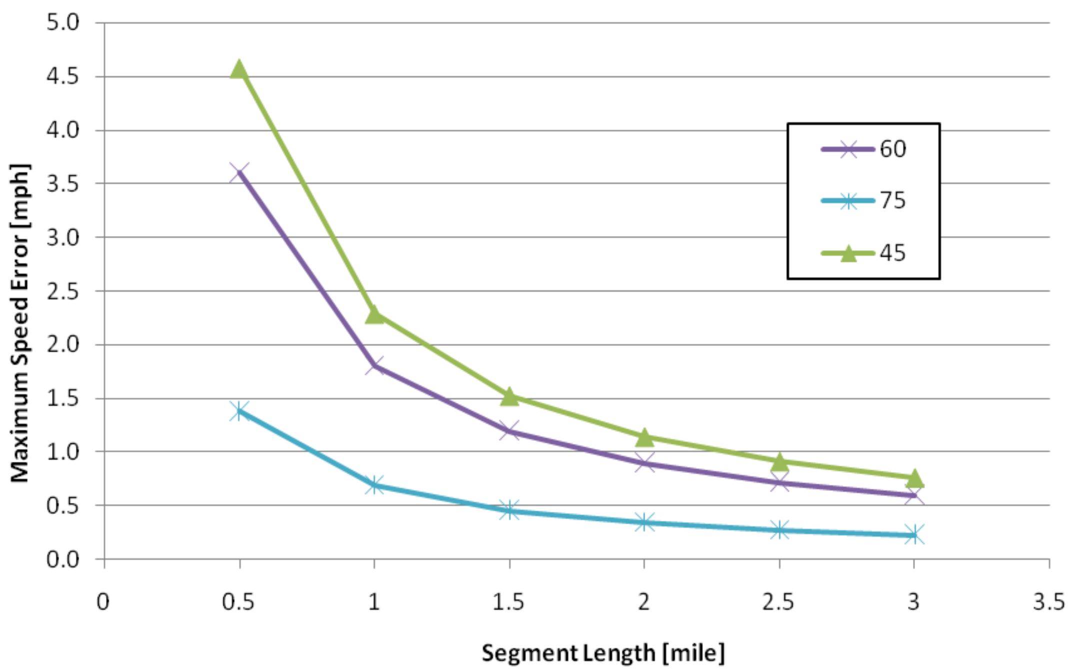
$$\Delta S\,[mph] \le \left[\frac{600 - (1.47)(5)S\,[mph]}{(3600)\dfrac{L\,[mile]}{S\,[mph]} + 5} \right] \div 1.47 \tag{2-6}$$

Figure 2.6 shows the changes in maximum possible errors in speed estimates at different speeds and over segments from 0.5 mile to three miles long. It can be observed from Figure 2.6 that in general the maximum error in speed estimate will be less on longer segments. In a one mile segment the error will be less than 2.5 mph in all different speed levels. Therefore, in this study freeway segments longer than one mile are primarily selected for validation purposes. Also, it should be noted that in Figure 2.6 at every given length the maximum possible error first increases with speed from 15 to 45 mph and then it starts to decrease as speed goes beyond the 45 mph threshold. This in fact is the result of the non-linear relationship between the maximum possible error in speed measurements and the actual speed of the observed vehicles as described by equation (2-6). Therefore, in Figure 2.6 the curves representing the maximum possible speed errors at speed ranges below and over 45 mph are separated from each other.

The research team believed that segments with large speed fluctuations over time would be good candidates for selection as test segments in the validation process. To this end, multiple days of INRIX data feed in each state where Bluetooth sensors were to be deployed were studied. Coefficient of variation (COV) was used as the measure for speed fluctuations. Therefore, segments with larger COV values were selected as candidates for Bluetooth deployment and data collection. These initial candidate segments were then forwarded to each state's appropriate officials for their evaluation and comments. Input from state officials regarding the viability of sensor deployment on the candidate segments, and valuable local knowledge about important segments in the core coverage area in each state was used to finalize the selections. The total length of the segments subject to validation in each state was determined as a function of the ratio of the total length of segments in that state for which INRIX provides speed data, to the total length of all such segments in all core states.



(a) Maximum Bluetooth Speed Estimate Error at Speeds Less Than 45mph



(b) Maximum Bluetooth Speed Estimate Error at Speeds Larger Than 45mph

Figure 2.6
Maximum possible speed error at different speeds and segment lengths

3 Comparison of Bluetooth Sensor Data with Floating Car Data

To verify the accuracy of speed estimates obtained through the use of Bluetooth technology, we compared them with those obtained from data produced by floating car runs. We conducted a statistical hypothesis test (Equation 3-1) in each speed bin to understand whether or not the mean speeds obtained from the Bluetooth sensor data were significantly different from those obtained from floating car data. The null hypotheses in these statistical tests were that the Bluetooth mean speeds (μ_{BT}) are not significantly different from the floating car mean speeds (μ_{FC}) in each speed bin.

$$\begin{cases} H0: \mu_{BT} = \mu_{FC} \\ H1: \mu_{BT} \neq \mu_{FC} \end{cases} \tag{3-1}$$

The statistic that was used in this test is given as:

$$Z = \frac{(\mu_{FC} - \mu_{BT}) - 0}{\sigma_{FC-BT}} \tag{3-2}$$

in which σ_{FC-BT} is the standard deviation of the difference between the floating car and the Bluetooth speed data in each speed bin and can be derived using the following formula:

$$\sigma_{FC-BT} = \sqrt{\frac{\sigma_{BT}^2}{N_{BT}} + \frac{\sigma_{FC}^2}{N_{FC}}} \tag{3-3}$$

in which σ_{BT}, is the standard deviation of the Bluetooth speeds in a speed bin, σ_{FC}, is the standard deviation of the floating car speeds in a speed bin, N_{BT}, is the number of Bluetooth speed observations in a speed bin, and N_{FC}, is the number of floating car speed observations in a speed bin.

Results of the z-tests (Equation 3-1) that were performed in these hypotheses testing are reported for each speed bin in Table 3.1. The results are shown for all freeway segments, those that are greater than one mile and those that are less than one mile. In freeway segments greater than one mile that are the main focus of validation in this study, the null hypothesis could not be rejected at extremely high levels of significance for the two lower speed bins. However, in the two higher speed bins the null hypothesis is rejected. These statistical tests show that at least at low speeds the Bluetooth sensor speed data are a good representative of the "ground truth." The rejection of the hypotheses at the higher speed levels may be attributed to the fact that the floating car drivers had much more flexibility in traveling at higher speeds than the average speed of traffic and given that the number of drivers on each segment was limited to one or at most two, the driver behavior and driving habits may have impacted the floating car speed data.

Table 3.1
Hypothesis test for similarity between means of Bluetooth and drive test speeds

FREEWAYS	SPEED BIN	No. Obs.	Bluetooth MEAN	Bluetooth SD	Floating Car MEAN	Floating Car SD	Speed Error Bias	Average Absolute Speed Error	Null Hypothesis rejected?
ALL	0-30	78	23.3	5.8	22.7	5.7	-0.6	2.6	N
	30-45	94	37.8	8.0	37.9	4.3	0.0	4.7	N
	45-60	241	56.8	6.8	54.8	3.7	-2.1	5.1	Y
	60+	359	63.3	5.2	65.6	3.7	2.4	4.8	Y
>=1 mile	0-30	47	23.2	6.4	22.5	5.8	-0.7	2.3	N
	30-45	72	38.0	7.0	38.0	4.1	0.0	4.0	N
	45-60	158	57.5	5.8	54.4	3.8	-3.1	4.9	Y
	60+	223	63.8	4.6	65.2	3.2	1.5	3.9	Y
<1 mile	0-30	31	23.5	4.9	23.0	5.5	-0.5	3.1	N
	30-45	22	37.3	10.7	37.4	4.8	0.1	6.9	N
	45-60	83	55.6	8.2	55.5	3.6	-0.1	5.5	N
	60+	136	62.4	5.9	66.3	4.3	3.9	6.4	Y

For benchmarking purposes, we performed similar analysis comparing the speed data reported by INRIX to the speed data from the floating car runs. The same type of statistical analysis was performed for each speed bin. In these hypotheses tests (Equation 3-4) the null hypotheses were that the INRIX mean speeds (μ_{Inrix}) were not significantly different from the floating car mean speeds (μ_{FC}) in each speed bin.

$$\begin{cases} H0: \mu_{Inrix} = \mu_{FC} \\ H1: \mu_{Inrix} \neq \mu_{FC} \end{cases} \qquad (3\text{-}4)$$

Table 3.2 summarizes the results of the z-tests performed to verify the null hypotheses. The results indicate that on freeway segments greater than one mile, in the 30-45 mph range, the floating car speeds and INRIX data are not significantly different from each other. However, in other speed ranges the mean of speed data reported by INRIX is statistically significantly different from the mean of speeds recorded by driving tests. We should note that the same caveats that we stated above regarding the floating car driver behavior and habits apply here as well. However, one should note that when considering all cases, overall the mean of Bluetooth speed data are statistically closer to the mean of the floating car speed data than the speed data reported by INRIX.

Table 3.2
Hypothesis test for similarity between means of INRIX and drive test speeds

FREEWAYS	SPEED BIN	No. Obs.	INRIX MEAN	INRIX SD	Floating Car MEAN	Floating Car SD	Speed Error Bias	Average Absolute Speed Error	Null Hypothesis rejected?
ALL	**0-30**	106	25.0	9.8	22.1	5.8	-3.7	7.0	**Y**
	30-45	123	39.0	11.6	37.9	4.4	-1.9	8.9	**N**
	45-60	398	56.0	7.7	55.1	3.6	-1.8	6.0	**Y**
	60+	750	61.0	6.1	65.9	3.7	4.3	5.8	**Y**
>=1 mile	**0-30**	62	27.0	10.8	22.1	5.9	-5.1	7.1	**Y**
	30-45	91	39.0	10.3	37.8	4.3	-1.2	8.0	**N**
	45-60	243	56.0	8.4	54.9	3.6	-1.2	6.1	**Y**
	60+	415	62.0	6.4	65.6	3.3	3.4	5.1	**Y**
<1 mile	**0-30**	44	23.0	7.8	22.0	5.6	-1.7	6.9	**N**
	30-45	32	42.0	14.7	38.2	4.7	-3.8	11.4	**N**
	45-60	155	58.0	6.2	55.4	3.6	-2.8	5.9	**Y**
	60+	335	60.0	5.7	66.2	4.1	5.4	6.7	**Y**

4 Evaluation Methodology

4.1 *Distance Measurement between Sensor Deployment Locations*

The Bluetooth technology measures a sample of travel times between two cross sections of the highway. The distance between a pair of sensors will then be needed to convert the travel times into speeds. In practice sensors were deployed based on the coordinates provided in the traffic message channel (TMC) location database supplied by INRIX. In the deployment process, every effort was made to minimize the distances between sensor deployment locations and the target TMC points. The targeted TMC points were pinpointed on a geographical information system (GIS) map overlaid on top of the aerial photos of the highways of interest so that the TMC points could be identified with ease in the field. Also, the TMC coordinates were inputted into a hand-held global positioning system (GPS) device which was used in the field. Apart from normal device and human errors that can be expected in this type of operation, occasionally lack of shoulders in the right place along the highway, and/or lack of a permanent object in the close proximity of the TMC point to which the sensor could be safely tethered introduced some unwanted but additional errors in the placement of the sensors. Sometimes, the location of the TMC point that was of interest fell in a construction zone that also could be a cause for minor errors.

Due to the importance of this issue and its effect on validation results a thorough analysis on the size and causes of the deployment errors were performed. To this end, the recorded coordinates of the sensor deployment locations (as recorded by the GPS component of the sensor upon deployment) were overlaid on the same GIS map as TMC points. Since the great circle distance between two points may not be an accurate estimate of the actual distance traveled by vehicles between two points along the highway, in all cases the highway distances between the sensor location and its corresponding TMC point were measured on a GIS system. These discrepancies are reported as the placement errors in the corresponding result tables which will appear in the following sections. The actual distance between any pair of deployed sensors is estimated using the same GIS map on which the TMC points were located. For each TMC segment and “ground truth” speed estimations, this is reported as the corrected length of the segment under consideration..

It can be shown that, if we were to use the standard TMC lengths instead of actual distances between sensors for speed estimation, the acceptable tolerance in sensor deployment would be a function of travel time between two sensors. Specifically, to keep the error in speed estimation to less than one mph, the discrepancy between the length of the segment and actual TMC length (in feet) should be less than 1.47 times observed travel time on the segment in seconds. For a five minute travel time this translates into a 441 ft or 8.3% (on a one mile segment) tolerance which for all practical purposes was adopted as the maximum acceptable tolerance in sensor deployments.

4.2 *Data Processing*

Data cleaning and preparation was performed in multiple steps. Figure 4.1 shows a step-by-step flowchart of the methodology adopted for validation in this project. First, matches between Bluetooth readings at consecutive sensors were found. Second, to eliminate the outliers and to identify valuable matches, all resulting matches were filtered through a series of filtering steps that are discussed below. Then, among the preserved matches the ones spanning multiple time intervals were identified and their equivalent INRIX speeds were estimated accordingly using a procedure that is described below. This was accomplished in the aggregation step whose outcomes are comparable with the five minute Bluetooth and INRIX speeds. Later, the speeds were compared against each other and quality measures were obtained. These measures should fall within the acceptable range of requirements as set forth in the contract of this project. Details of each step are provided in the following sections.

4.2.1 Matching

In order to obtain vehicle travel times and their corresponding speeds between two consecutive Bluetooth sensor locations, the two data sets that are collected by the Bluetooth sensors in these locations should be matched. Essentially, matching is performed based on the MAC addresses of the devices that are registered at each location. For instance, Table 4.1 summarizes an example involving two readings of the same machine access control (MAC) address at either end of the TMC segment designated as 103-04098.

Table 4.1
An example of two matched observations

CASE No.	MACID	DATE	TIME	TMC	SENSOR
41431	00:00:A0:14:A1:FF	20080906	203605	103-04098	1
37606	00:00:A0:14:A1:FF	20080906	203809	103-04098	2

CASE No.1	CASE No.2	MACID	TMC	DATE	TIME	TRAVEL TIME[sec]
41431	37606	00:00:A0:14:A1:FF	103-04098	20080906	203809	124

Also reported in this table, are the results of the matching performed on the pair of Bluetooth readings is included. It should be noted that the resulting match is assigned to the end time of the observed trip. Travel time is simply obtained by subtracting the start time from the end time.

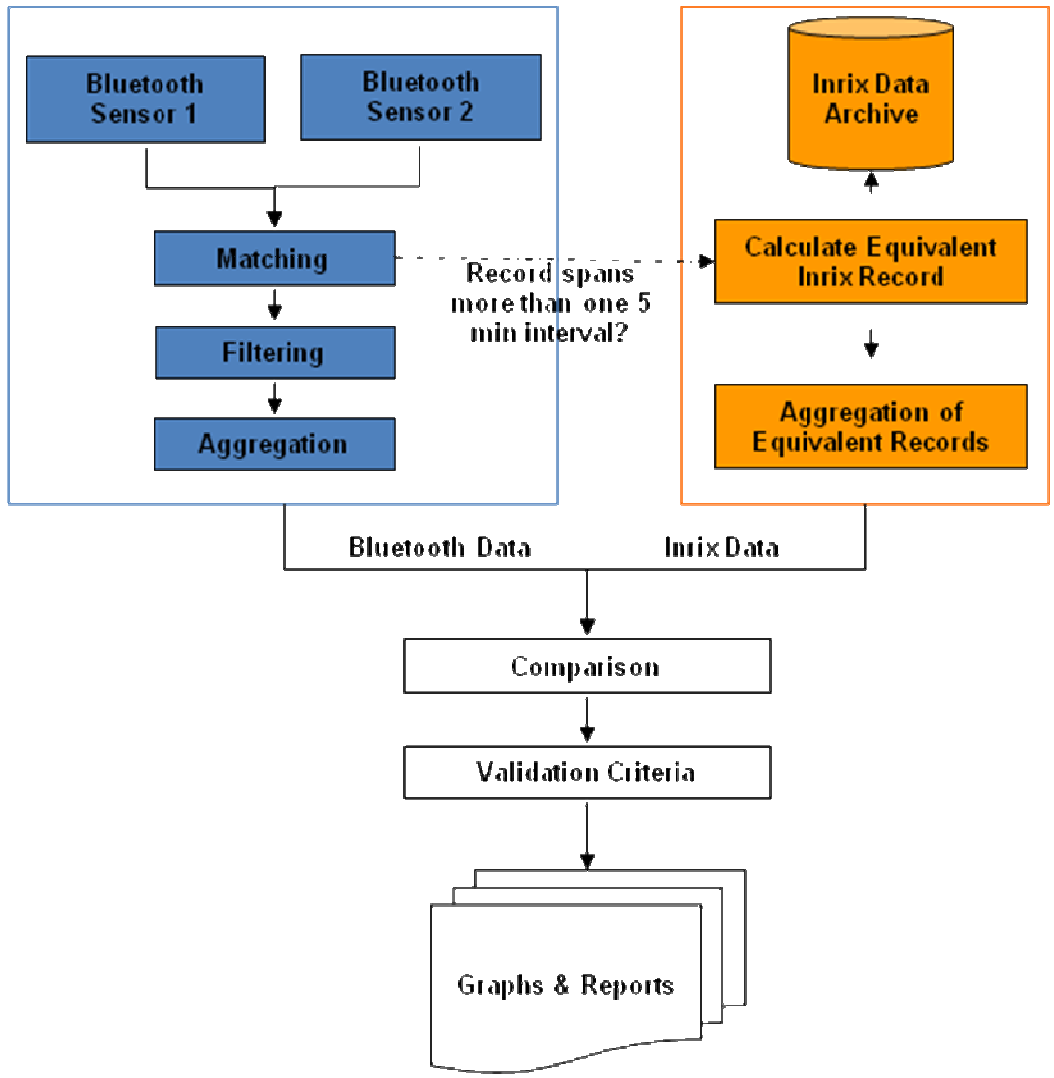


Figure 4.1
Validation methodology flowchart

4.2.2 Filtering

Some matches obtained in the previous stage might be unacceptable due to several reasons. These include matches that result in: observations with unreasonably large travel times; observations in particular time periods that are very far from the average of all travel times observed in those time periods; small number of observations that are not enough to establish a reliable "ground truth" speed for comparison; and finally, observations that have erratic variations.

To address each of these potential problems, separate filters were designed and sequentially applied to the pool of unfiltered observations that result from the matching step. In particular, we designed and implemented four filters that are discussed in the following paragraphs. The first two filters are designed to identify and discard outliers among single observations in each time interval. The third and the fourth filters are designed to exclude time intervals during which we either do not have enough observations (proxy for low volume traffic conditions) or when there are large variations among individual observations within the time interval even if there is a sufficient number of observations to consider.

4.2.2.1 *Filtering outlier observations*

Filter 1: In this filter the variations in speed observations are considered to identify outlier matched observations. To that end, all observations corresponding to each of the five minute time intervals for which we have Bluetooth observations are identified and the average and standard deviation of the speeds in those time intervals are calculated. It should be noted that the conversion to speed is based on the measured distance between sensor locations as explained previously. Observations that correspond to speeds falling within ±1.5 times the standard deviation are kept and the rest are discarded. Assuming a normal distribution for the observations around the mean, this approach translates into keeping nearly 87 percent of the data. At this point the number of observations, the averages and the standard deviations of the speed in all five minute time intervals for which we have Bluetooth data are updated and kept ready for future use in the analysis.

Filter 2: Abnormal travel times typically indicate a match between two observations at consecutive Bluetooth sensors in which the same MAC address has been registered during different vehicle trips between these locations. This is mainly due to the sampling nature of the technology utilized to measure the “ground truth”. Filtering these outliers is quite easy since they suggest a much larger travel time on segments that are normally traveled in minutes. Therefore, as the second filter the observations with travel times more than 3600 seconds (one hour) that survived the first filter are discarded.

4.2.2.2 *Filtering low-volume and erratic time intervals*

Filter 3: This filter is designed to exclude all five minute time intervals that correspond to traffic volumes that are less than 500 vehicles per hour. This filter is partly designed to ensure that the estimated “ground truth” speeds are reliable as well. Internal University of Maryland (UMD) studies have shown that Bluetooth sensors capture one in 20 vehicles passing in front of them. Based on this we hypothesized that when in a five minute time interval we have less than three observations the traffic volume is most likely less than 500 vehicles per hour. Therefore, in the third filter the five minute time intervals that have less than three observations are excluded from further consideration in the validation process.

Filter 4: Finally, to ensure that the variability among speed observations in a five minute time interval is within a reasonable level, the coefficient of variations (COV) of Bluetooth speeds in each five minute time interval that survives the third filter is estimated and five minute time intervals that have a COV greater than one are excluded and their corresponding observations are discarded from further consideration in the validation process.

Two sample graphs illustrating the effect of applying these filters on Bluetooth sensor data for two representative TMC segments are presented in Figure 4.2. In these graphs, the light blue dots represent the Bluetooth observations that are kept in the analysis, the dark blue dots are those observations that are discarded and the black line represents the mean of the Bluetooth observations in consecutive five-minute time intervals. The five-minute time intervals that are discarded from analysis are not shown in the graphs.

4.2.3 Aggregation

Individual observations in each five-minute time interval must be aggregated to produce the space mean speed corresponding to that time interval. This speed estimate will be the basis of comparison with the corresponding INRIX data feed and therefore plays a crucial role in determining the results of the validation. In this section, specifics of the aggregation methodology are explained in detail.

4.2.3.1 Bluetooth data aggregation to estimate space mean speed

Space mean speed in a five minute interval is obtained as the ratio of the segment length to the average observed travel times in that time interval. In other words,

$$S_{BT} = \frac{L_r}{\frac{\sum_{i=1}^{n} T_i}{n}} \times 3600 \qquad (4\text{-}1)$$

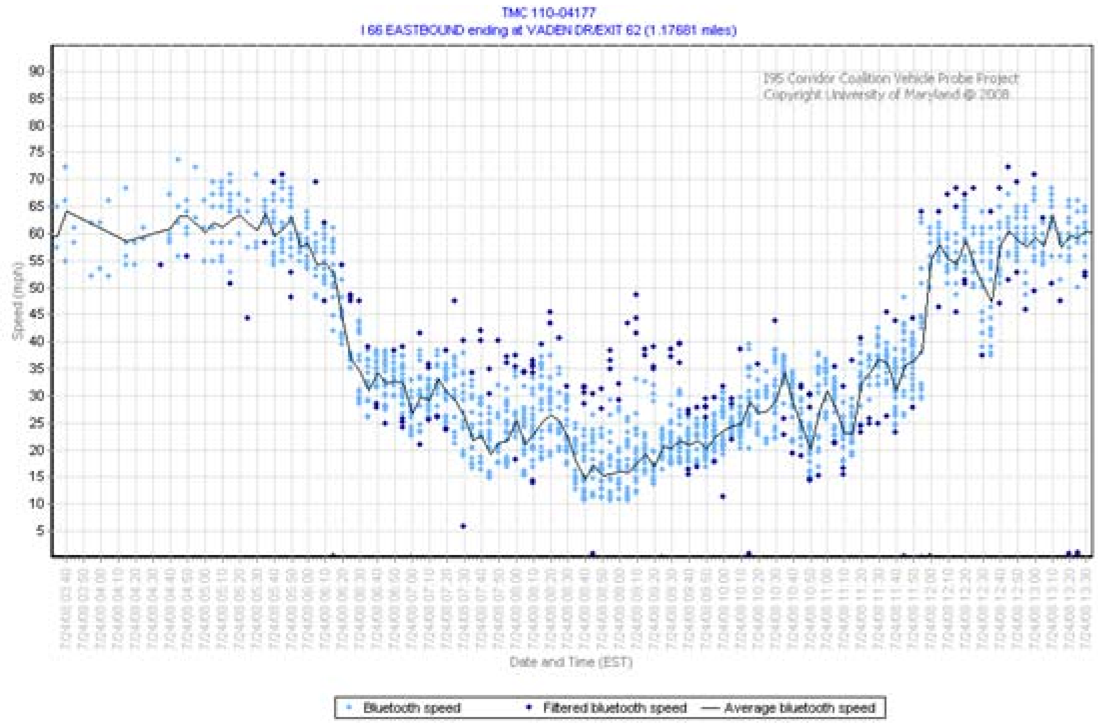
where, S_{BT} is the space mean speed in miles per hour, L_r is the real distance between the pair of sensors in miles, T_i is the travel time of the ith observation in seconds, and n is the number of observations in the five minute time interval in question.

4.2.3.2 INRIX data aggregation

In order to aggregate the equivalent INRIX speed estimates at each five minute time interval corresponding to the Bluetooth observations assigned to the same time interval, a simple arithmetic average on INRIX speed estimates is performed. In other words,

$$S_{Inrix} = \frac{\sum_{i=1}^{n} s_{i,eq}}{n} \qquad (4\text{-}2)$$

where, S_{Inrix} is the aggregated INRIX speed in miles per hour, and $s_{i,eq}$ is the equivalent INRIX speed estimate corresponding to observation i, in miles per hour, and is estimated based on the method explained in the next section.



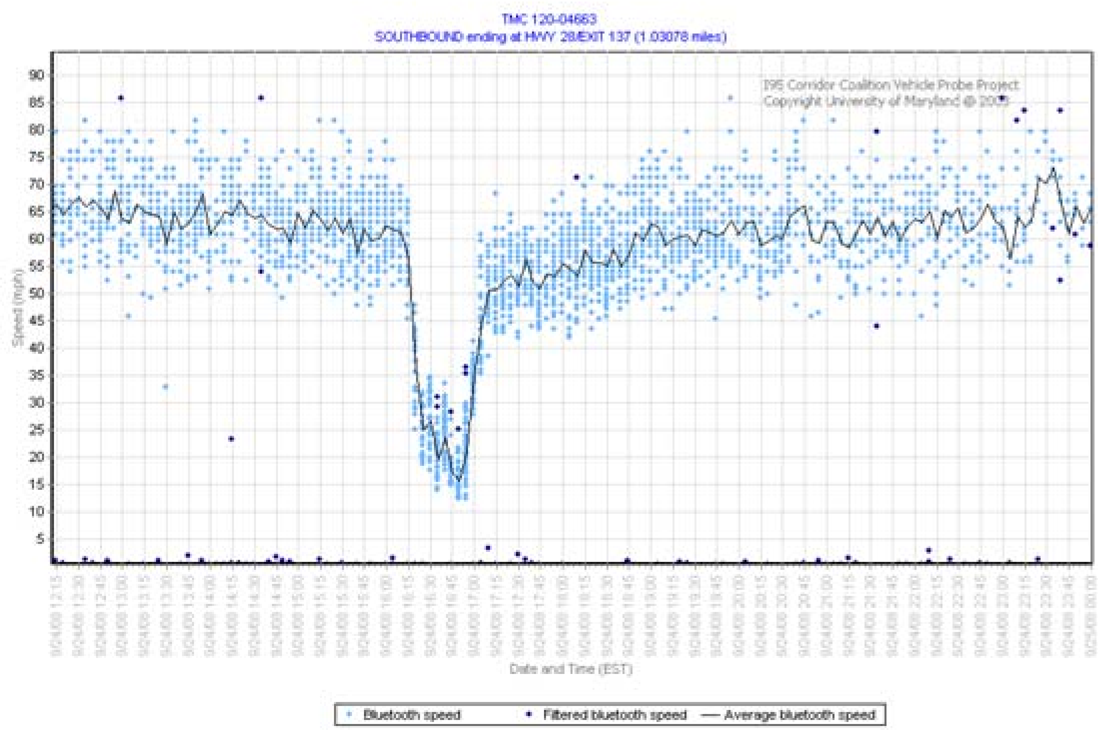


Figure 4.2
Effects of the application of the filtering processes on two samples of Bluetooth data

4.2.3.3 *Equivalent INRIX speed estimation*

Generally, when an observed Bluetooth match both starts and ends in a single time interval the equivalent speed from INRIX data feed will be the same as the speed reported by INRIX for that time interval. In this case no further calculation is needed.

When a single Bluetooth observation represents a trip that started and ended in different five minute time intervals, then an equivalent INRIX speed for that observed trip must be estimated based on the speeds reported by INRIX for the five minute time intervals that cover the trip. This speed estimate is then used in the aggregation step to calculate the comparable INRIX speed for the corresponding time interval. Note that the Bluetooth observations are assigned to the five minute time intervals in which their corresponding vehicle trip ends.

Thus, when a match starts and ends in two different time intervals in order to come up with comparable speed estimates from INRIX's data the following procedure is used:

1- Determine the amount of time the observed vehicle spent in each of the five minute time intervals, and
2- Calculate a weighted average speed based on INRIX reported speeds in those five minute intervals. The weights used in this calculation are the ratio of the time the observed vehicle spent in each time interval to the total observed travel time.

To illustrate this procedure an example is given here. In the example a "ground truth" match starting at 10:03 and ending at 10:13 on a 2.66 mile long road segment is considered. Figure 4.3 shows the start and end time of the observed trip in relation to the five minute intervals for which INRIX has provided its speed estimates. The observed travel time is equal to 10 minutes and the average travel speed can be calculated as 2.66/10*60 = 16 mph.

In calculating the corresponding INRIX speed, we note that the trip start time corresponds to the 10:05 time interval and the trip end time corresponds to the 10:15 time interval that is not the same.

As can be seen in Figure 4.3 the time this vehicle has spent in the three consecutive five minute intervals from 10:05 to 10:15 has been two, five, and three minutes, respectively. Therefore, the equivalent speed for this "ground truth" match calculated based on the INRIX's data feed will be equal to:

$$\frac{5\times 3+15\times 5+10\times 2}{3+5+2}=11\,[mph] \qquad (4\text{-}3)$$

It should be noted that if we apply the method suggested by INRIX in one of their earlier comments to this case, the same result will be obtained:

$$\frac{2.66}{\frac{0.33}{20}+\frac{0.83}{10}+\frac{1.25}{15}+\frac{0.25}{5}} \cong 11\,[mph] \tag{4-4}$$

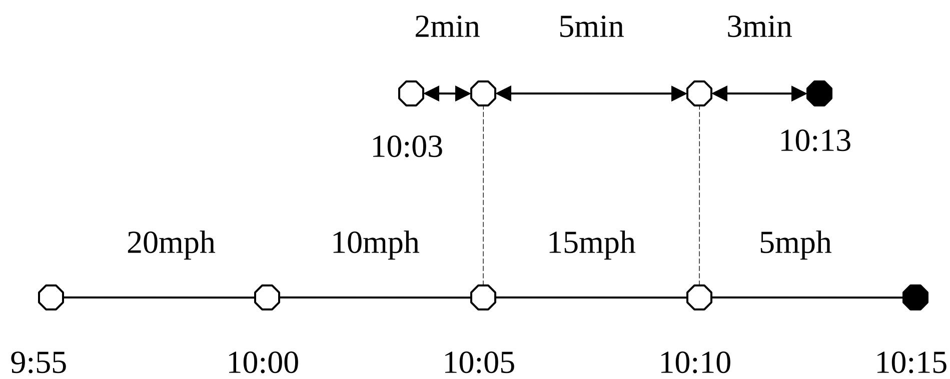


Figure 4.3
An illustration of equivalent INRIX speed calculation

In this particular example if we have three observations that belong to the 10:15 time interval, as shown in the first two columns of Table 4.2, the aggregated Bluetooth and INRIX speeds calculated using the procedures discussed above are as shown in the last two columns of the table.

Table 4.2
Sample calculations in the aggregation step

Start Time	End Time	Travel Time [sec]	BT Speed [mph]	Equivalent INRIX Speed [mph]
10:03:00	10:13:00	600	16.0	11.0
10:02:00	10:11:00	540	17.7	12.2
10:04:00	10:14:00	600	16.0	10.5
Average		580	**16.5**	**11.2**

The “ground truth” space mean speed in this five minute interval is therefore computed as:

$$S_{BT} = \frac{2.66\,[mile]}{580\,[\mathrm{sec}]} \times 3600\,[\frac{\mathrm{sec}}{hr}] = 16.5\,[mph] \tag{4-5}$$

The corresponding average INRIX speed in the same time interval will be the arithmetic average of the equivalent INRIX speeds estimated for each observation, that is:

$$S_{Inrix} = \frac{11.0 + 12.2 + 10.5}{3} = 11.2\,[mph] \tag{4-6}$$

4.2.4 Comparison and Quality Measures

In every traffic stream a certain level of variability in speeds among different vehicles and drivers may be expected. Therefore, it is preferred to develop measures that reflect the degree of variability among the observed speeds on a segment of the roadway during each time interval. The standard deviation of the travel speed observations in the five minute time intervals and the standard error of the mean estimate in those intervals are used as indicators of variability in aggregated speeds.

Standard deviation is the square root of the speed variance in each five minute time interval and is given as:

$$S.D._{BT} = \sqrt{V_{BT}} \tag{4-7}$$

where, $S.D._{BT}$ is the standard deviation of the observed Bluetooth speeds on a specific segment of the roadway in any given five minute time interval; and V_{BT} is the variance of the observed Bluetooth speeds $(s_{i,bt})$ on a specific segment of the roadway in the same five minute time interval. V_{BT} can be calculated as:

$$V_{BT} = \frac{\sum_{i=1}^{n} (s_{i,bt} - \overline{S}_{BT})^2}{n} \tag{4-8}$$

where, $\overline{S}_{BT}$ is the arithmetic average of the observed Bluetooth speeds on a specific segment of the roadway in a five minute interval, and can be calculated as:

$$\overline{S}_{BT} = \frac{\sum_{i=1}^{n} s_{i,bt}}{n} \tag{4-9}$$

Standard error is the unbiased estimate of the expected error in a sample estimate of the population mean and is defined as the ratio of the standard deviation of the observed Bluetooth speeds to the square root of the number of observations in a five-minute interval as shown below:

$$S.E._{BT} = \frac{S.D._{BT}}{\sqrt{n}} \tag{4-10}$$

where, $S.E._{BT}$ is the standard error of the Bluetooth speed mean estimate on a specific segment of the roadway in any given five minute interval.

In order to give the reader a better perspective of the variability in the Bluetooth observations and also to account for its effects on final data quality measures, four different errors are calculated for each five minute time interval based on different bands constructed around the mean of the Bluetooth observation. In a time interval, errors are defined as the distance from the equivalent INRIX speed to the closer extent of each of the following:

1. The mean Bluetooth observations space mean speed estimate (e_1),
2. The 95% confidence band around the mean of the Bluetooth observations space mean speed estimate (e_2),
3. The 0.25 standard deviation band around the mean of the Bluetooth observations space mean speed estimate (e_3), and
4. The 0.5 standard deviation band around the mean of the Bluetooth observations space mean speed estimate (e_4).

More specifically, these error measures can be defined in exact terms using the definitions given earlier as shown below:

$$e_1 = S_{Inrix} - S_{BT} \tag{4-11}$$

$$e_2 : \begin{cases} if\ (S_{BT} - 1.96 \times S.E._{BT}) \le S_{Inrix} \le (S_{BT} + 1.96 \times S.E._{BT}) \Rightarrow e_2 = 0 \\ if\ (S_{Inrix} \le (S_{BT} - 1.96 \times S.E._{BT}) \Rightarrow e_2 = S_{Inrix} - (S_{BT} - 1.96 \times S.E._{BT}) \\ if\ (S_{Inrix} \ge (S_{BT} + 1.96 \times S.E._{BT}) \Rightarrow e_2 = S_{Inrix} - (S_{BT} + 1.96 \times S.E._{BT}) \end{cases} \tag{4-12}$$

$$e_3 : \begin{cases} if\ (S_{BT} - 0.25 \times S.D._{BT}) \le S_{Inrix} \le (S_{BT} + 0.25 \times S.D._{BT}) \Rightarrow e_3 = 0 \\ if\ (S_{Inrix} \le (S_{BT} - 0.25 \times S.D._{BT}) \Rightarrow e_3 = S_{Inrix} - (S_{BT} - 0.25 \times S.D._{BT}) \\ if\ (S_{Inrix} \ge (S_{BT} + 0.25 \times S.D._{BT}) \Rightarrow e_3 = S_{Inrix} - (S_{BT} + 0.25 \times S.D._{BT}) \end{cases} \tag{4-13}$$

$$e_4 : \begin{cases} if\ (S_{BT} - 0.5 \times S.D._{BT}) \le S_{Inrix} \le (S_{BT} + 0.5 \times S.D._{BT}) \Rightarrow e_4 = 0 \\ if\ (S_{Inrix} \le (S_{BT} - 0.5 \times S.D._{BT}) \Rightarrow e_4 = S_{Inrix} - (S_{BT} - 0.5 \times S.D._{BT}) \\ if\ (S_{Inrix} \ge (S_{BT} + 0.5 \times S.D._{BT}) \Rightarrow e_4 = S_{Inrix} - (S_{BT} + 0.5 \times S.D._{BT}) \end{cases} \tag{4-14}$$

4.3 *Data Quality Requirements as per Contract*

Data quality as defined in the contract of this project will be primarily measured based on two criteria namely “average absolute speed error” and “speed error bias.” In this report by speed we mean space mean speed (SMS) which is the quantity that was to be measured and reported by INRIX as per the contract. This degree to which the INRIX data satisfied the contract was measured in terms of the deviation of this data from the 95% confidence band around the mean (alternative 2 in section 4.2.4.)

Data quality requirements are in effect whenever the traffic volume is more than 500 vehicles per hour in a given direction on a segment of the roadway. These measures should be calculated and verified separately in each of the following speed ranges: below 30 mph; 30 mph to 45 mph; 45 mph to 60 mph; and greater than 60 mph.

It is important to note that the validation speed or the "ground truth" speed is considered as the basis for speed range definitions. It means that if the validation speed for a five minute time interval is equal to 40 mph and the corresponding INRIX reported speed is 47 mph, then the comparison and its associated error measures will contribute to those of the 30 mph to 45 mph speed bin. To further clarify this, both measures and the requirements that INRIX data has to meet with regard to each of them in order to pass the validation test are explained below.

Let,

S_{ij}(INRIX) = speed data for segment i at time j from INRIX database
S_{ij}(Validation) = validation speed for segment i at time j

Average Absolute Speed Error (mph)
Absolute Error(i,j) = Abs(S_{ij}(INRIX) - S_{ij}(Validation))
Average Absolute Error = Mean(Absolute Error(i,j))

As stipulated in the contract, speed data shall have a maximum average absolute error of 10 mph in each of the speed ranges.

Speed Error Bias (mph)
Error(i,j) = S_{ij}(INRIX) - S_{ij}(Validation)
Average Error = Mean(Error(i,j))

As stipulated in the contract, speed data shall have a maximum average error of ±5mph in each speed range.

Lag time (min)
To ensure that the data provided by INRIX is reflecting current conditions on the ground and to control the lag time in the INRIX data updates an allowable lag time requirement is introduced in the contract. This lag time measure is less than or equal to eight minutes.

As a first step in the investigation of the impact of the allowable lag time on the data quality measures, the INRIX data was shifted five minutes back in time and the results are reported for both original and shifted INRIX data. The research team continues to investigate the lag time and will provide the results of this investigation in future reports.

INRIX scores

Associated with its reported speed data, INRIX provides a score. Possible scores are 30, 20 and 10 with the following interpretations as provided by INRIX:

- “30” -high score, based on real-time data for that specific segment
- “20” -medium score, based on real-time data across multiple segments and/or based on a combination of expected real-time data
- “10” -low score, based primarily on historical data

In this report these scores will be used to separate data points with high score (score 30) from lower score data (scores 10, and 20). The validation results are reported in both high score and all categories in each speed bin.

5 Evaluation Results for the State of Delaware

5.1 *Data Collection*

Bluetooth sensor deployments in Delaware started on Thursday, September 4, 2008. The actual deployments in Delaware were performed by Delaware Department of Transportation (DelDOT) personnel. Sensors remained in the same position until they were retrieved the following week on the evening of Tuesday, September 9, 2008. This round of data collections in Delaware was designed to cover segments of the highways along which both recurrent and non-recurrent congestions could be expected during both peak and off-peak periods.

Figure 5.1 presents a snapshot of the roadway segments over which Bluetooth sensors were deployed in Delaware.

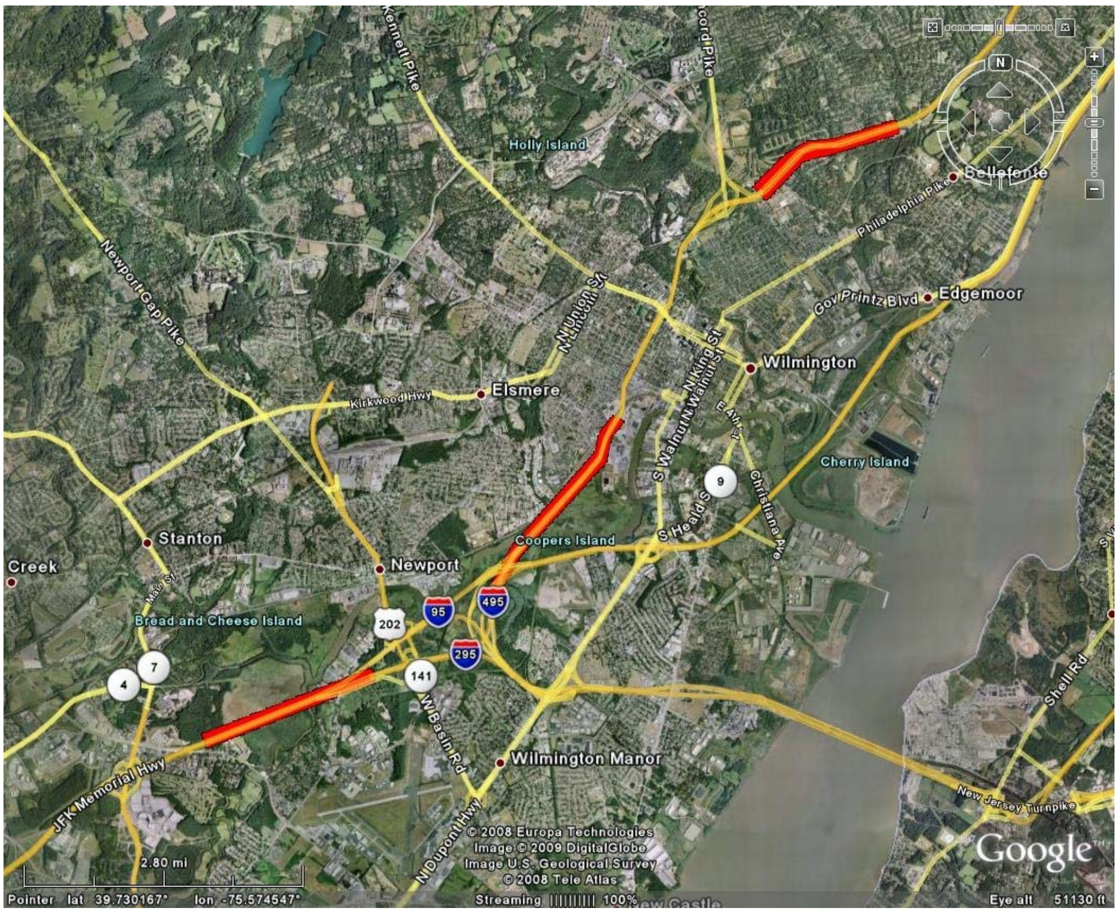


Figure 5.1
TMC segments selected for validation in Delaware

The coordinates of the locations at which the Bluetooth sensors were deployed throughout the state of Delaware are reported in Table A.1 in Appendix A. Table A.1 also presents the distances that have been used in the estimation of Bluetooth speeds based on travel times. Table 5.1 presents a list of specific TMC segments that were selected as the validation sample in Delaware. In total, results of validation on three freeway TMC segments are reported in the body of this report and in Appendix A. These segments cover a total length of 5.6 miles.

5.2 *Analysis of Results*

This section presents the data quality comparisons for Delaware. First, a series of graphs showing the Bluetooth observations on one of the segments in Delaware are presented. These graphs provide a qualitative basis for comparison between INRIX speed data and the estimated Bluetooth speeds.

Figure 5.2 shows every single Bluetooth speed estimate at every time interval on segment 103-04103. This figure also highlights the observations that are deemed as outliers during the application of the filtering methodology that was explained earlier. The remaining observations are then used to obtain the mean estimate of speed at each time interval.

A 24 hour slice of data on this segment for September 5, 2008 is shown in Figure 5.3 which incorporates the mean Bluetooth speed estimate along with the 95% confidence interval band of the mean estimate as well as the corresponding INRIX speeds. This figure provides a visual aid to observe the overall INRIX data compared to the Bluetooth speeds.

Figures 5.4 and 5.5 demonstrate the trends of both Bluetooth and INRIX speeds over the same time period on the same segment. Figure 5.4 includes the number of Bluetooth observations used in the speed estimation for each five minute interval and Figure 5.5 shows the reported scores for INRIX speeds.

In Figure 5.6, all individual Bluetooth speed observations (outliers and non-outliers identified by different colors), the mean speed estimate and its associated 95% confidence interval band, as well as the INRIX data are presented in one place to give a better picture of the raw data as well as the final outcomes of the analysis versus the INRIX speeds.

These graphs are produced for each TMC and all graphs for the segments picked for validation in Delaware are included in the CD-ROM that accompanies this report.

Table 5.2 summarizes the data quality measures obtained as a result of comparison between Bluetooth and all reported INRIX speeds, including all scores.

The comparisons between the Bluetooth data with the corresponding INRIX speed data for which INRIX indicated high score are summarized in the Table 5.3.

Table 5.1
Traffic Message Channel segments picked for validation in Delaware

TYPE	TMC	HIGHWAY	DIRECTIN	STARTING AT	ENDING AT	COUNTY	LENGTH (mile)
	103+04107	I 95	NORTHBOUND	I 295/I 495/EXIT 5	HWY 4/MD AVE/6TH AVE/EXIT 6	NEW CASTLE	2.2
Freeways	**103-04103**	I 95	SOUTHBOUND	EXIT 5A	HWY 58/EXIT 4	NEW CASTLE	1.8
	103-04110	I 95	SOUTHBOUND	HWY 3/MARSH RD/EXIT 9	US 202/CONCORD PIKE/EXIT 8	NEW CASTLE	1.6
Grand Total							**5.6**

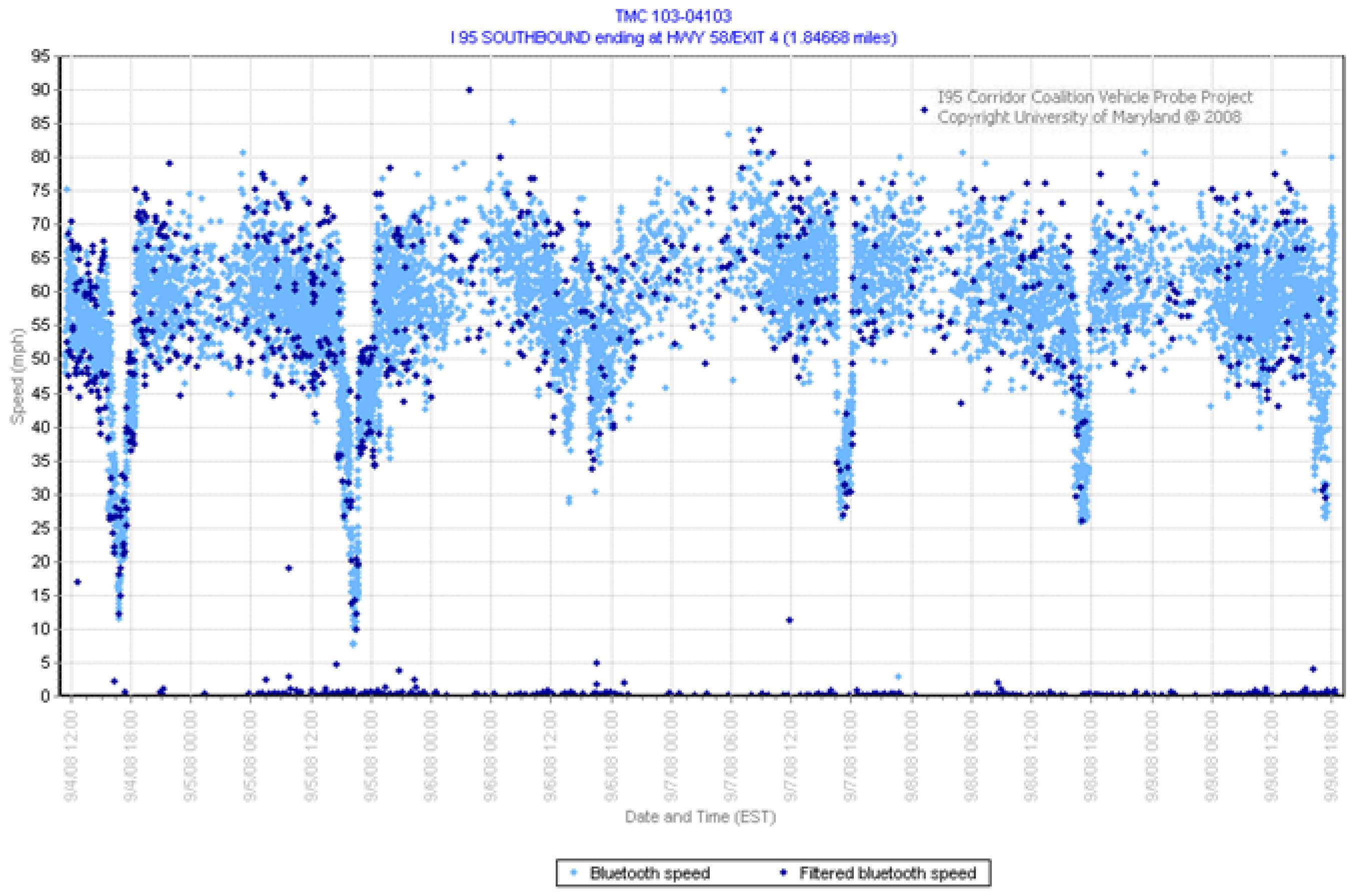


Figure 5.2
Bluetooth observations and outliers on a sample segment in Delaware
(all data)

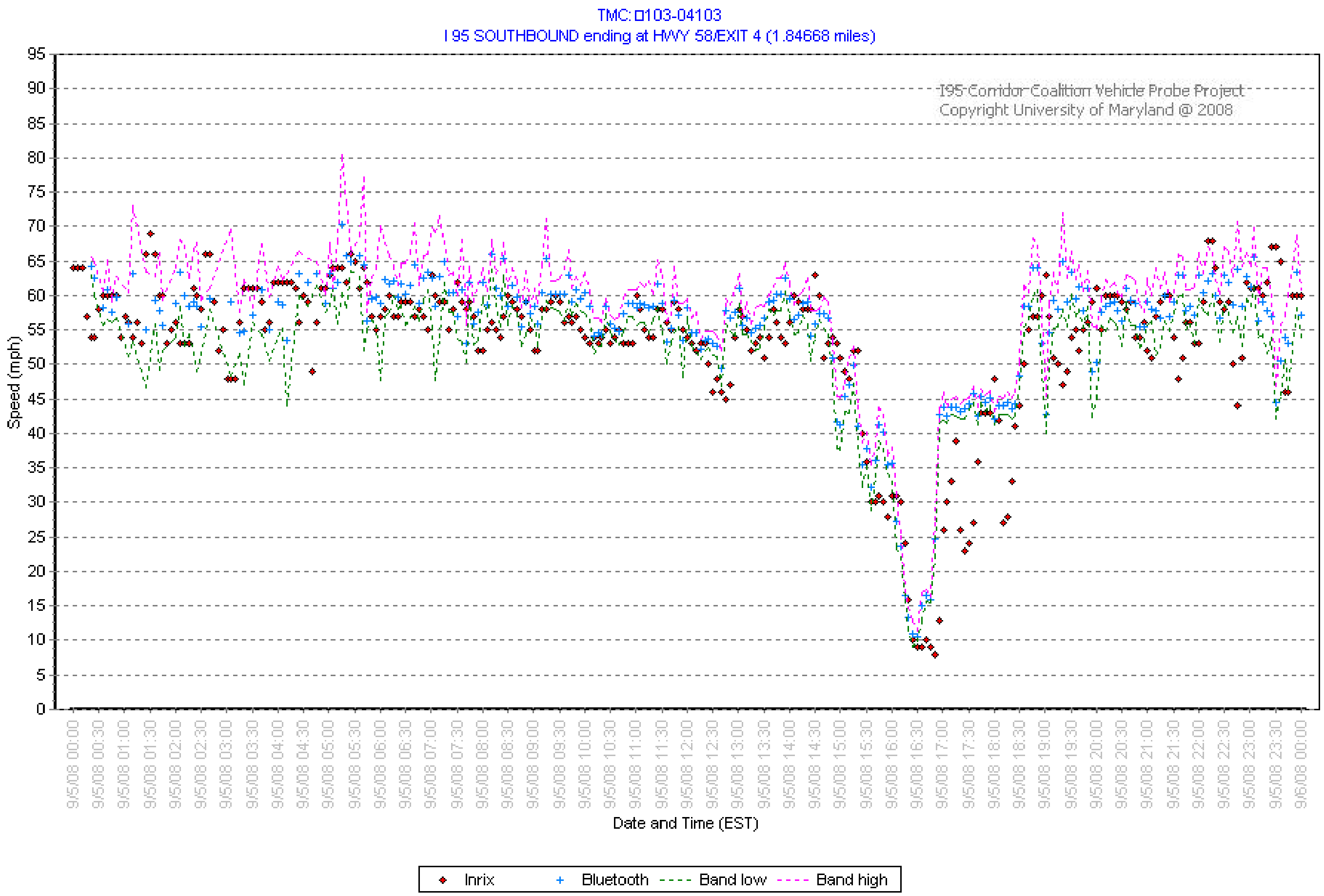


Figure 5.3
Bluetooth mean estimate and its 95% confidence band with INRIX speeds on a sample segment in Delaware, 5 September 2008 (all data)

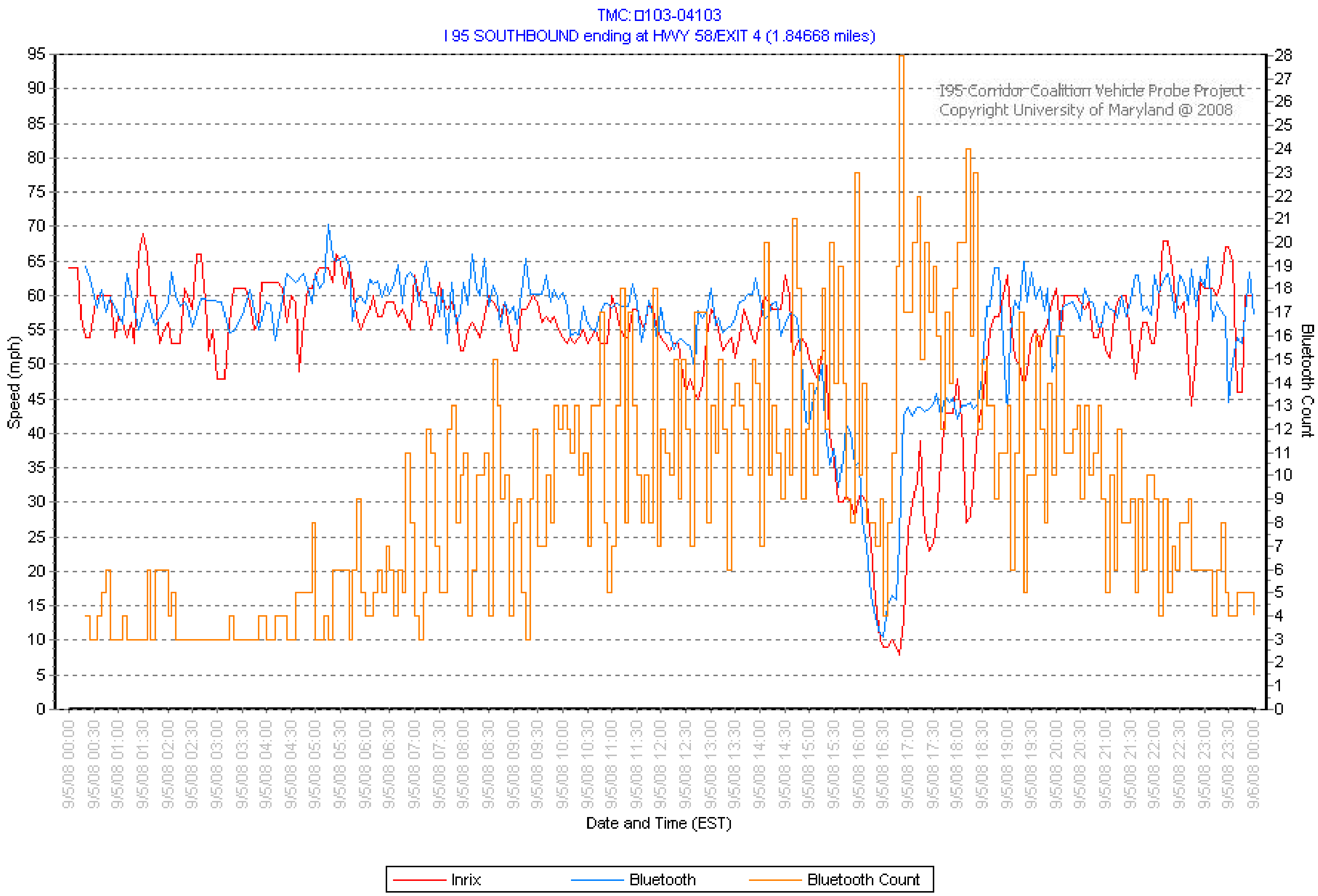


Figure 5.4
Bluetooth and INRIX speeds with number of Bluetooth observations on a sample segment in Delaware, 5 September 2008 (all data)

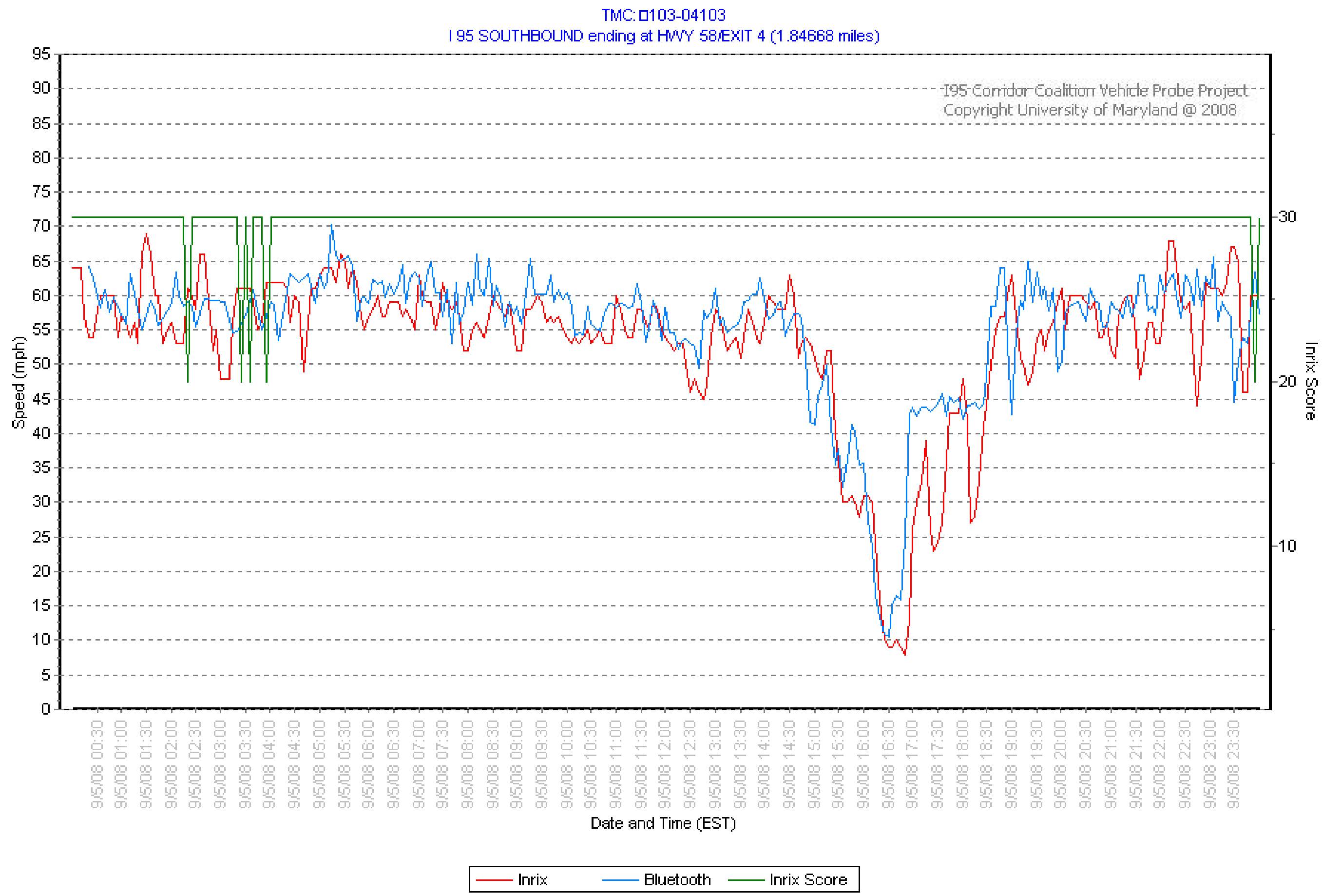


Figure 5.5
Bluetooth and INRIX speeds with the score on a sample segment in Delaware, 5 September 2008 (all data)

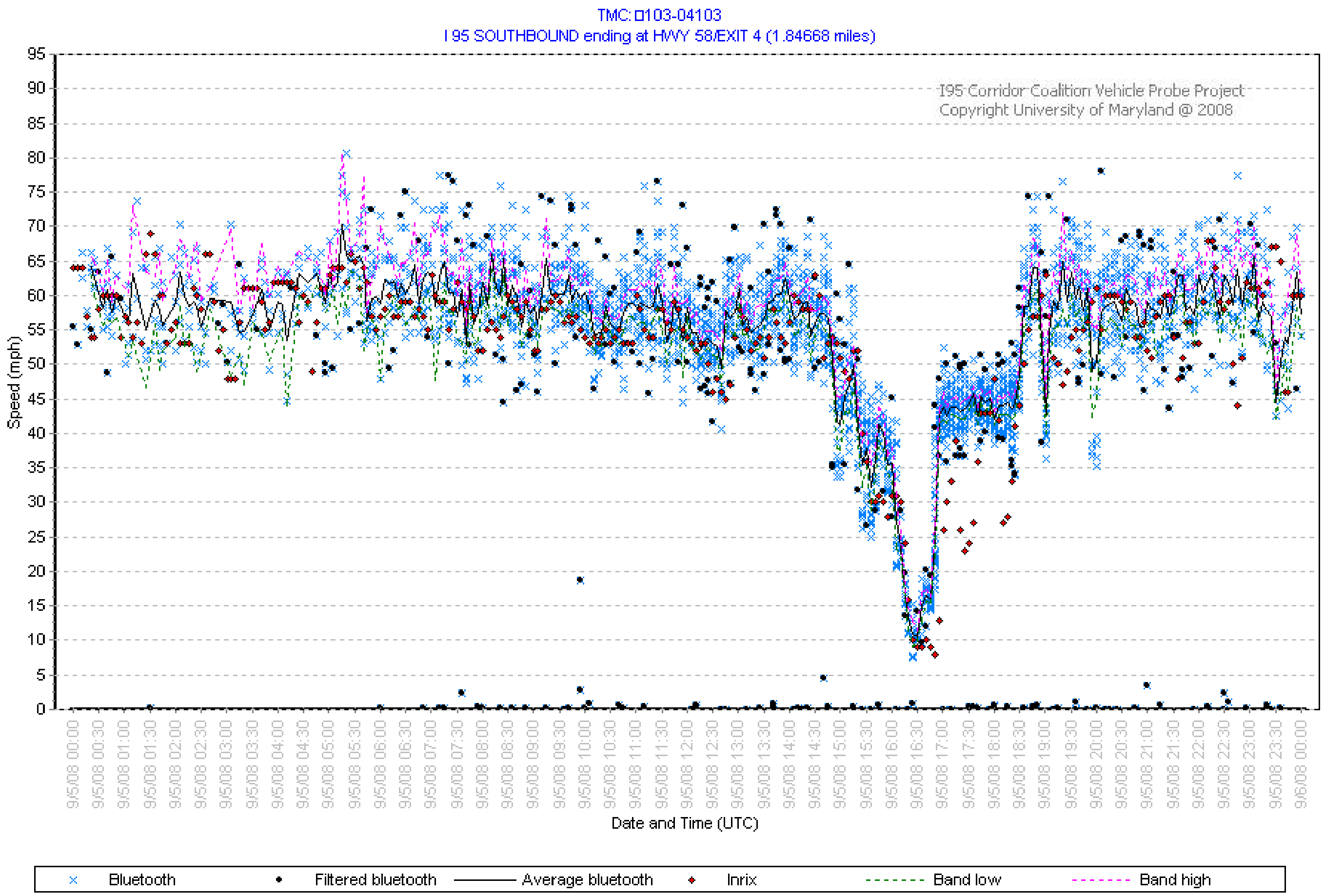


Figure 5.6
Bluetooth and INRIX speeds on a sample segment
in Delaware, 5 September 2008 (all data)

In all speed bins INRIX data passes the data quality measures set forth by the contract when errors are measured as a distance from the 1.96 times the standard error and 0.5 times the standard deviation bands. However, when compared to the computed mean and the 0.25 times the standard deviation band the INRIX data fails to pass the data quality requirements in the less than 45 mph speed bins. Considering the high score INRIX data alone, the results of the analysis are essentially the same.

Figures 5.7 and 5.8 show the overall speed error bias for different speed bins, and the average absolute speed errors for all segments in Delaware, respectively. These figures correspond to Table 5.2. Likewise, Figures 5.9 and 5.10 show the same error measures for all segments in Delaware for speed data for which INRIX indicated high score (score 30 as mentioned before). Figures 5.4 and 5.5 correspond to the results exhibited in Table 5.3.

Table 5.4 shows the percentage of the time intervals that have met the data quality requirements as described in the contract for each speed bin for all TMCs in Delaware. Table 5.5 presents the same information when high score INRIX data has been used in the evaluations.

In both tables 5.4 and 5.5 the columns that show the percentage falling inside the band represent the percentage of the time intervals for which INRIX provides travel time and speed data that falls inside the corresponding band as described in section 4.2.4. The columns that show the percentage within five mph of the band represent the percentage of the INRIX data that lay within five mph of the band including the data points that fall inside the corresponding band. When comparing to the mean of the Bluetooth data, numbers in the percentage equal to mean column show the percentage of the INRIX observations that are exactly equal to their corresponding Bluetooth observation and the percentage within five mph of the mean show the portion of the INRIX data that falls within five mph of the Bluetooth mean.

5.3 *Shifted INRIX Data*

In this section, results of the comparisons between Bluetooth sensor speed data and the INRIX speed data that are shifted five minutes back in time in Delaware are reported. Table 5.6 summarizes the data quality measures obtained as a result of the comparisons between Bluetooth and all reported INRIX speeds, including all scores.

The comparisons made between the Bluetooth data with the corresponding INRIX speed data for which INRIX indicated high score are summarized in the Table 5.7.

Figures 5.11 and 5.12 show the overall speed error bias for different speed bins and the average absolute speed errors for all segments in Delaware. These figures correspond to Table 5.6. Likewise, Figures 5.13 and 5.14 show the same error measures for all segments in Delaware for speed data for which INRIX indicated high score (score 30 as mentioned before). Figures 5.13 and 5.14 correspond to the results exhibited in Table 5.7.

Generally speaking, the five minute shift in INRIX data does not have an impact on the data quality measures. The shifted INRIX data in both cases (all and high score data) do not result in better data quality measures as compared with the prior comparison in which INRIX data was not shifted.

Detailed data for individual TMC segments in Delaware are presented in Appendix A. This appendix also presents the results of the evaluation of the INRIX data reported for freeway segments that are less than one mile long.

Table 5.2
Data quality measures for freeway segments greater than one mile in Delaware (all data)

SPEED BIN	Data Quality Measures for: 1.96 SE Band – Speed Error Bias	1.96 SE Band – Average Absolute Speed Error	Mean – Speed Error Bias	Mean – Average Absolute Speed Error	0.25 SD Band – Speed Error Bias	0.25 SD Band – Average Absolute Speed Error	0.5 SD Band – Speed Error Bias	0.5 SD Band – Average Absolute Speed Error	No. of Obs.
0-30	-0.2	6.5	2.5	10.9	1.7	9.4	0.9	8.0	36
30-45	-1.9	8.5	-0.1	11.8	-0.7	10.4	-1.3	9.2	108
45-60	-0.1	1.2	0.0	3.6	0.0	2.5	0.0	1.8	893
60+	-2.4	2.5	-4.9	5.5	-4.1	4.4	-3.3	3.5	1349

Table 5.3
Data quality measures for freeway segments greater than one mile in Delaware (INRIX high score)

SPEED BIN	Data Quality Measures for: 1.96 SE Band – Speed Error Bias	1.96 SE Band – Average Absolute Speed Error	Mean – Speed Error Bias	Mean – Average Absolute Speed Error	0.25 SD Band – Speed Error Bias	0.25 SD Band – Average Absolute Speed Error	0.5 SD Band – Speed Error Bias	0.5 SD Band – Average Absolute Speed Error	No. of Obs.
0-30	-0.2	6.5	2.5	10.9	1.7	9.4	0.9	8.0	36
30-45	-1.9	8.5	-0.1	11.8	-0.7	10.4	-1.3	9.2	108
45-60	-0.1	1.2	-0.1	3.5	-0.1	2.5	-0.1	1.8	868
60+	-2.4	2.5	-4.9	5.5	-4.1	4.5	-3.4	3.6	1295

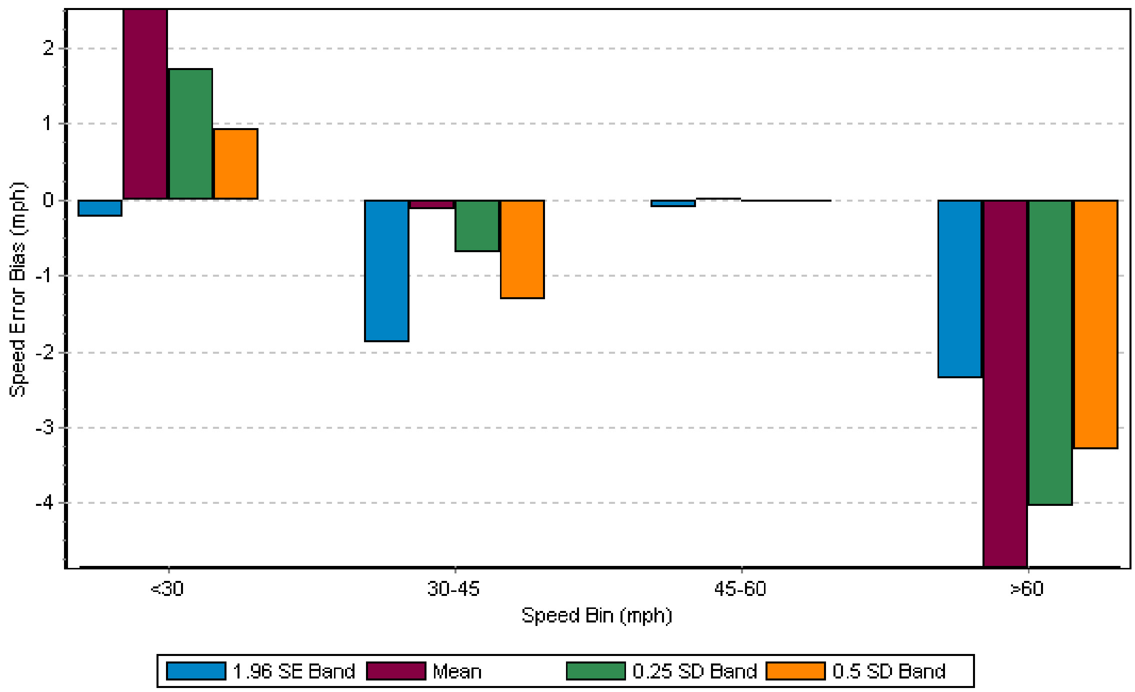


Figure 5.7
Speed error bias for freeway segments greater than one mile in Delaware (all data)

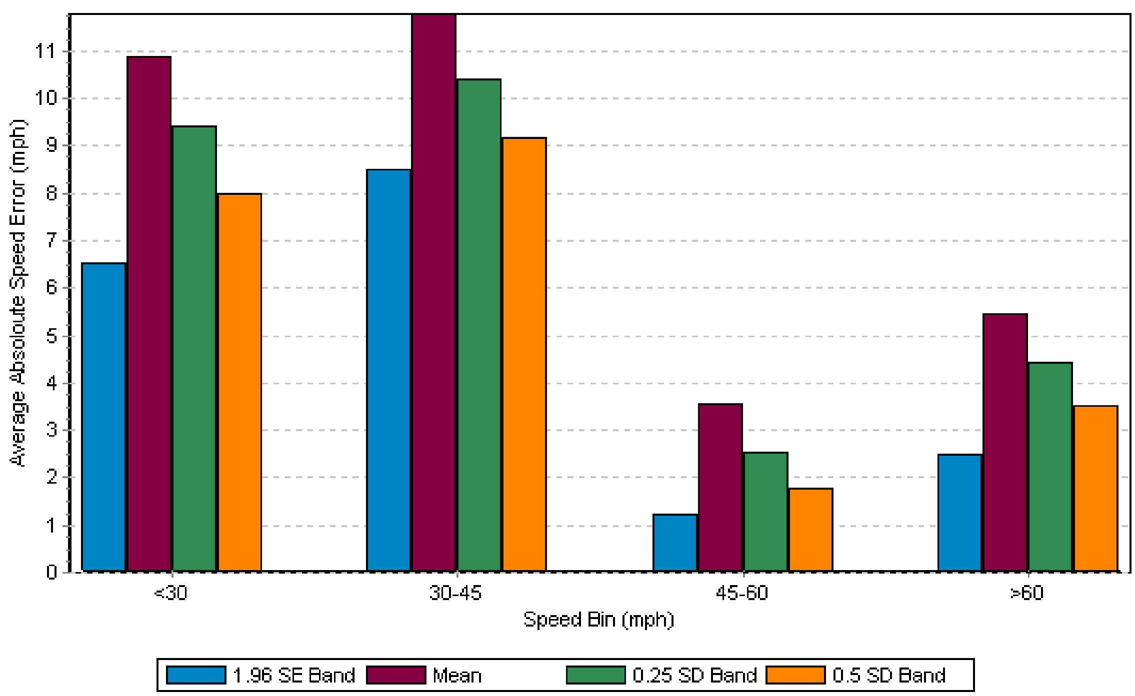


Figure 5.8
Average absolute speed error for freeway segments greater than one mile in Delaware (all data)

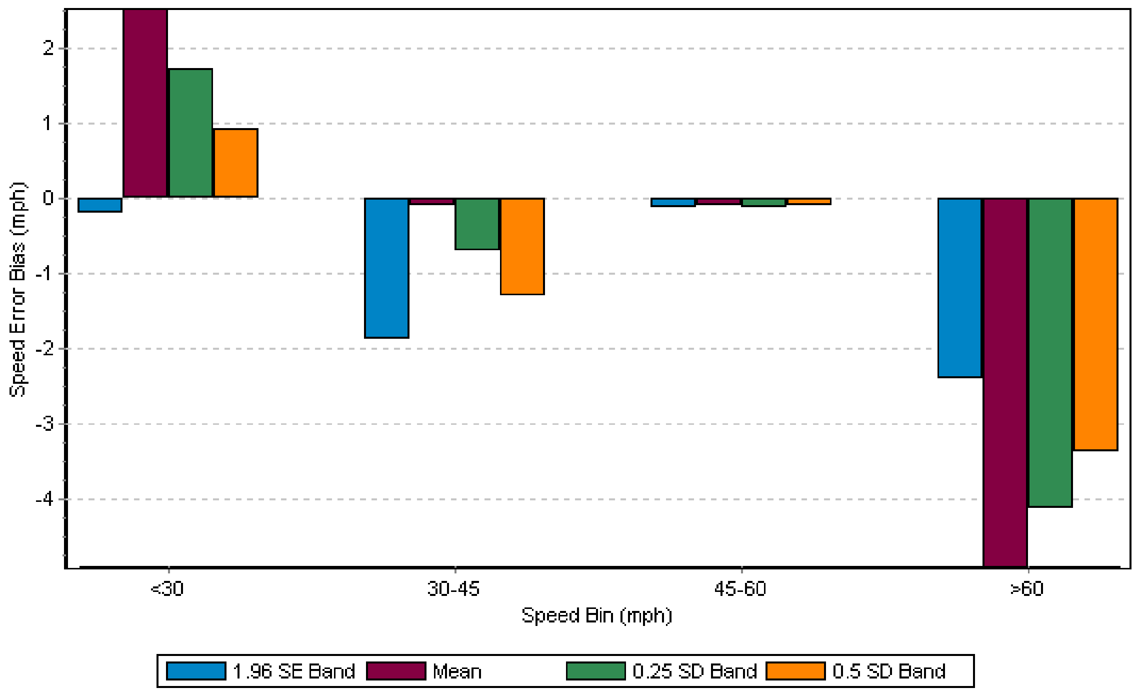


Figure 5.9
Speed error bias for freeway segments greater than one mile in Delaware (INRIX high score)

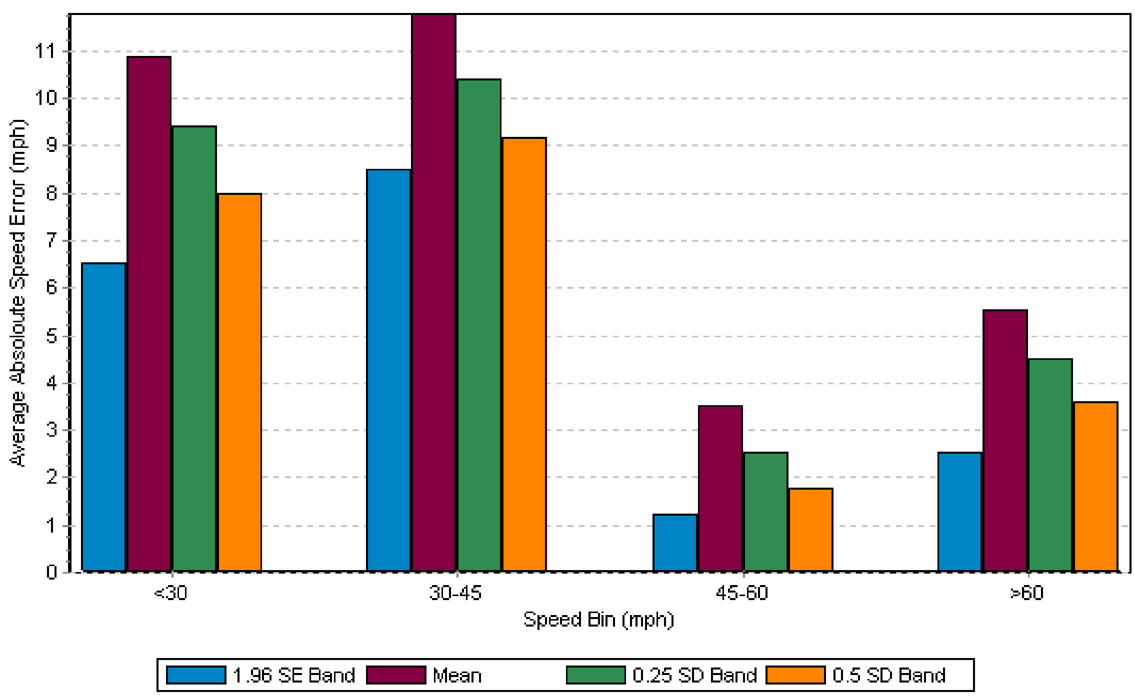


Figure 5.10
Average absolute speed error for freeway segments greater than one mile in Delaware (INRIX high score)

Table 5.4

Percent observations meeting data quality criteria for freeway segments greater than one mile in Delaware (all data)

SPEED BIN	Data Quality Measures for: 1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		No. of Obs.
	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Equal to Mean	Percentage within 5 mph of the Mean	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	
0-30	11%	36%	0%	28%	0%	28%	8%	31%	36
30-45	17%	43%	0%	28%	6%	31%	13%	40%	108
45-60	56%	94%	0%	76%	18%	84%	39%	90%	893
60+	39%	79%	0%	49%	12%	61%	24%	71%	1349

Table 5.5

Percent observations meeting data quality criteria for freeway segments greater than one mile in Delaware (INRIX high score)

SPEED BIN	Data Quality Measures for: 1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		No. of Obs.
	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Equal to Mean	Percentage within 5 mph of the Mean	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	
0-30	11%	36%	0%	28%	0%	28%	8%	31%	36
30-45	17%	43%	0%	28%	6%	31%	13%	40%	108
45-60	56%	94%	0%	76%	19%	84%	39%	90%	868
60+	38%	79%	0%	48%	11%	60%	23%	70%	1295

Table 5.6
Data quality measures for freeway segments greater than one mile in Delaware (all data, five minute shift)

SPEED BIN	Data Quality Measures for 1.96 SE Band: Speed Error Bias	1.96 SE Band: Average Absolute Speed Error	Mean: Speed Error Bias	Mean: Average Absolute Speed Error	0.25 SD Band: Speed Error Bias	0.25 SD Band: Average Absolute Speed Error	0.5 SD Band: Speed Error Bias	0.5 SD Band: Average Absolute Speed Error	No. of Obs.
0-30	0.1	6.1	2.7	10.4	1.9	8.9	0.4	1.2	36
30-45	-2.7	7.5	-1.0	10.6	-1.6	9.3	0.4	-2.2	108
45-60	0.0	1.2	0.1	3.5	0.1	2.5	0.8	0.1	893
60+	-2.3	2.5	-4.9	5.5	-4.0	4.4	0.6	-3.3	1349

Table 5.7
Data quality measures for freeway segments greater than one mile in Delaware (INRIX high score, five minute shift)

SPEED BIN	Data Quality Measures for 1.96 SE Band: Speed Error Bias	1.96 SE Band: Average Absolute Speed Error	Mean: Speed Error Bias	Mean: Average Absolute Speed Error	0.25 SD Band: Speed Error Bias	0.25 SD Band: Average Absolute Speed Error	0.5 SD Band: Speed Error Bias	0.5 SD Band: Average Absolute Speed Error	No. of Obs.
0-30	0.1	6.1	2.7	10.4	1.9	8.9	1.2	7.6	36
30-45	-2.7	7.5	-1.0	10.6	-1.6	9.3	-2.2	8.1	108
45-60	0.0	1.2	-0.1	3.4	0.0	2.4	0.0	1.7	854
60+	-2.4	2.6	-5.0	5.6	-4.1	4.5	-3.4	3.6	1289

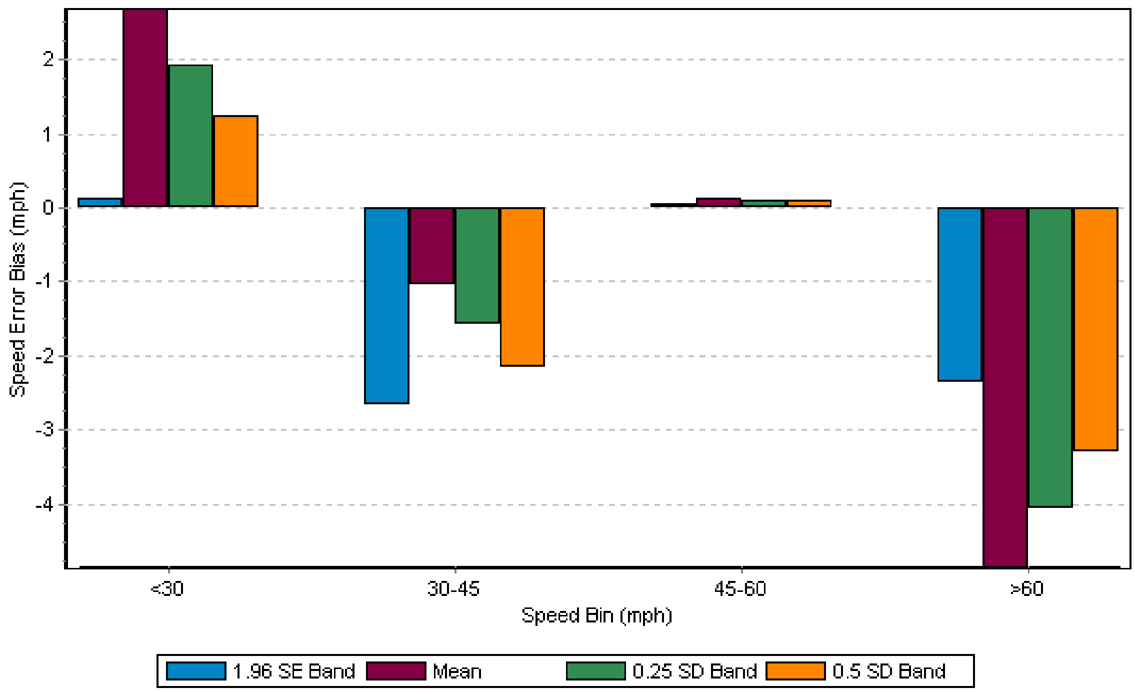


Figure 5.11
Speed error bias for freeway segments greater than one mile in Delaware (all data, five minute shift)

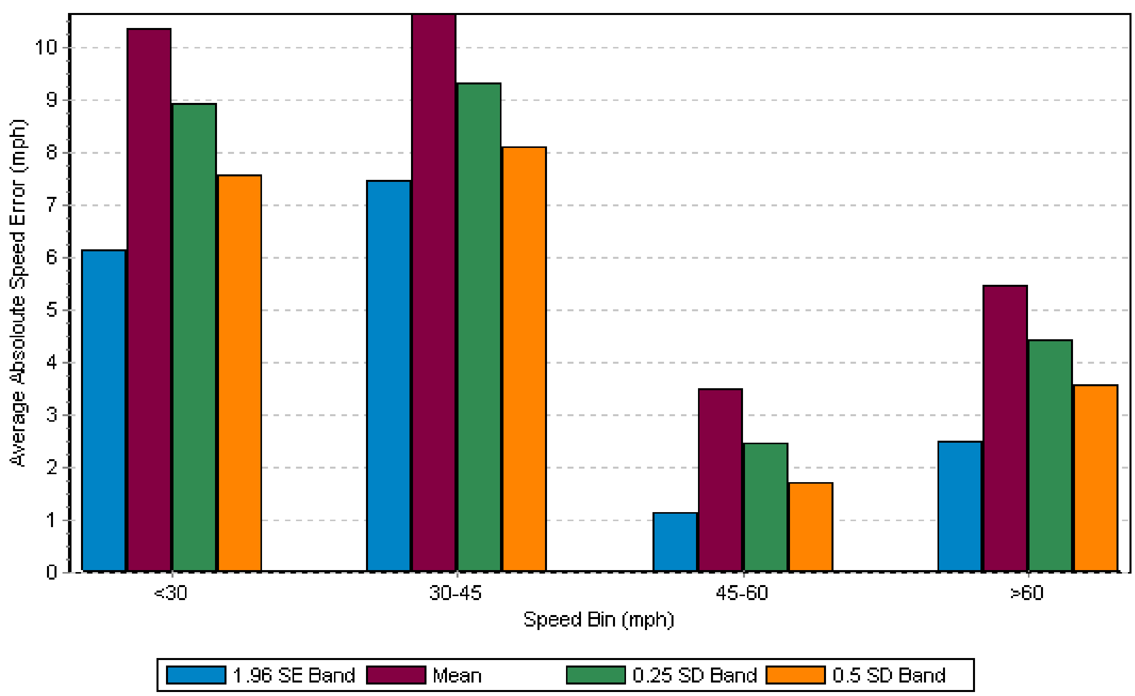


Figure 5.12
Average absolute speed error for freeway segments greater than one mile in Delaware (all data, five minute shift)

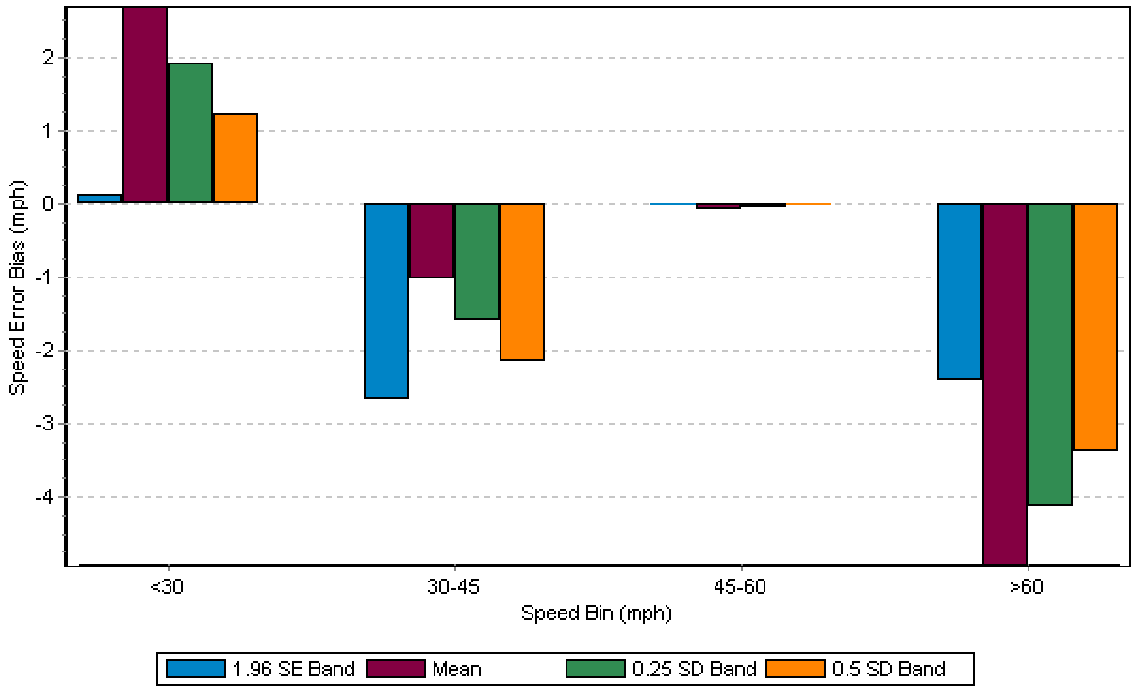


Figure 5.13
Speed error bias for freeway segments greater than one mile in Delaware (INRIX high score, five minute shift)

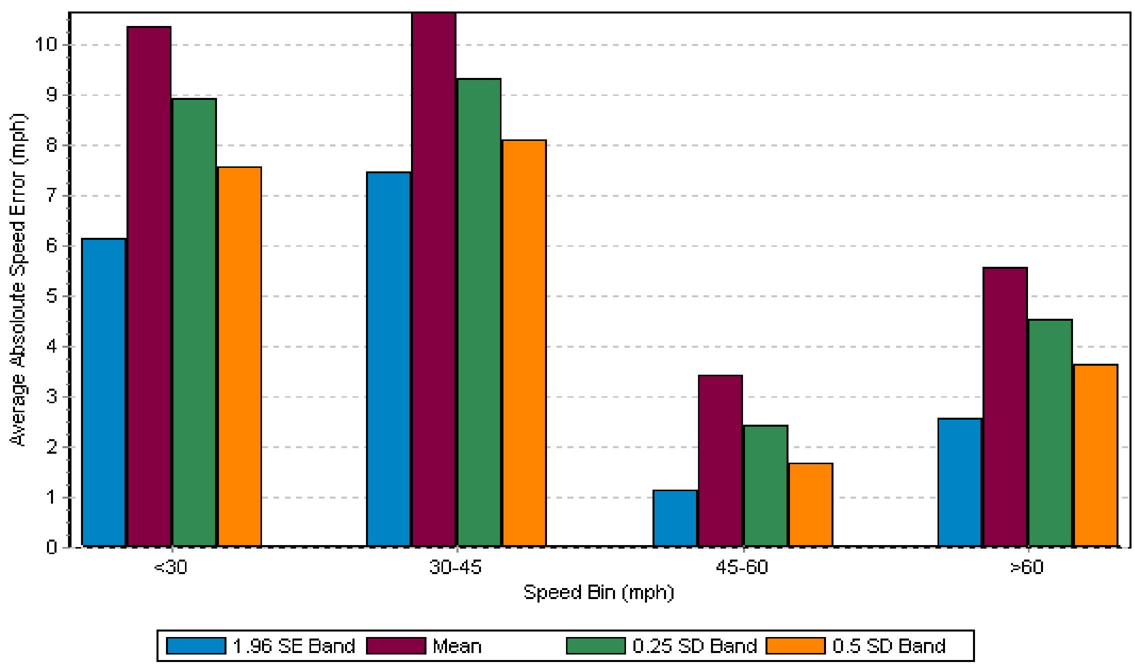


Figure 5.14
Average absolute speed error for freeway segments greater than one mile in Delaware (INRIX high score, five minute shift)

6 Evaluation Results for the State of Maryland

6.1 *Data Collection*

The first batch of Bluetooth sensor deployments in Maryland started on Monday, July 28, 2008 in areas around Washington, D.C. and ended on Friday, August 1, 2008. The second batch of sensors were deployed in the Baltimore area starting on Monday, August 4, 2008 and after some rotations of the sensors over different highways and directions the data collection was finished on the evening of Thursday, August 7, 2008. This round of data collections in Maryland was also designed to cover segments of the main highways in the I-95 corridor along which both recurrent and non-recurrent congestions could be expected during both peak and off-peak periods.

Figures 6.1 and 6.2 present snapshots of the corridors in which Bluetooth sensors were deployed in the state of Maryland.

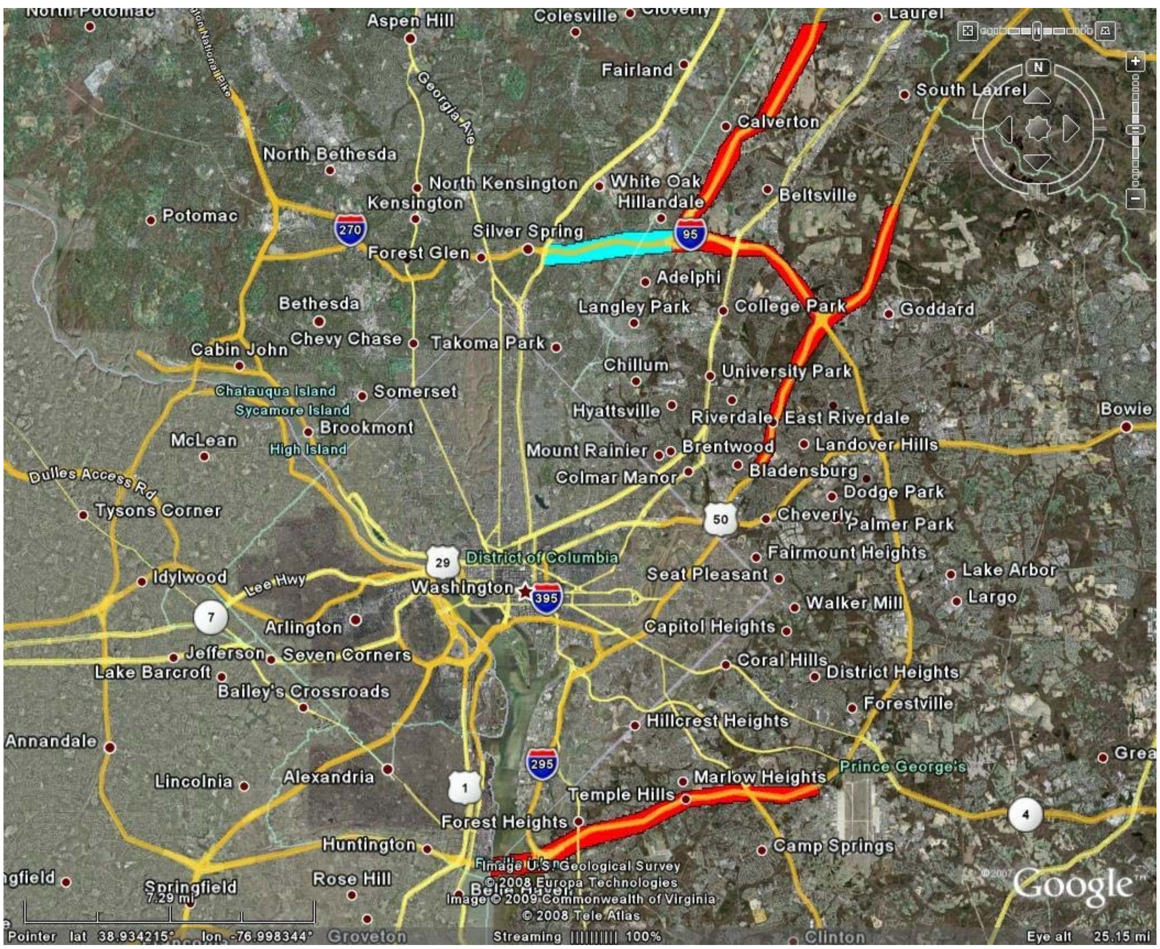


Figure 6.1
TMC segments selected for validation in the Washington D.C. and, Maryland area

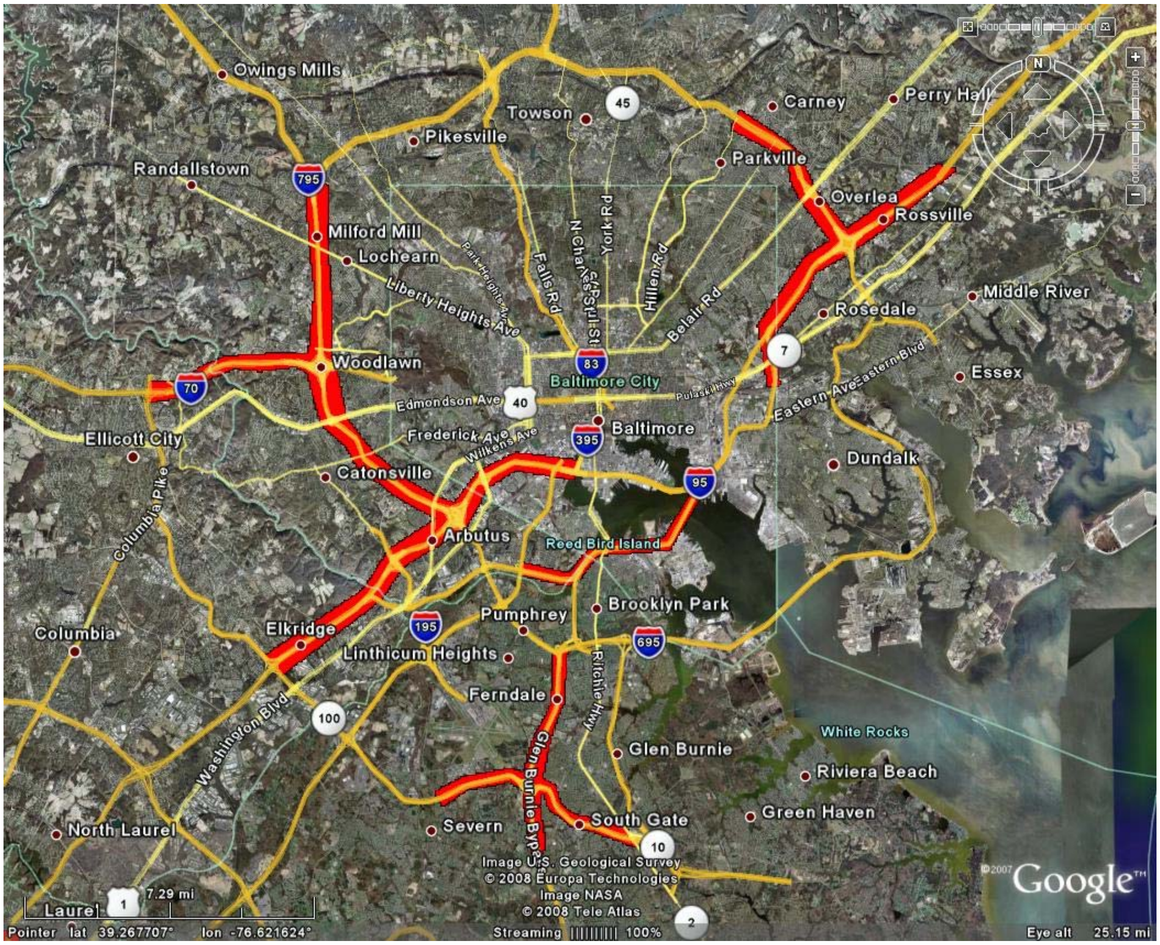


Figure 6.2
TMC segments selected for validation in the Baltimore, Maryland area

The coordinates of the locations at which the Bluetooth sensors were deployed throughout the state of Maryland are reported in the Table B.1 in Appendix B. Table B.1 also presents the distances that have been used in the estimation of Bluetooth speeds based on travel times. Table 6.1 presents a list of specific TMC segments that were selected as the validation sample in Maryland. In total, results of validation on 26 freeway TMC segments are reported in the body of this report and in Appendix B. These segments cover a total length of around 34 miles. Out of 26 freeway segments under consideration 13 segments are longer than one mile.

6.2 *Analysis of Results*

This section presents the data quality comparisons for Maryland. First, a series of graphs showing the Bluetooth observations on one of the segments in Maryland are presented. These graphs provide a qualitative basis for comparison between INRIX speed data and the estimated Bluetooth speeds.

Table 6.1
Traffic Message Channel segments picked for validation in Maryland

Type	TMC	HIGHWAY	DIRECTION	STARTING AT	ENDING AT	COUNTY	LENGTH (mile)
Freeways	**110-04267**	HWY 295	SOUTHBOUND	RIVERDALE RD	HWY 450	PRINCE GEORGE'S	1.2
	110-04268	HWY 295	SOUTHBOUND	I 95/I 495	RIVERDALE RD	PRINCE GEORGE'S	1.9
	110-04271	HWY 295	SOUTHBOUND	POWDER MILL RD	GODDARD RD	PRINCE GEORGE'S	1.8
	110+04640	I 495	CLOCKWISE	HWY 337/ALLENTOWN RD/EXIT 9	HWY 5/BRANCH AVE/EXIT 7	PRINCE GEORGE'S	1.1
	110+04641	I 495	CLOCKWISE	HWY 5/BRANCH AVE/EXIT 7	HWY 414/ST BARNABAS RD/EXIT 4	PRINCE GEORGE'S	2.2
	110+04642	I 495	CLOCKWISE	HWY 414/ST BARNABAS RD/EXIT 4	HWY 210/EXIT 3	PRINCE GEORGE'S	1.0
	110+04522	I 695	CLOCKWISE	SECURITY BLVD/EXIT 17	HWY 26/EXIT 18	BALTIMORE	2.0
	110-04521	I 695	COUNTERCLOCKWISE	HWY 26/EXIT 18	SECURITY BLVD/EXIT 17	BALTIMORE	2.0
	110+04483	I 70	WESTBOUND	I 695/EXIT 91	US 29/EXIT 87	HOWARD	3.3
	110-04482	I 70	EASTBOUND	US 29/EXIT 87	I 695/EXIT 91	BALTIMORE	3.8
	110+04422	I 95	NORTHBOUND	HWY 100/EXIT 43	I 895/EXIT 46	HOWARD	2.4
	110+04424	I 95	NORTHBOUND	I 195/HWY 166/EXIT 47	I 695/EXIT 49	BALTIMORE	1.2
	110+04374	I 97	NORTHBOUND	HWY 648/EXIT 16	I 695/EXIT 17	ANNE ARUNDEL	1.2
	Sub-Total						25.1
	110-04270	HWY 295	SOUTHBOUND	GODDARD RD	HWY 193	PRINCE GEORGE'S	0.9
	110+04520	I 695	CLOCKWISE	US 40/EXIT 15	I 70/EXIT 16	BALTIMORE	0.7
	110+04523	I 695	CLOCKWISE	HWY 26/EXIT 18	I 795/EXIT 19	BALTIMORE	0.8
	110+04537	I 695	CLOCKWISE	HWY 41/PERRING PKWY/EXIT 30	HWY 147/HARFORD RD/EXIT 31	BALTIMORE	0.6
	110+04539	I 695	CLOCKWISE	HWY 43/WHITEMARSH BLVD/EXIT 31	US 1/EXIT 32	BALTIMORE	0.9
	110-04522	I 695	COUNTERCLOCKWISE	I 795/EXIT 19	HWY 26/EXIT 18	BALTIMORE	0.8
	110-04538	I 695	COUNTERCLOCKWISE	US 1/EXIT 32	HWY 43/WHITEMARSH BLVD/EXIT 31	BALTIMORE	0.7
	110-04539	I 695	COUNTERCLOCKWISE	I 95/EXIT 33	US 1/EXIT 32	BALTIMORE	0.8
	110+04370	I 97	NORTHBOUND	HWY 3 BUS/NEW CUT RD/EXIT 12	HWY 174/QUARTERFIELD RD/EXIT 13	ANNE ARUNDEL	0.6
	110+04372	I 97	NORTHBOUND	HWY 100/EXIT 14	HWY 162/HWY 176/EXIT 15	ANNE ARUNDEL	0.6
	110-04369	I 97	SOUTHBOUND	HWY 174/QUARTERFIELD RD/EXIT 13	HWY 3 BUS/NEW CUT RD/EXIT 12	ANNE ARUNDEL	0.6
	110+05248	US 29	NORTHBOUND	HWY 175	HWY 108	HOWARD	0.6
	110-05247	US 29	SOUTHBOUND	HWY 108	HWY 175	HOWARD	0.4
	Sub-Total						9
	Grand Total						34.1

Figure 6.3 shows every single Bluetooth speed estimate at every time interval on segment 110+04640. This figure also highlights the observations that are deemed as outliers during the application of the filtering methodology that was explained earlier. The remaining observations are then used to obtain the mean estimate of speed at each time interval.

A 24 hour slice of data on this segment for August 1, 2008 is shown in Figure 6.4 which incorporates the mean Bluetooth speed estimate along with the 95% confidence interval band of the mean estimate as well as the corresponding INRIX speeds. This figure provides a visual aid to observe the overall behavior of the INRIX data compared to the Bluetooth speeds.

Figures 6.5 and 6.6 demonstrate the trends of both Bluetooth and INRIX speeds over the same time period on the same segment. Figure 6.5 includes the number of Bluetooth observations used in the speed estimation for each five minute interval and Figure 6.6 shows the reported scores for INRIX speeds.

In Figure 6.7, all individual Bluetooth speed observations (outliers and non-outliers identified with different colors), the mean speed estimate and its associated 95% confidence interval band, as well as the INRIX data are presented in one place to give a better picture of the raw data as well as the final outcomes of the analysis versus the INRIX speeds.

These graphs are produced for each TMC and all graphs for the segments picked for validation in Maryland are included in the CD-ROM that accompanies this report.

Table 6.2 summarizes the data quality measures obtained as a result of comparison between Bluetooth and all reported INRIX speeds, including all scores.

The comparisons between the Bluetooth data with the corresponding INRIX speed data for which INRIX indicated high score are summarized in the Table 6.3.

In all speed bins, except for the less than 30 mph, INRIX data passes the data quality measures set forth by the contract when errors are measured as a distance from the 1.96 times the standard error and 0.5 times the standard deviation bands. However, when compared to the computed mean and the 0.25 times the standard deviation band the INRIX data fails to pass the data quality requirements in less than 45 mph speeds, primarily on the basis of speed error bias measure. Considering the high score INRIX data alone, the results of the analysis are essentially the same.

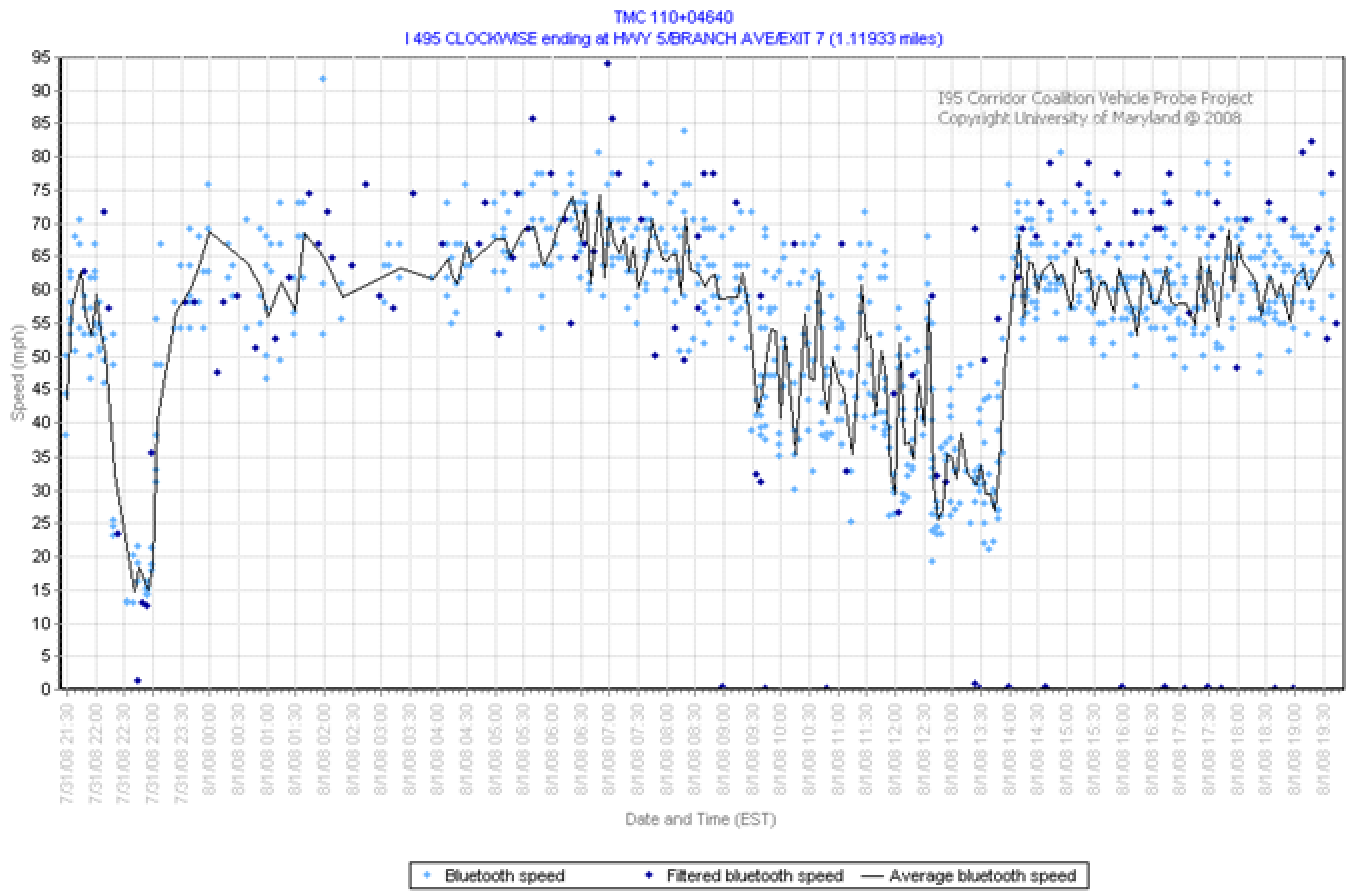


Figure 6.3
Bluetooth observations and outliers on a sample segment in Maryland (all data)

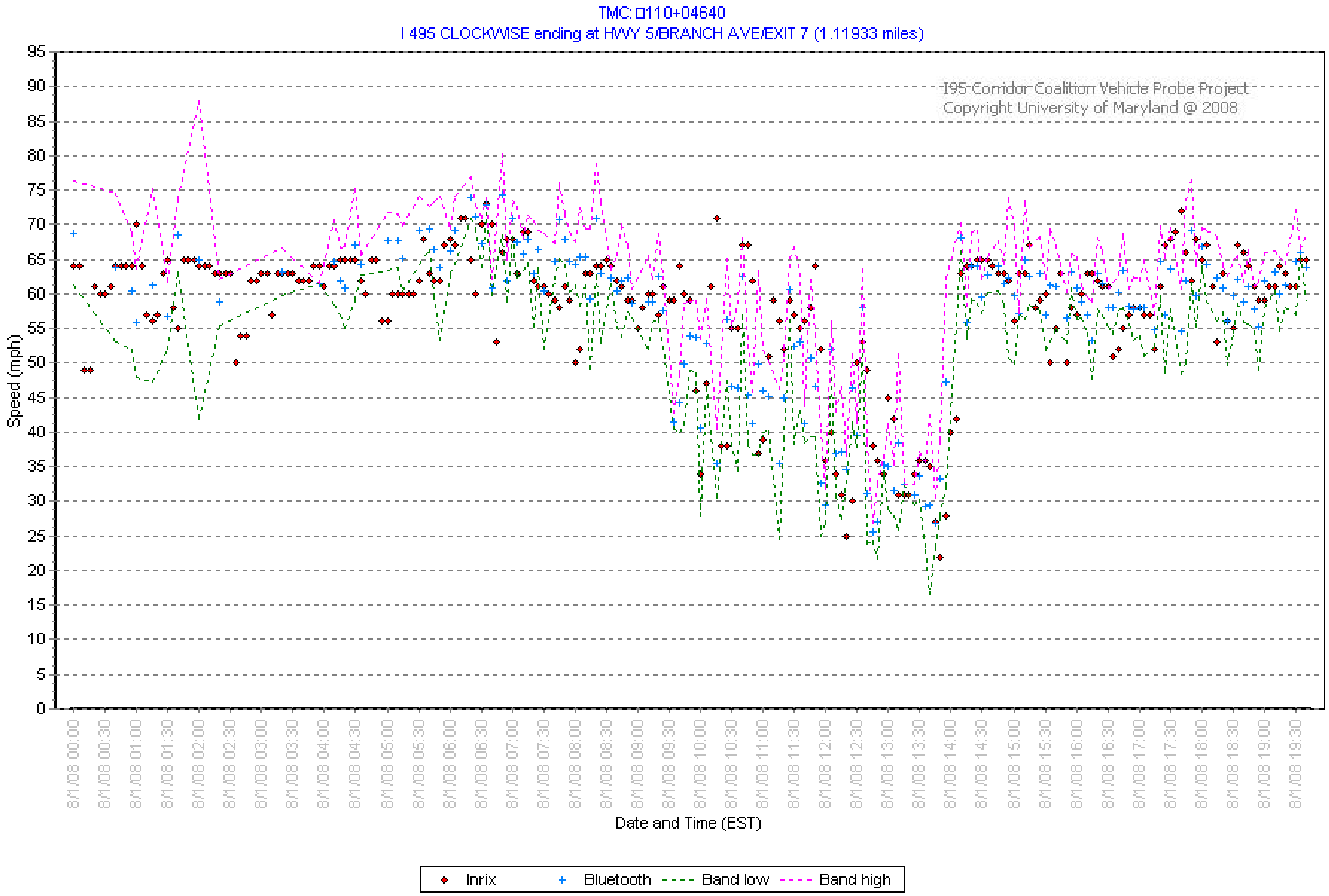


Figure 6.4
Bluetooth mean estimate and its 95% confidence band with INRIX speeds on a sample segment in Maryland, 1 August 2008 (all data)

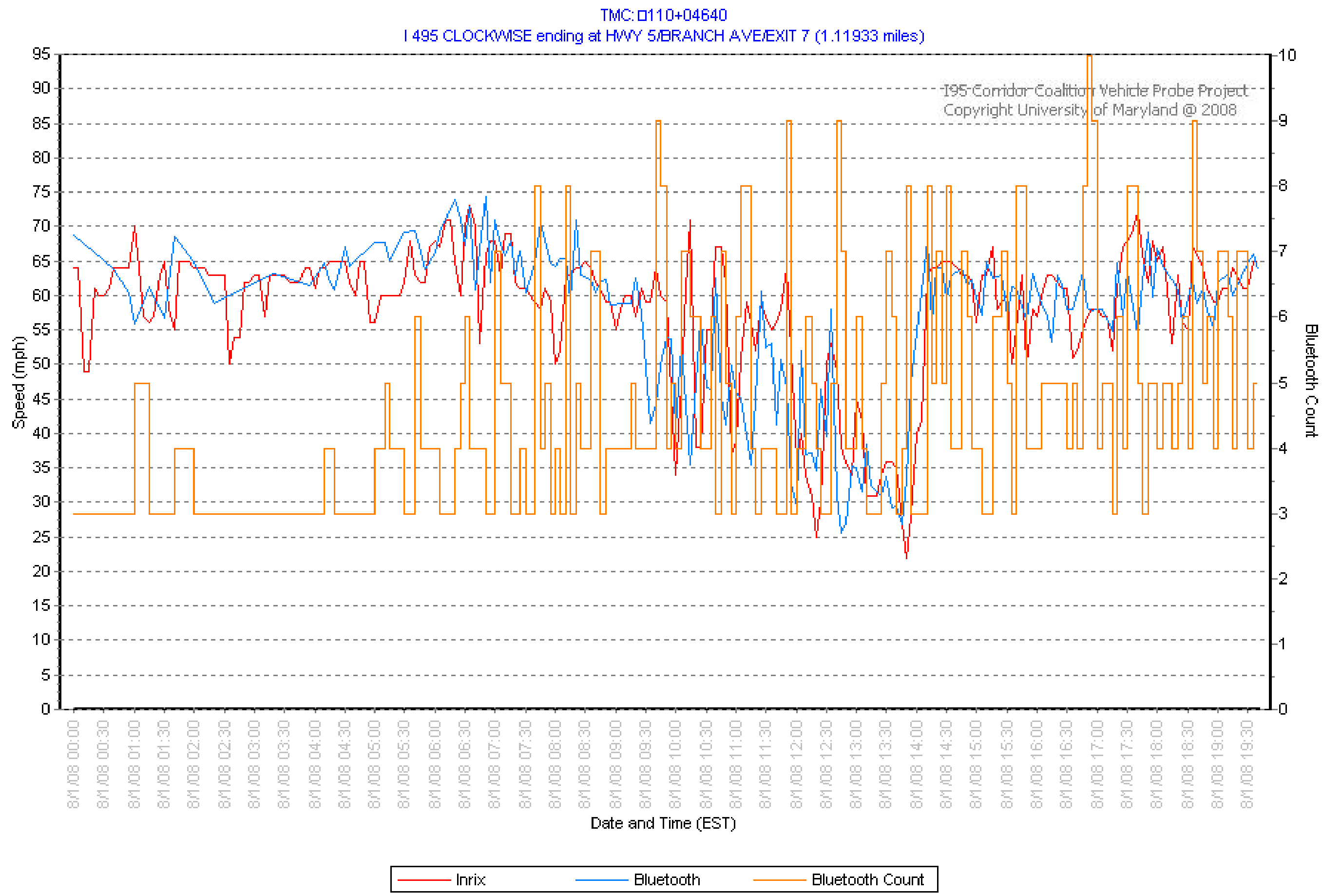


Figure 6.5
Bluetooth and INRIX speeds with number of Bluetooth observations on a sample segment in Maryland, 1 August 2008 (all data)

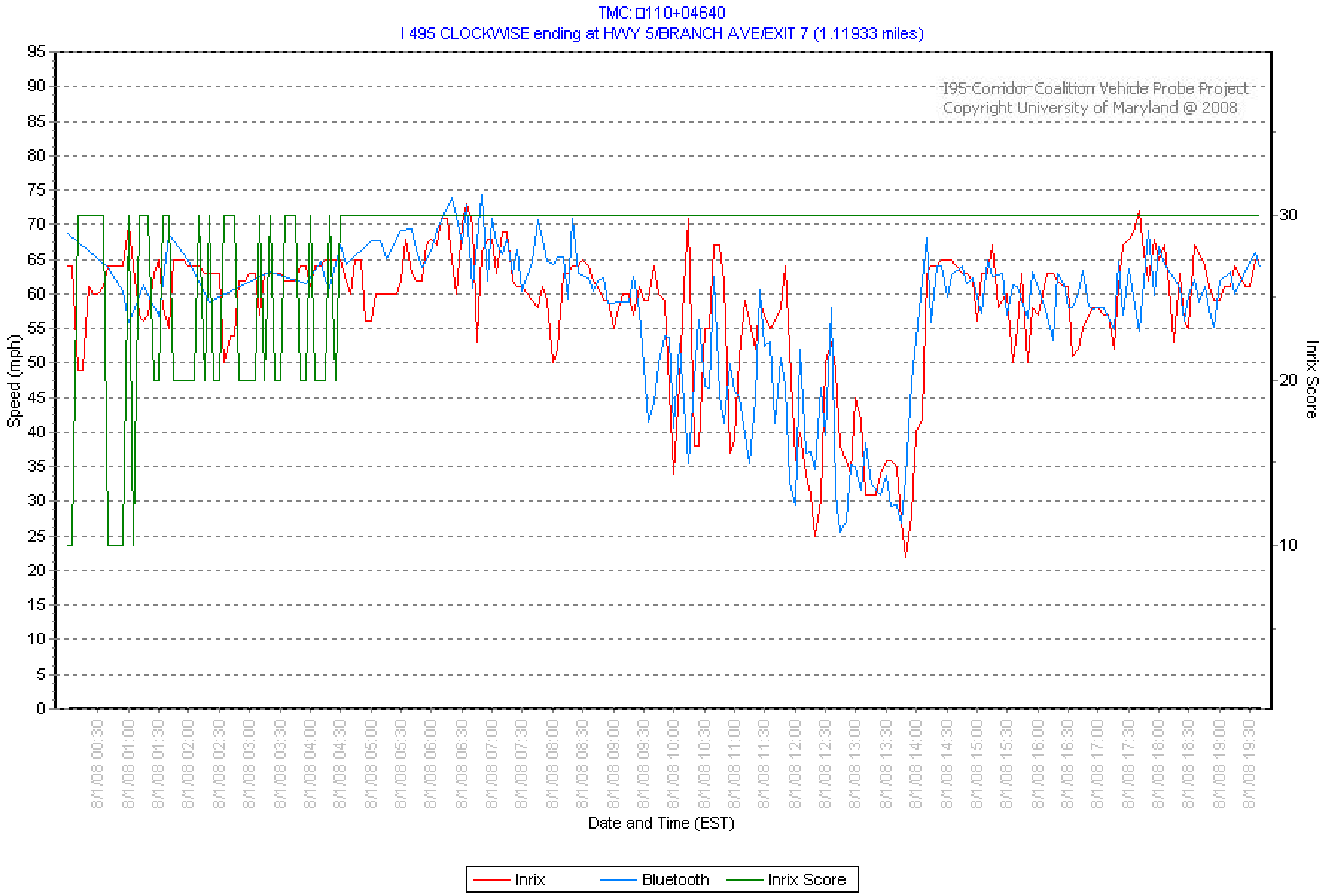


Figure 6.6
Bluetooth and INRIX speeds with the score on a sample segment in Maryland, 1 August 2008 (all data)

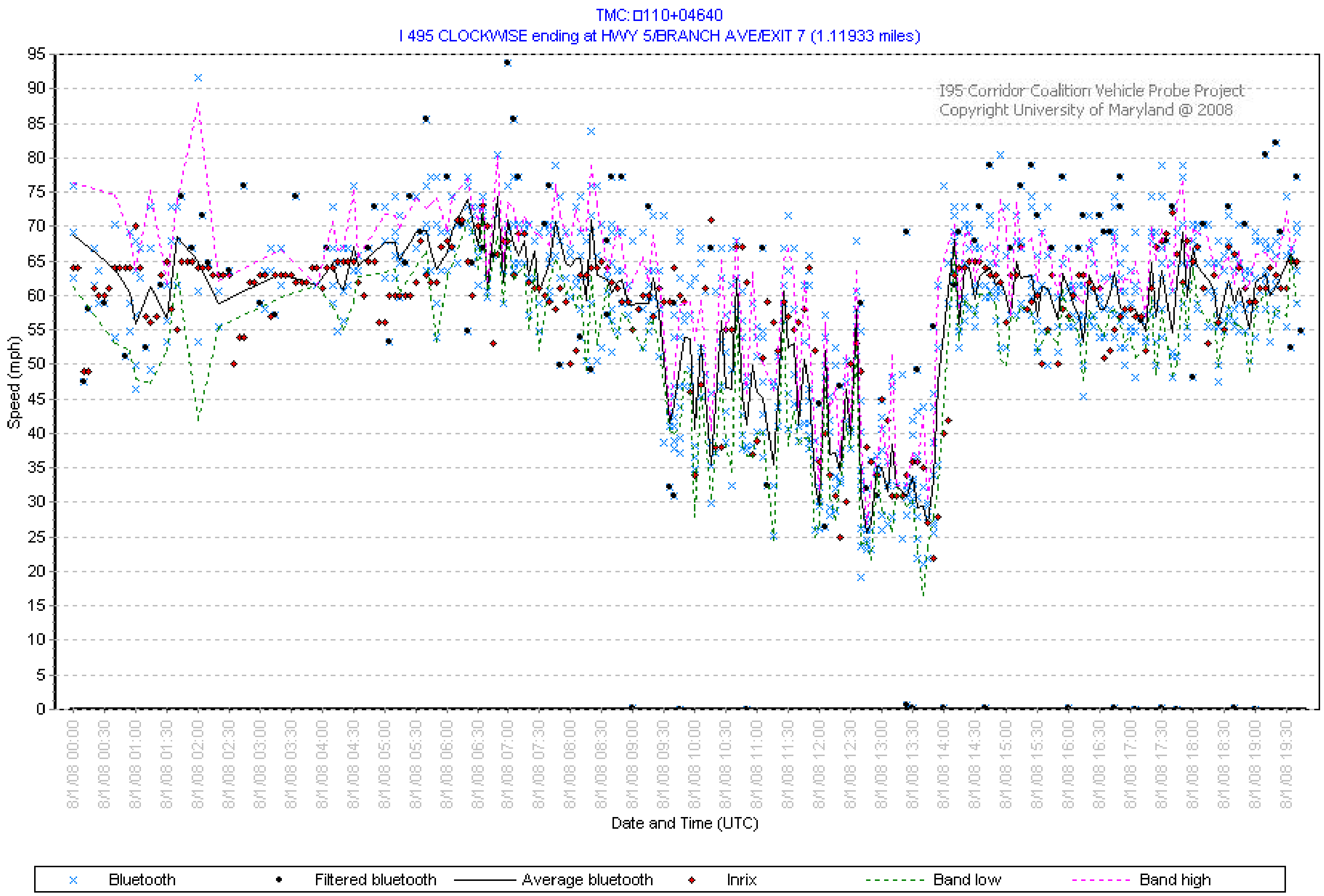


Figure 6.7
Bluetooth and INRIX speeds on a sample segment in Maryland, 1 August 2008 (all data)

Figures 6.8 and 6.9 show the overall speed error bias for different speed bins and the average absolute speed errors for all segments in Maryland, respectively. These figures correspond to Table 6.2. Likewise, Figures 6.10 and 6.11 show the same error measures for all segments in Maryland for speed data for which INRIX indicated high score (score 30 as mentioned before). Figures 6.10 and 6.11 correspond to the results exhibited in Table 6.3.

Table 6.4 shows the percentage of the time intervals that have met the data quality requirements as described in the contract for each speed bin for all TMCs in Maryland. Table 6.5 presents the same information when high score INRIX data has been used in the evaluations.

In both tables 6.4 and 6.5 the columns that show the percentage falling inside the band represent the percentage of the time intervals for which INRIX provides travel time and speed data that falls inside the corresponding band as described in section 4.2.4. The columns that show the percentage within five mph of the band represent the percentage of the INRIX data that lay within five mph of the band including the data points that fall inside the corresponding band. When comparing to the mean of the Bluetooth data, numbers in the percentage equal to mean column show the percentage of the INRIX observations that are exactly equal to their corresponding Bluetooth observation and the percentage within five mph of the mean show the portion of the INRIX data that falls within five mph of the Bluetooth mean.

6.3 *Shifted INRIX Data*

In this section, results of comparisons made between Bluetooth sensor speed data and the INRIX speed data that are shifted five minutes back in time in Maryland are reported. Table 6.6 summarizes the data quality measures obtained as a result of comparison between Bluetooth and all reported INRIX speeds, including all scores.

The comparisons made between the Bluetooth data with the corresponding INRIX speed data for which INRIX indicated high score are summarized in the Table 6.7.

Figures 6.12 and 6.13 show the overall speed error bias for different speed bins, and the average absolute speed errors for all segments in Maryland. These figures correspond to Table 6.6. Likewise, Figures 6.14 and 6.15 show the same error measures for all segments in Maryland for speed data for which INRIX indicated high score (score 30 as mentioned before). Figures 6.14 and 6.15 correspond to the results exhibited in Table 6.7.

Generally speaking, the five minute shift in INRIX data does not have an impact on the data quality measures. The shifted INRIX data in both cases (all and high score data) do not result in better data quality measures as compared with the prior comparison in which INRIX data was not shifted.

Detailed data for individual TMC segments in Maryland are presented in Appendix B. This appendix also presents the results of the evaluation of the INRIX data reported for freeway segments that are less than one mile long.

Table 6.2
Data quality measures for freeway segments greater than one mile in Maryland (all data)

SPEED BIN	Data Quality Measures for: 1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		No. of Obs.
	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	7.2	7.8	10.6	11.7	9.2	10.1	8.0	8.7	29
30-45	4.0	6.7	6.1	10.7	5.5	9.3	4.9	7.9	69
45-60	-0.7	3.3	-0.2	6.2	-0.4	5.1	-0.6	4.1	370
60+	-1.3	1.8	-2.2	4.0	-1.9	3.1	-1.6	2.4	1298

Table 6.3
Data quality measures for freeway segments greater than one mile in Maryland (INRIX high score)

SPEED BIN	Data Quality Measures for: 1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		No. of Obs.
	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	7.2	7.8	10.6	11.7	9.2	10.1	8.0	8.7	29
30-45	4.1	6.8	6.0	10.6	5.4	9.2	4.8	7.9	68
45-60	-0.6	3.2	-0.2	6.1	-0.4	5.0	-0.5	4.0	336
60+	-1.3	1.7	-2.2	3.9	-1.9	3.0	-1.6	2.3	1223

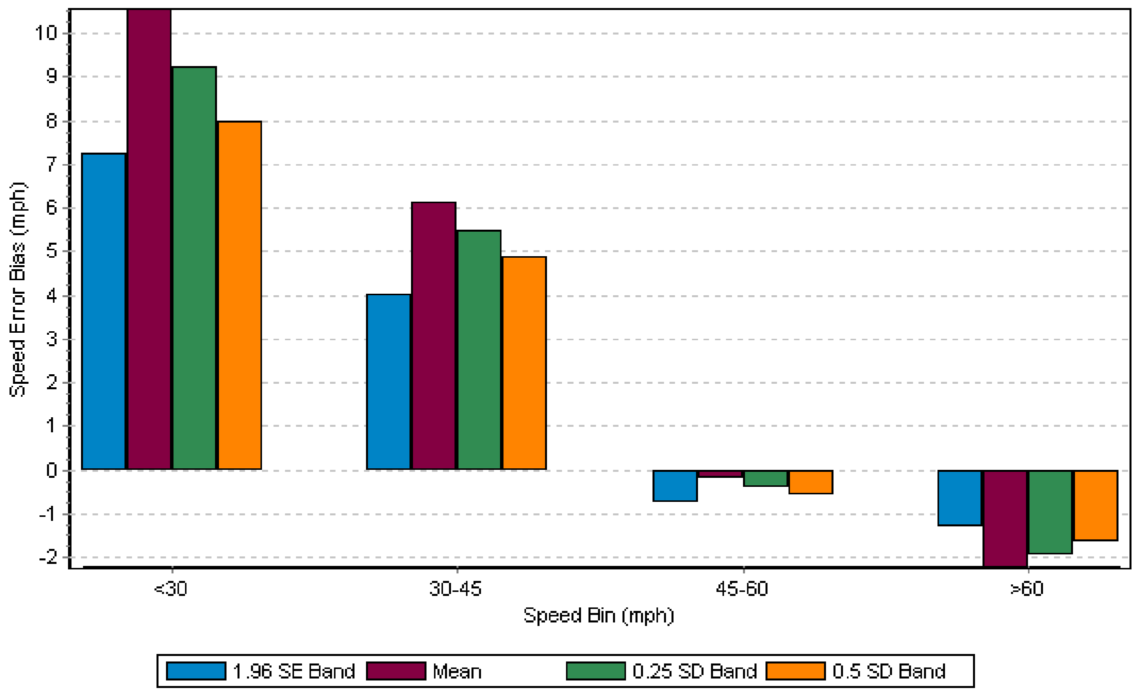


Figure 6.8
Speed error bias for freeway segments greater than one mile in Maryland (all data)

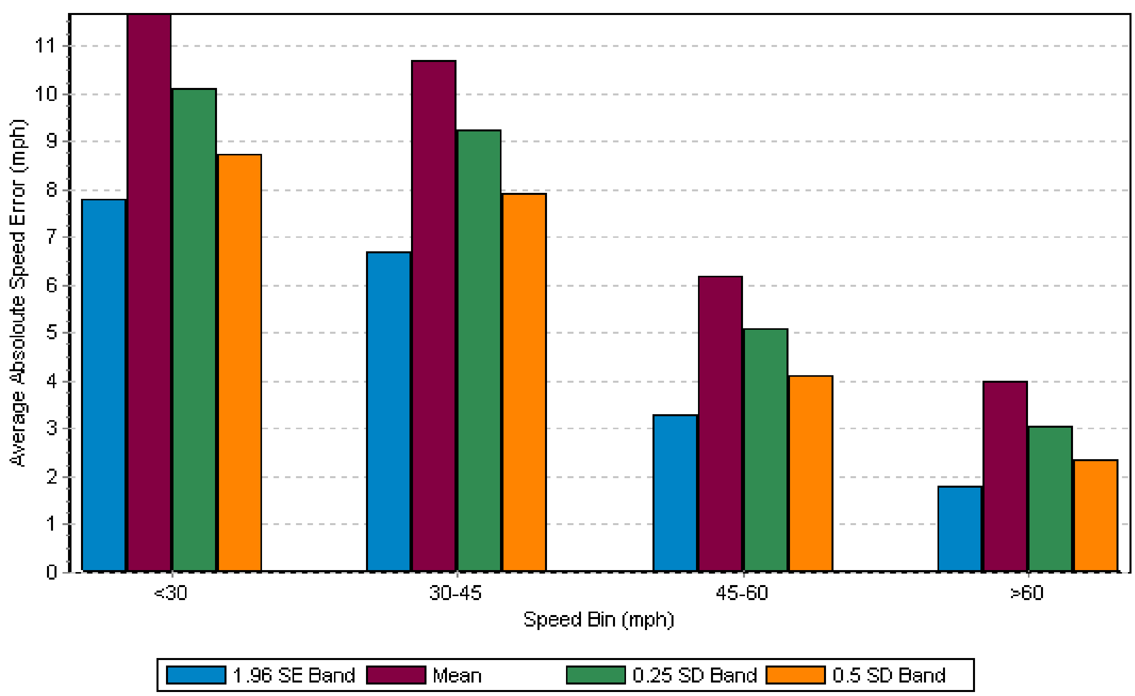


Figure 6.9
Average absolute speed error for freeway segments greater than one mile in Maryland (all data)

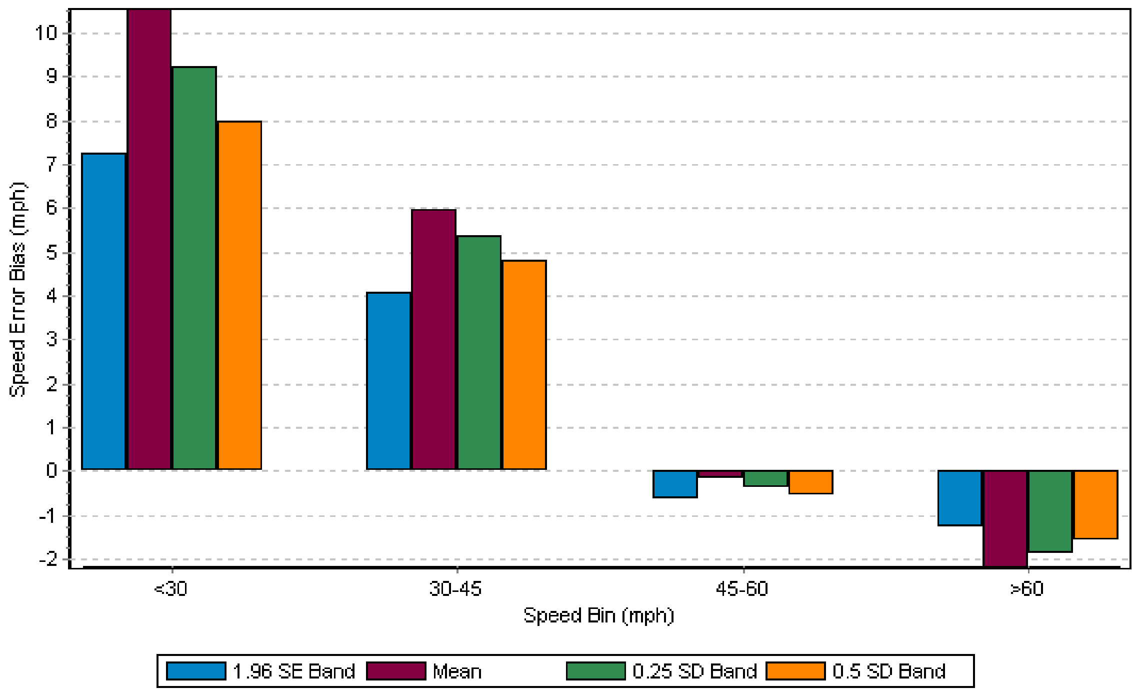


Figure 6.10
Speed error bias for freeway segments greater than one mile in Maryland (INRIX high score)

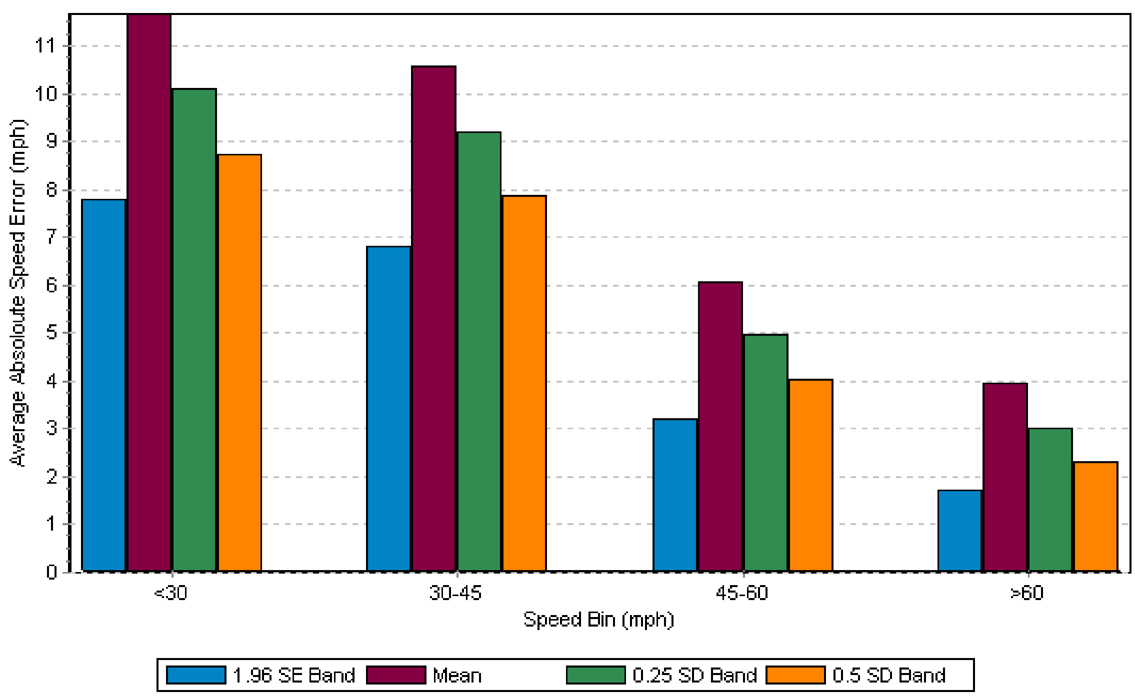


Figure 6.11
Average absolute speed error for freeway segments greater than one mile in Maryland (INRIX high score)

Table 6.4
Percent observations meeting data quality criteria for freeway segments greater than one mile in Maryland (all data)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Equal to Mean	Percentage within 5 mph of the Mean	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	
0-30	28%	55%	0%	38%	10%	45%	24%	48%	29
30-45	17%	46%	0%	28%	3%	38%	12%	41%	69
45-60	31%	80%	0%	51%	11%	63%	20%	71%	370
60+	55%	90%	0%	74%	19%	81%	39%	85%	1298

Table 6.5
Percent observations meeting data quality criteria for freeway segments greater than one mile in Maryland (INRIX high score)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Equal to Mean	Percentage within 5 mph of the Mean	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	
0-30	28%	55%	0%	38%	10%	45%	24%	48%	29
30-45	16%	46%	0%	28%	3%	38%	12%	41%	68
45-60	30%	79%	0%	51%	10%	63%	19%	71%	336
60+	54%	90%	0%	73%	19%	81%	38%	85%	1223

Table 6.6
Data quality measures for freeway segments greater than one mile in Maryland (all data, five minute shift)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	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	6.2	7.0	7.9	10.4	7.3	8.9	6.6	7.8	29
30-45	2.5	5.0	4.2	8.8	3.6	7.4	3.1	6.1	69
45-60	-0.5	3.0	0.3	5.9	0.0	4.8	-0.3	3.8	370
60+	-1.3	1.8	-2.2	3.9	-1.9	3.0	-1.6	2.3	1298

Table 6.7
Data quality measures for freeway segments greater than one mile in Maryland (INRIX high score, five minute shift)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	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	6.2	7.0	7.9	10.4	7.3	8.9	6.6	7.8	29
30-45	2.5	5.0	4.2	8.8	3.6	7.4	3.1	6.1	69
45-60	-0.3	2.8	0.4	5.6	0.1	4.5	-0.1	3.6	330
60+	-1.2	1.7	-2.1	3.8	-1.8	2.9	-1.5	2.2	1206

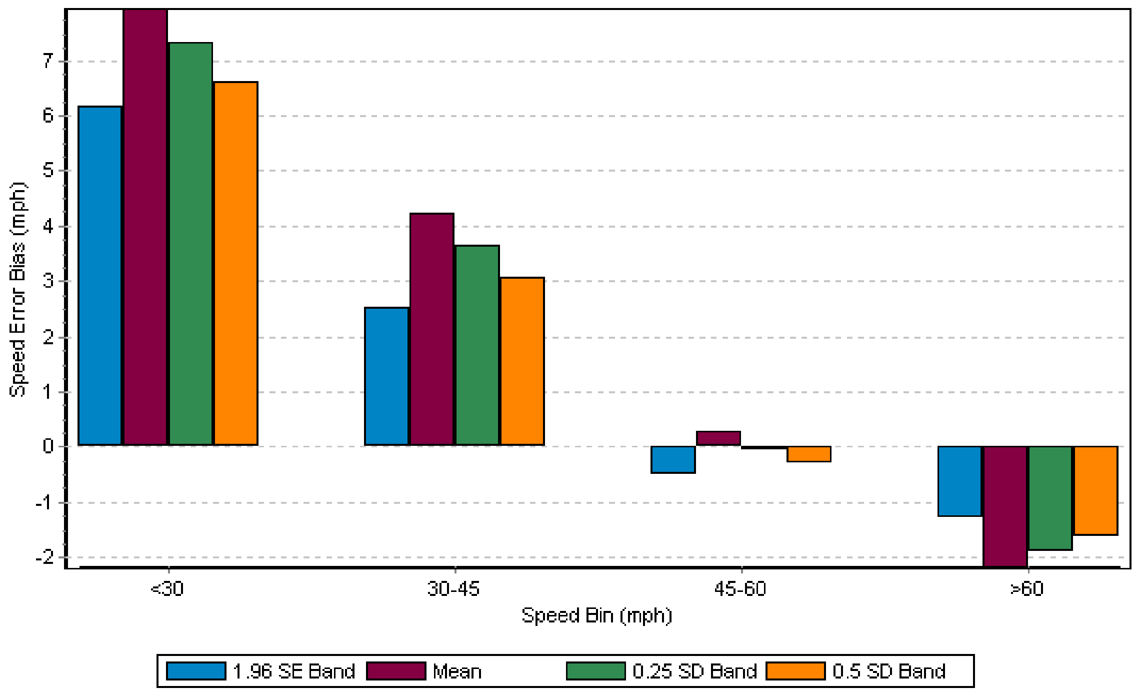


Figure 6.12
Speed error bias for freeway segments greater than one mile in Maryland (all data, five minute shift)

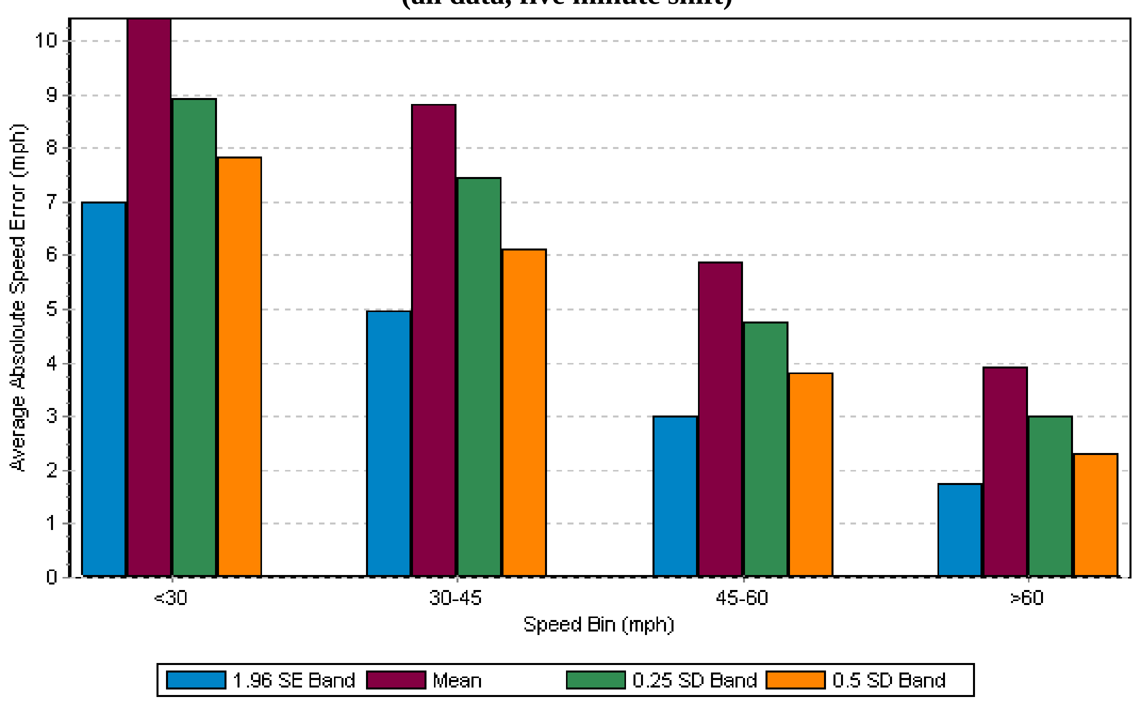


Figure 6.13
Average absolute speed error for freeway segments greater than one mile in Maryland (all data, five minute shift)

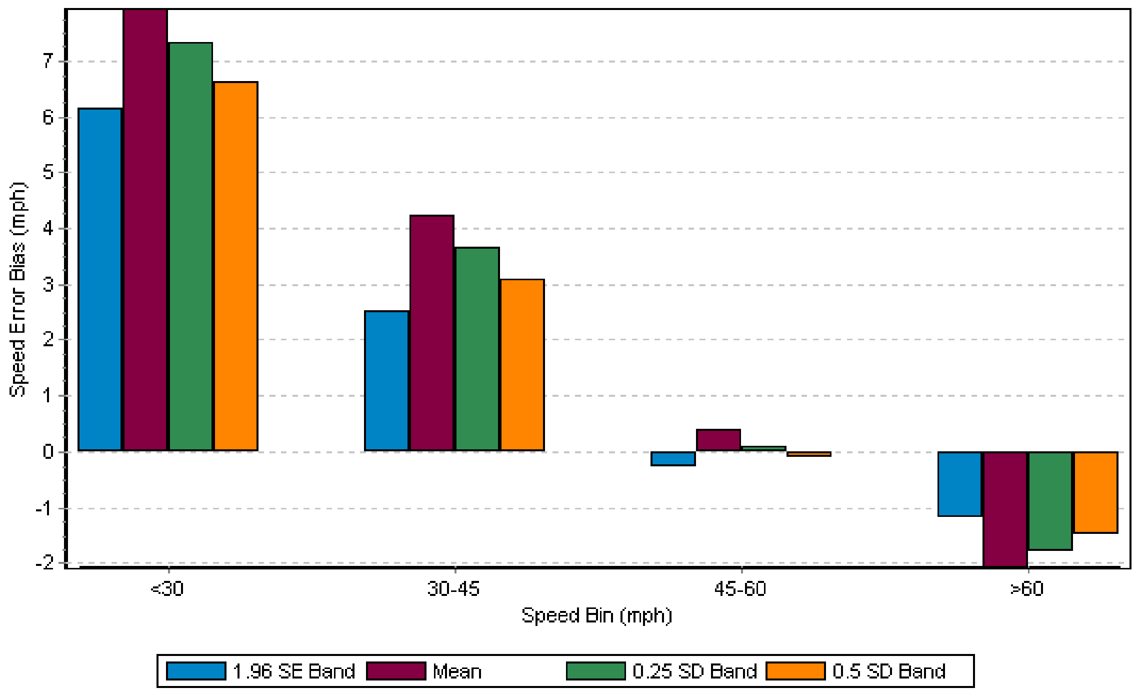


Figure 6.14
Speed error bias for freeway segments greater than one mile in Maryland (INRIX high score, five minute shift)

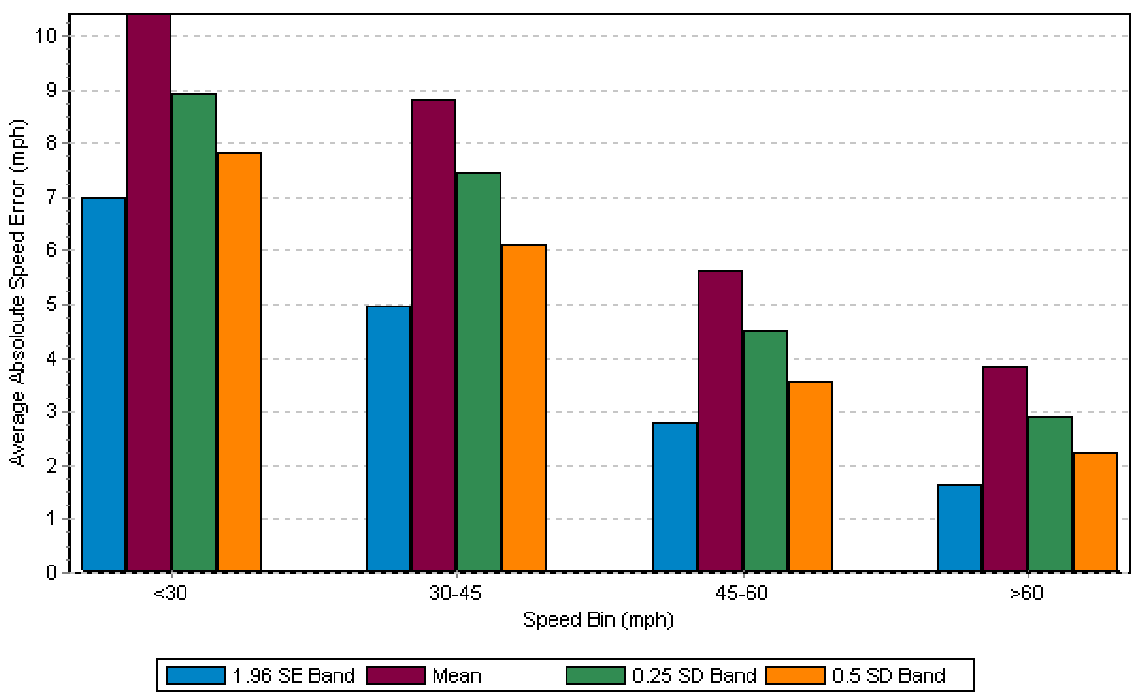


Figure 6.15
Average absolute speed error for freeway segments greater than one mile in Maryland (INRIX high score, five minute shift)

7 Evaluation Results for the State of New Jersey

7.1 *Data Collection*

Data collection in New Jersey was the most comprehensive among all the states for which we collected data. This is due to the fact that New Jersey has the largest share of miles covered among all the core states. Data collection in New Jersey started on September 15, 2008 and went on for three weeks. During each week a specific region of the state was targeted and, for the most part, the deployed sensors were left in place from Monday to Friday. Due to the inclement weather forecast in the region it was not possible for the Turnpike Authority personnel to provide assistance in the redeployments on Friday of the second week.

During the first week, the focus of data collection was on the northern region of the state. Deployments in this region were assisted by New Jersey Department of Transportation (NJDOT) personnel. Figure 7.1 shows a snapshot of the corridors over which sensors were deployed during the first week. In this period, in total, 20 sensors were deployed on the I-80 corridor from I-287 to the George Washington bridge in the east, and on route 1 (US-1) from US-9 all the way to the interchange with I-295 in the south.

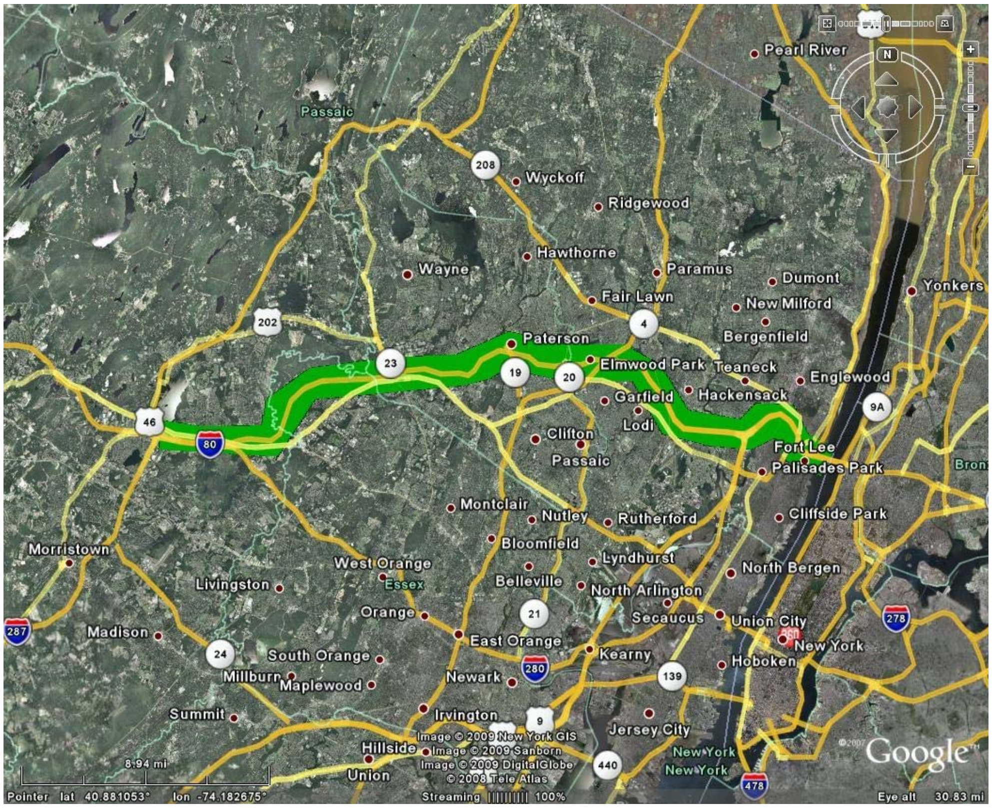


Figure 7.1
Segments picked for validation in the first week of data collection, New Jersey

In the second week, the central regions including the Garden State Parkway and the New Jersey Turnpike were targeted. Figure 7.2 shows the corridors that were the subject of data collection effort during the second week. In total, during the second week 20 sensors were deployed on the Garden State Parkway from the Essex toll plaza to the Raritan toll plaza and on New Jersey Turnpike from interchange 9 to interchange 6. The sensors were deployed on Monday, September 22, 2008 and, as mentioned before, were removed on Monday, September 29, 2008.

Figure 7.2
Segments picked for validation in the second week of data collection, New Jersey

The third week of data collection was dedicated to the North-South freeway stretch from the Walt Whitman Bridge on I-76 to I-295 and later NJ-42 up to the Atlantic City toll road, and I-295 corridor from exit 26 to exit 36. In total, 20 sensors were deployed on these segments on Tuesday, September 30, 2008 and remained in place until Friday, October 3, 2008.

The coordinates of the locations at which the Bluetooth sensors were deployed throughout the state of New Jersey are reported in Table C.1 in Appendix C. Table C.1 also presents the distances that have been used in the estimation of Bluetooth speeds based on travel times. Table 7.1 presents a list of specific TMC segments which were selected as the validation sample in New Jersey. In total, results of validation on 12 TMC segments on freeways are reported in the body of this report. These segments cover a total length of over 28.2 miles. Out of 12 freeway segments under consideration, 11 segments are longer than one mile.

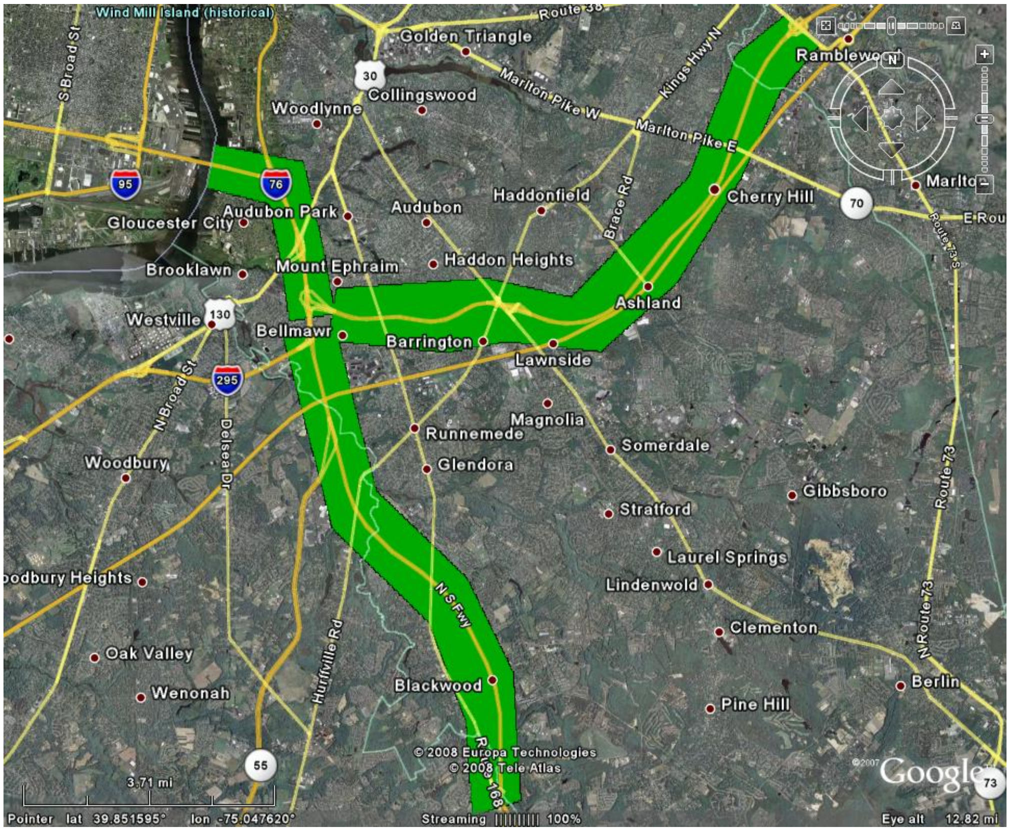


Figure 7.3
Segments picked for validation in the third week of data collection, New Jersey

7.2 *Analysis of Results*

This section presents the data quality comparisons for New Jersey. First, a series of graphs showing the Bluetooth observations on one of the segments in New Jersey are presented. These graphs provide a qualitative basis for comparison between the INRIX speed data and the estimated Bluetooth speeds.

Figure 7.4 shows every single Bluetooth speed estimate at every time interval on segment 120-04663. Figure 7.4 also highlights the observations that are deemed as outliers during the application of the filtering methodology that was explained earlier. The remaining observations are then used to obtain the mean estimate of speed at each time interval.

A 24 hour slice of data on this segment for September 24, 2008 is shown in Figure 7.5 that incorporates the mean Bluetooth speed estimate along with the 95% confidence interval band of the estimate as well as the corresponding INRIX speeds. Figure 7.5 provides a visual aid to observe the overall behavior of INRIX data compared to the Bluetooth speeds.

Figures 7.6 and 7.7 demonstrate the trends of both Bluetooth and INRIX speeds over the same time period on the same segment. Figure 7.6 includes the number of Bluetooth observations used in the speed estimation for each five minute interval and Figure 7.7 shows the reported scores for INRIX speeds.

In Figure 7.8, all individual Bluetooth speed observations (outliers and non-outliers identified with different colors), the mean speed estimate and its associated 95% confidence interval band, as well as the INRIX data are presented in one place to give a better picture of the raw data as well as the final outcomes of the analysis versus the INRIX speeds.

These graphs are produced for each TMC and all graphs for the segments picked for validation in New Jersey are included in the CD-ROM that accompanies this report.

Table 7.2 summarizes the data quality measures obtained as a result of comparison between Bluetooth and all reported INRIX speeds, including all scores. The comparisons between the Bluetooth data with the corresponding INRIX speed data for which INRIX indicated high score are summarized in the Table 7.3.

In all higher speed bins over 45 mph, INRIX data passes the data quality measures set forth by contract when errors are measured as a distance from the 1.96 the standard error, the point mean estimate, and 0.25 and 0.5 times the standard deviation bands. However, when compared to the 1.96 times the standard error and 0.5 times the standard deviation bands, the INRIX data barely fails to pass the data quality requirements in 30-45 mph speed bin. Considering the high score INRIX data alone, the results of the analysis are essentially the same with minor improvements all around. But, in the final analysis the high score speed data provided by INRIX also failed to pass the specified requirements in the lower speed bins.

Figures 7.9 and 7.10 show the overall speed error bias for different speed bins, and the average absolute speed errors for all segments in New Jersey, respectively. These figures correspond to Table 7.2. Likewise, Figures 7.11 and 7.12 show the same error measures for all segments in New Jersey for speed data for which INRIX indicated high score (score 30 as mentioned before). Figures 7.11 and 7.12 correspond to the results exhibited in Table 7.3.

Table 7.4 shows the percentage of the time intervals that have met the data quality requirements as described in the contract for each speed bin for all TMCs in New Jersey. Table 7.5 presents the same information when high score INRIX data has been used in the evaluations.

In both tables 7.4 and 7.5 the columns that show the percentage falling inside the band represent the percentage of the time intervals for which INRIX provides travel time and speed data that falls inside the corresponding band as described in section 4.2.4. The columns that show the percentage within five mph of the band represent the percentage of the INRIX data that lay within five mph of the band including the data points that fall inside the corresponding band.

When comparing to the mean of the Bluetooth data, numbers in the percentage equal to mean column show the percentage of the INRIX observations that are exactly equal to their corresponding Bluetooth observation and the percentage within five mph of the mean show the portion of the INRIX data that falls within five mph of the Bluetooth mean.

Table 7.1
Traffic Message Channel segments picked for validation in New Jersey

TYPE	TMC	HIGHWAY	DIRECTION	STARTING AT	ENDING AT	COUNTY	LENGTH (mile)
Freeways	103-04211	I 295	SOUTHBOUND	US 30/EXIT 29	HWY 168/EXIT 28	CAMDEN	1.7
	103-04213	I 295	SOUTHBOUND	MELROSE AVE/EXIT 31	WARWICK RD/EXIT 30	CAMDEN	1.1
	103-04216	I 295	SOUTHBOUND	HWY 73/EXIT 36	HWY 70/EXIT 34	CAMDEN	1.5
	103-04243	NJ TPKE	SOUTHBOUND	US 206/EXIT 7	NEW JERSEY TPKE/EXIT 6	BURLINGTON	1.7
	103-04244	NJ TPKE	SOUTHBOUND	WOODROW WILSON SERVICE AREA	US 206/EXIT 7	BURLINGTON	4.4
	103-04246	NJ TPKE	SOUTHBOUND	FRANKLIN ST/EXIT 8	I 195/EXIT 7	MERCER	6.7
	120-04305	I 80	EASTBOUND	UNION BLVD/EXIT 55	SQUIRRELWOOD RD/EXIT 56	PASSAIC	1.4
	120-04309	I 80	EASTBOUND	HOOK MOUNTAIN RD/EXIT 48	TWO BRIDGES RD/EXIT 52	ESSEX	4.6
	120-04310	I 80	EASTBOUND	US 46/EXIT 47	HOOK MOUNTAIN RD/EXIT 48	MORRIS	1.1
	120-04563	I 95	SOUTHBOUND	CRANBURY HALF ACRE RD	MERCER/MIDDLESEX CNTY LINE	MIDDLESEX	2.5
	120-04663	GARDEN STATE PKWY	SOUTHBOUND	EXIT 138	HWY 28/EXIT 137	UNION	1
	Sub-Total						**27.7**
	103+04291	I 76	EASTBOUND	I 676/EXIT 2	US 130/EXIT 1	CAMDEN	0.5
	Sub-Total						**0.5**
Total							**28.2**

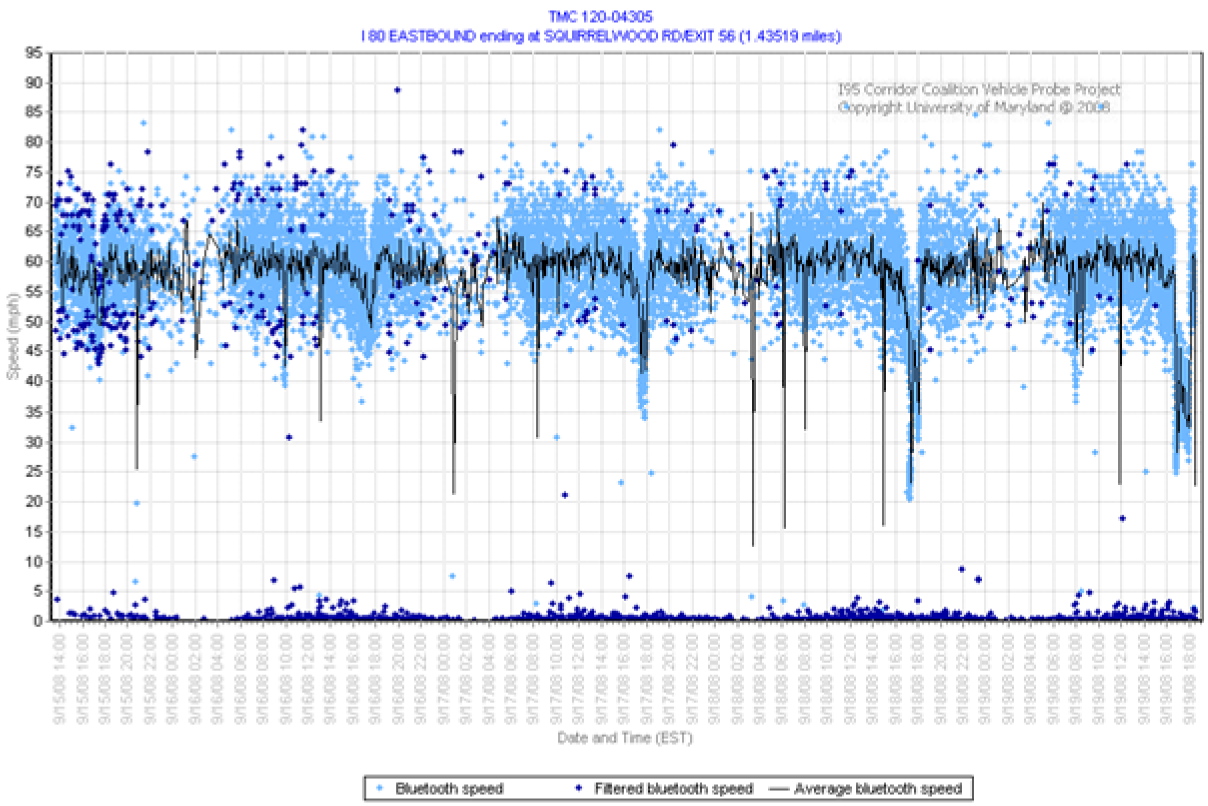


Figure 7.4
Bluetooth observations and outliers on a sample segment in New Jersey (all data)

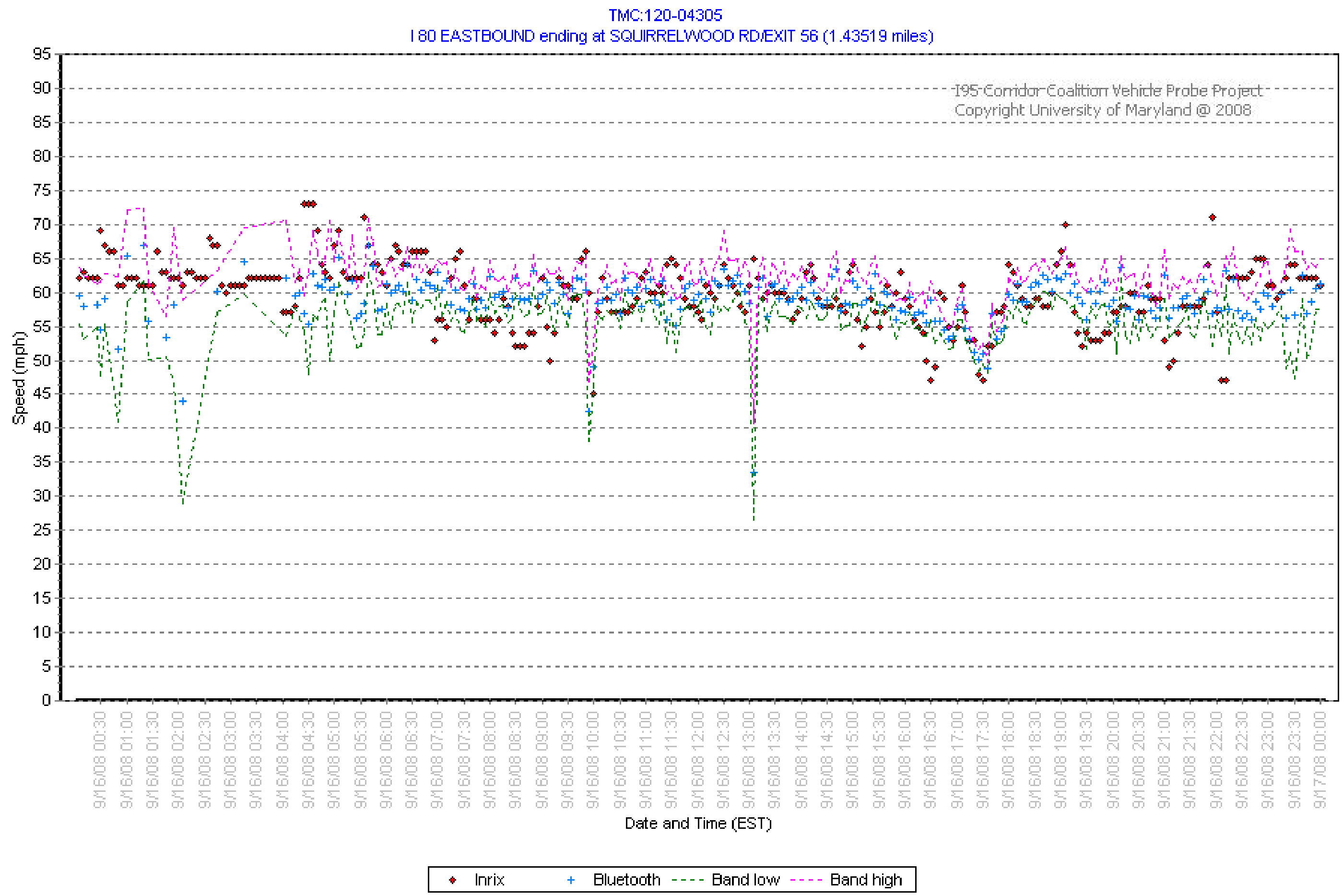


Figure 7.5
Bluetooth mean estimate and its 95% confidence band with INRIX speeds on a sample segment in New Jersey, 16 September 2008 (all data)

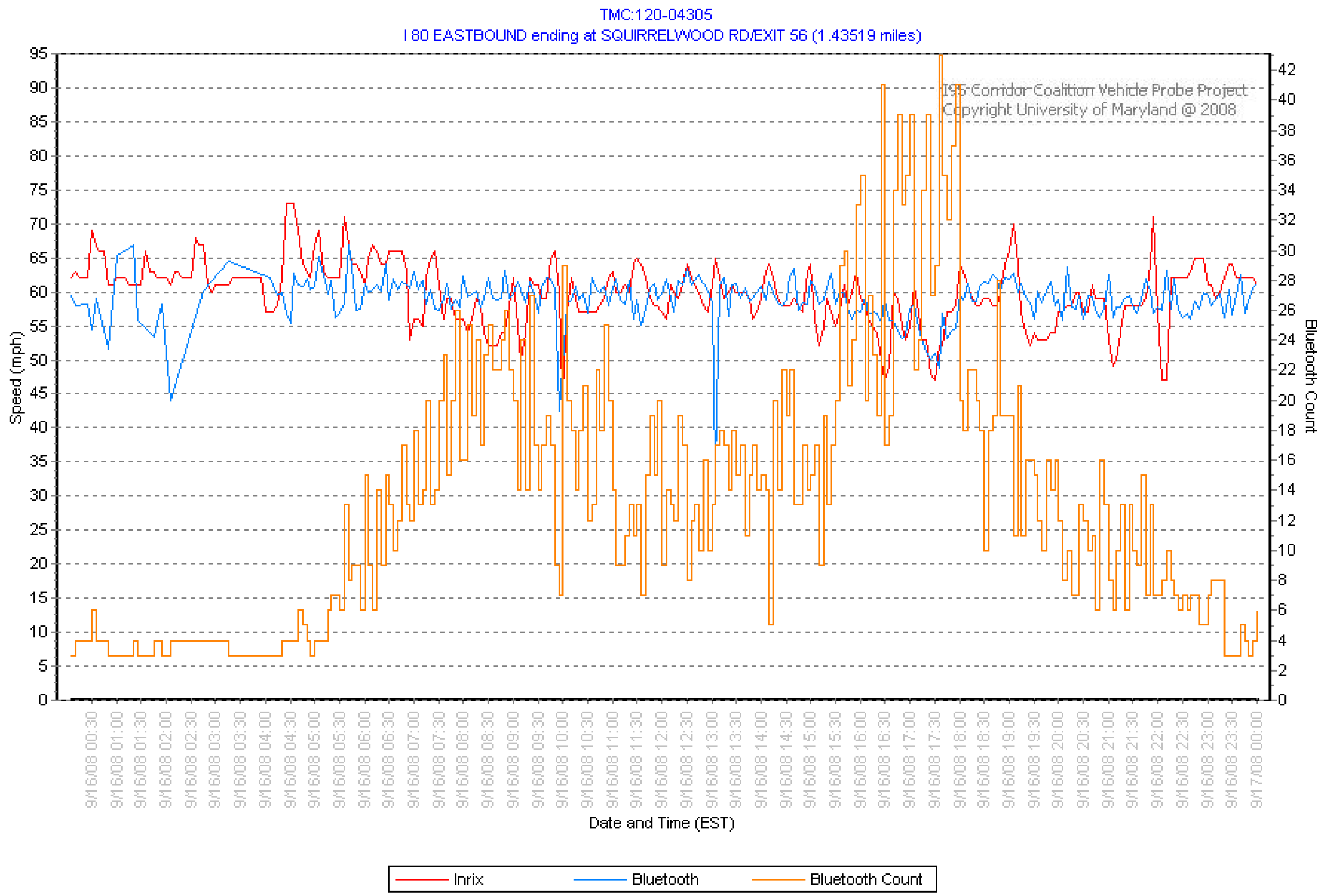


Figure 7.6
Bluetooth and INRIX speeds with number of Bluetooth observations on a sample segment in New Jersey, 16 September 2008 (all data)

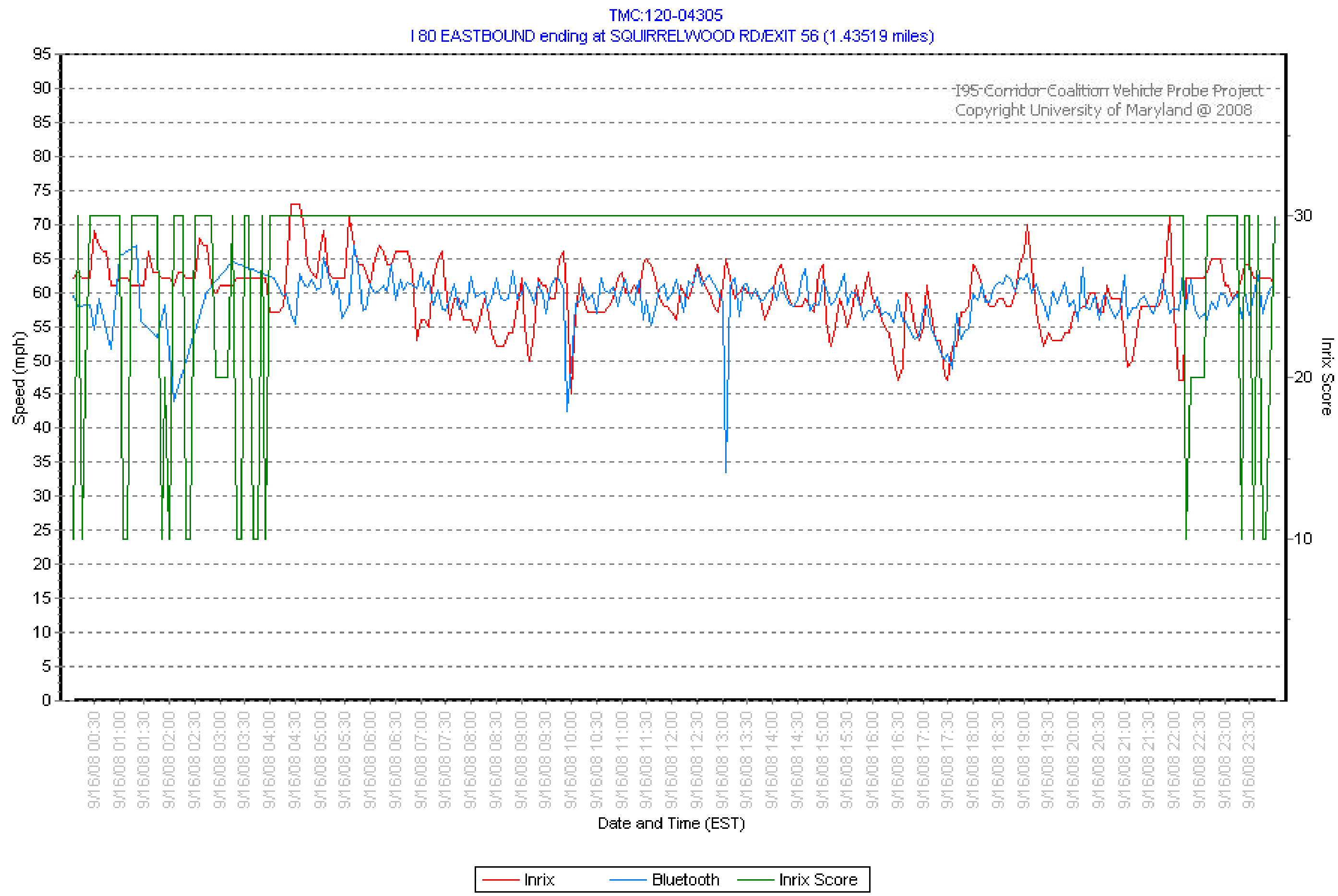


Figure 7.7
Bluetooth and INRIX speeds with the score on a sample segment in New Jersey, 16 September 2008 (all data)

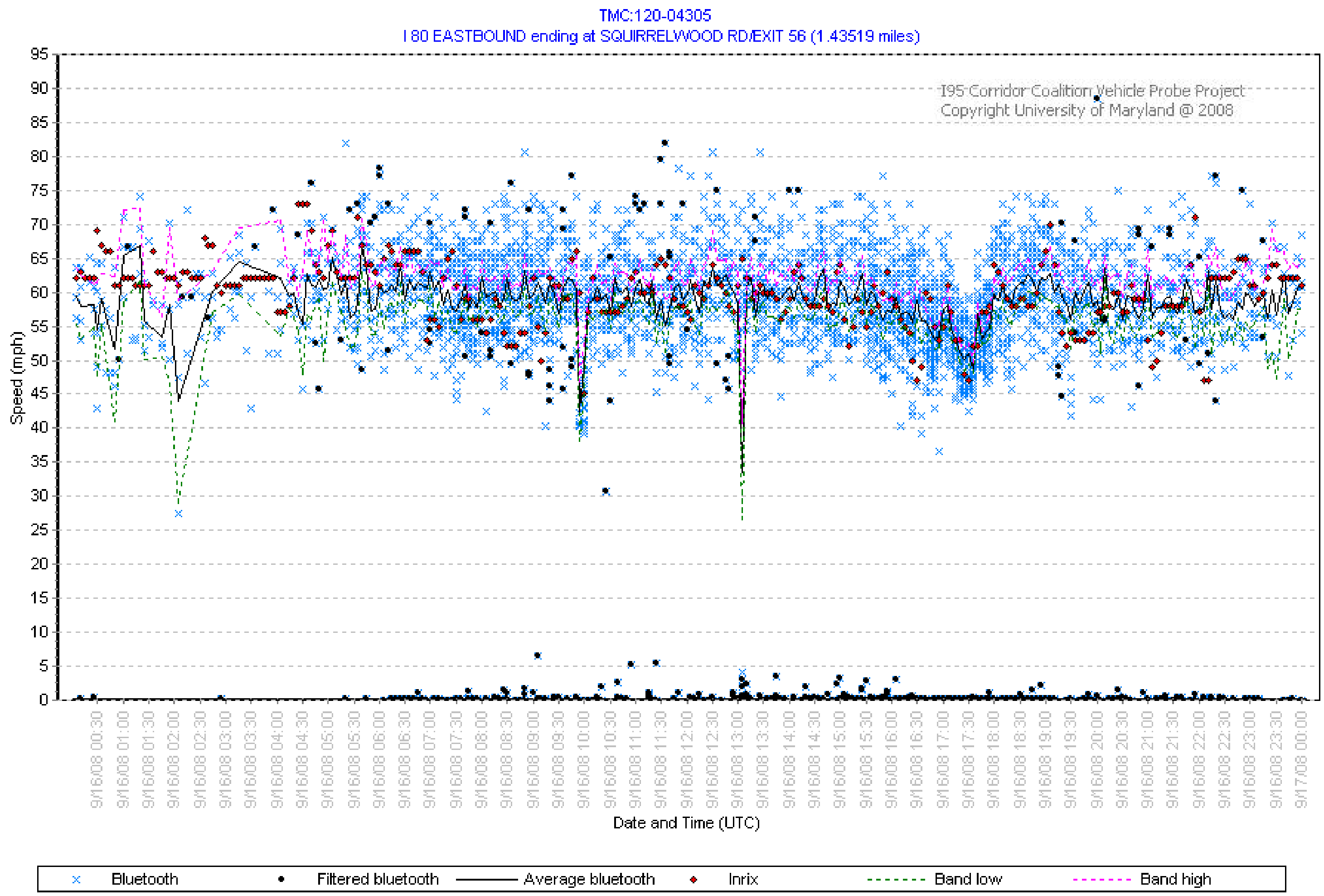


Figure 7.8
Bluetooth and INRIX speeds on a sample segment in New Jersey, 16 September 2008 (all data)

Table 7.2
Data quality measures for freeway segments in New Jersey
(all data)

SPEED BIN	Data Quality Measures for 1.96 SE Band: Speed Error Bias	1.96 SE Band: Average Absolute Speed Error	Mean: Speed Error Bias	Mean: Average Absolute Speed Error	0.25 SD Band: Speed Error Bias	0.25 SD Band: Average Absolute Speed Error	0.5 SD Band: Speed Error Bias	0.5 SD Band: Average Absolute Speed Error	No. of Obs.
0-30	8.3	9.5	10.9	12.5	9.8	11.1	8.7	9.8	79
30-45	5.3	8.3	7.6	11.6	6.6	10.1	5.7	8.6	168
45-60	0.7	2.4	1.9	4.8	1.5	3.6	1.1	2.7	1595
60+	-1.6	1.9	-3.1	4.2	-2.5	3.1	-1.9	2.3	10251

Table 7.3
Data quality measures for freeway segments greater than one mile in New Jersey
(INRIX high score)

SPEED BIN	Data Quality Measures for 1.96 SE Band: Speed Error Bias	1.96 SE Band: Average Absolute Speed Error	Mean: Speed Error Bias	Mean: Average Absolute Speed Error	0.25 SD Band: Speed Error Bias	0.25 SD Band: Average Absolute Speed Error	0.5 SD Band: Speed Error Bias	0.5 SD Band: Average Absolute Speed Error	No. of Obs.
0-30	8.3	9.5	10.9	12.5	9.8	11.1	8.7	9.8	79
30-45	5.2	8.3	7.4	11.5	6.5	10.0	5.6	8.5	166
45-60	0.4	2.3	1.3	4.6	1.0	3.4	0.7	2.5	1426
60+	-1.7	2.0	-3.2	4.3	-2.5	3.2	-1.9	2.3	9899

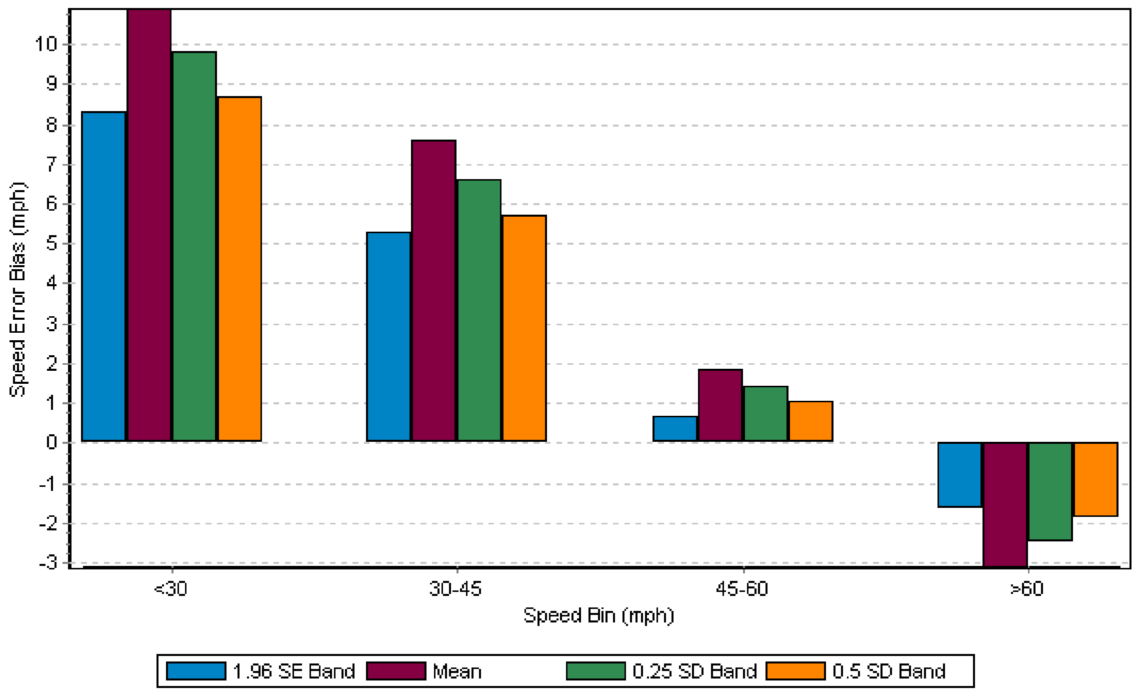


Figure 7.9
Speed error bias for freeway segments greater than one mile in New Jersey (all data)

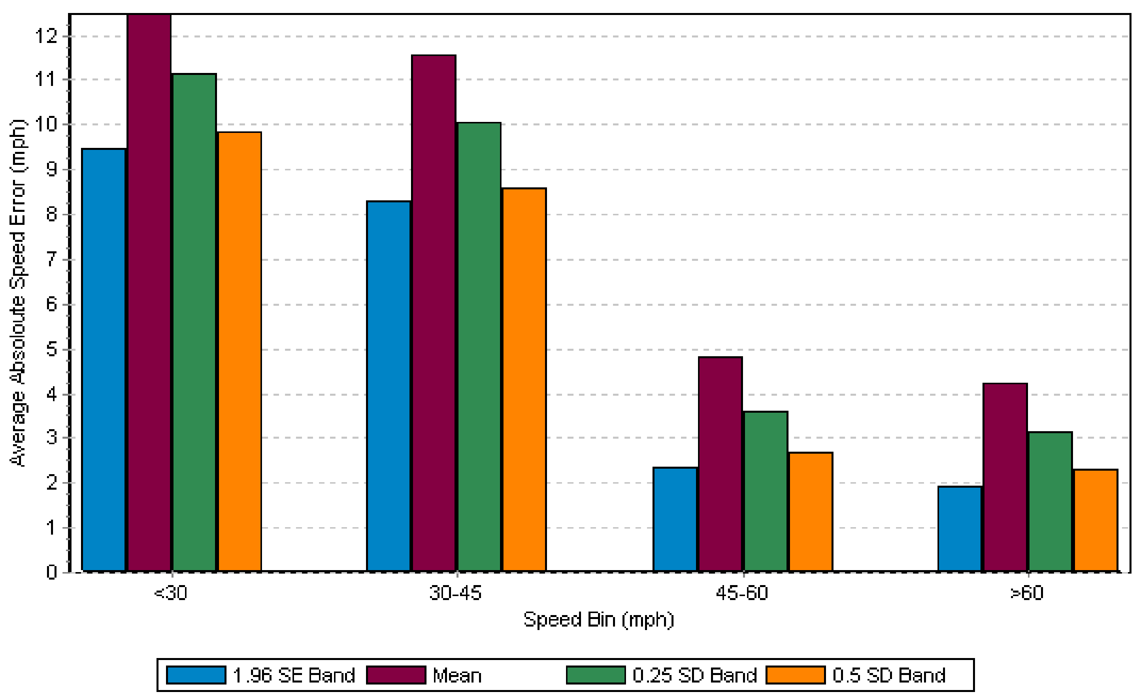


Figure 7.10
Average absolute speed error for freeway segments greater than one mile in New Jersey (all data)

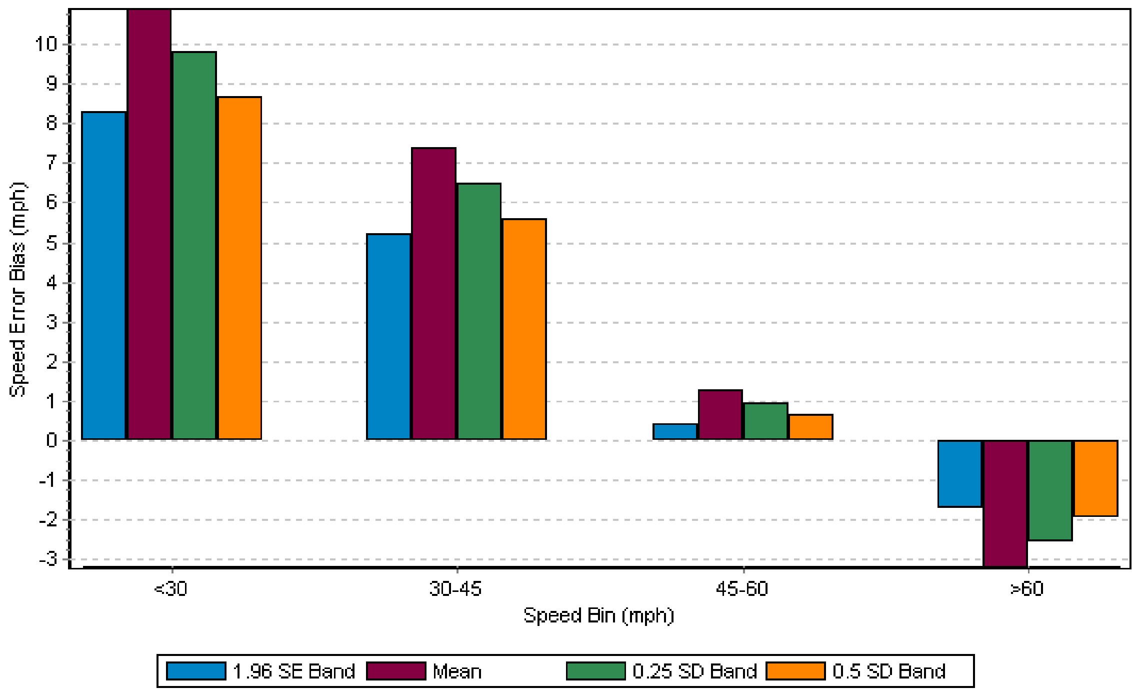


Figure 7.11
Speed error bias for freeway segments greater than one mile in New Jersey (INRIX high score)

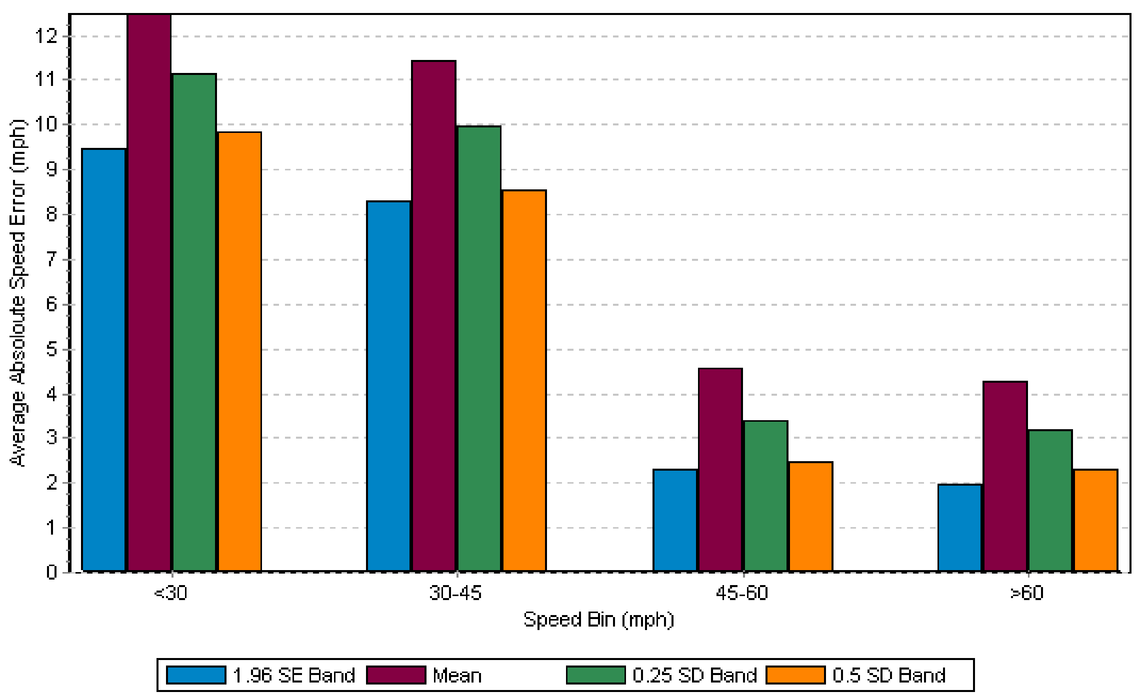


Figure 7.12
Average absolute speed error for freeway segments greater than one mile in New Jersey (INRIX high score)

Table 7.4
Percent observations meeting data quality criteria for freeway segments greater than one mile in New Jersey (all data)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Equal to Mean	Percentage within 5 mph of the Mean	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	
0-30	9%	49%	0%	46%	6%	47%	10%	51%	79
30-45	11%	38%	0%	30%	6%	34%	13%	37%	168
45-60	41%	83%	0%	60%	18%	71%	35%	80%	1595
60+	42%	88%	0%	67%	17%	78%	33%	85%	10251

Table 7.5
Percent observations meeting data quality criteria for freeway segments greater than one mile in New Jersey (INRIX high score)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Equal to Mean	Percentage within 5 mph of the Mean	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	
0-30	9%	49%	0%	46%	6%	47%	10%	51%	79
30-45	11%	38%	0%	31%	6%	34%	13%	37%	166
45-60	42%	84%	0%	64%	20%	74%	39%	82%	1426
60+	41%	88%	0%	66%	17%	77%	33%	85%	9899

7.3 *Shifted INRIX Data*

In this section results of comparisons made between Bluetooth sensor speed data and the INRIX speed data that are shifted five minutes back in time in New Jersey are reported. Table 7.6 summarizes the data quality measures obtained as a result of comparison between Bluetooth and all reported INRIX speeds, including all scores.

The comparisons made between the Bluetooth data with the corresponding INRIX speed data for which INRIX indicated high score are summarized in the Table 7.7.

Figures 7.13 and 7.14 show the overall speed error bias for different speed bins, and the average absolute speed errors for all segments in New Jersey. These figures correspond to Table 7.6. Likewise, Figures 7.15 and 7.16 show the same error measures for all segments in New Jersey for speed data for which INRIX indicated high score (score 30 as mentioned before). Figures 7.15 and 7.16 correspond to the results exhibited in Table 7.7.

Generally speaking, the five minute shift in INRIX data does not have a major impact on the data quality measures. However, the error measures in the shifted case are marginally improved as compared to the errors associated with the normal case. Again there is not much difference between the flagged speed data for which INRIX reports high score and the rest of data provided by INRIX.

Detailed data for individual TMC segments in New Jersey are presented in Appendix C. This appendix also presents the results of the evaluation of the INRIX data reported for the freeway segments that are less than one mile long.

Table 7.6
Data quality measures for freeway segments greater than one mile in New Jersey
(all data, five minute shift)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	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	6.1	7.4	8.7	10.5	7.6	9.1	6.4	7.8	79
30-45	4.3	6.4	6.6	9.6	5.6	8.1	4.6	6.7	167
45-60	0.7	2.2	1.8	4.6	1.4	3.5	1.1	2.5	1588
60+	-1.6	1.9	-3.1	4.2	-2.4	3.1	-1.9	2.2	10229

Table 7.7
Data quality measures for freeway segments greater than one mile in New Jersey
(INRIX high score, five minute shift)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	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	6.1	7.4	8.7	10.5	7.6	9.1	6.4	7.8	79
30-45	4.2	6.3	6.4	9.4	5.4	7.9	4.5	6.5	165
45-60	0.4	2.2	1.2	4.4	1.0	3.2	0.7	2.3	1403
60+	-1.7	1.9	-3.2	4.2	-2.5	3.1	-1.9	2.3	9805

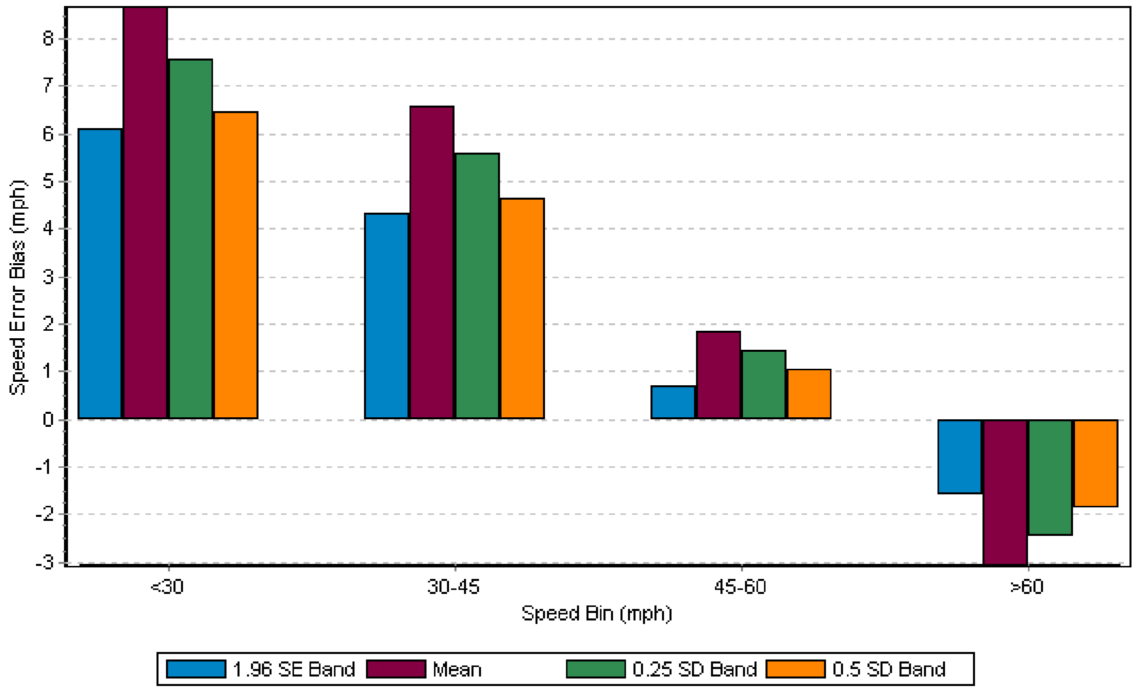


Figure 7.13
Speed error bias for freeway segments greater than one mile in New Jersey (all data, five minute shift)

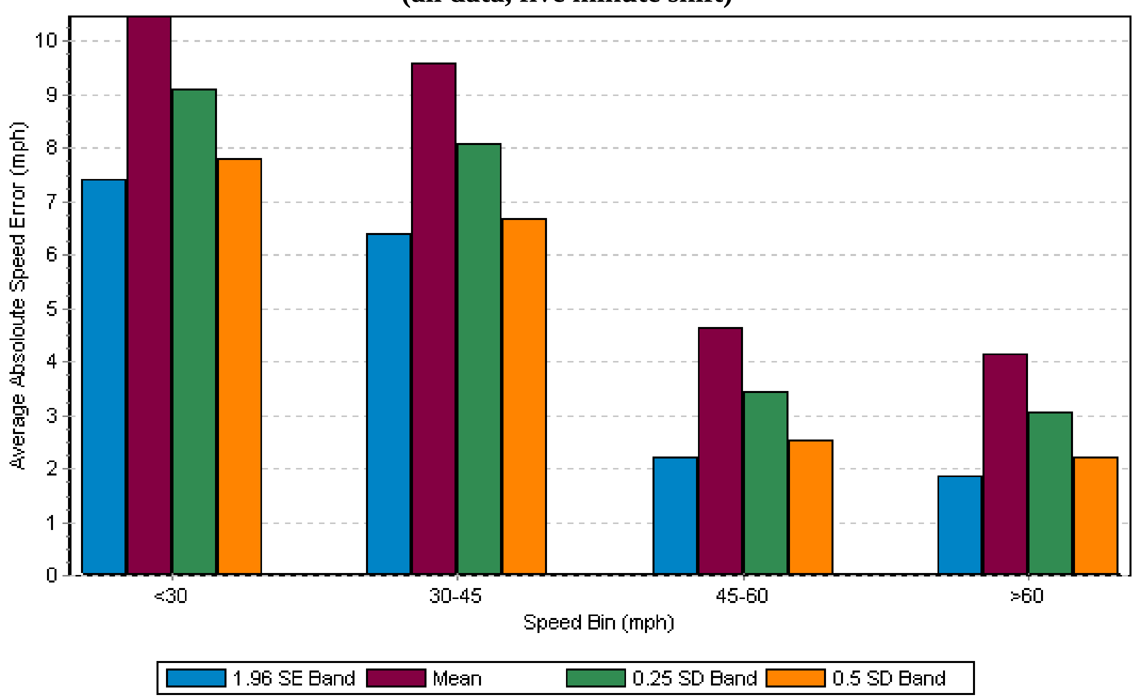


Figure 7.14
Average absolute speed error for freeway segments greater than one mile in New Jersey (all data, five minute shift)

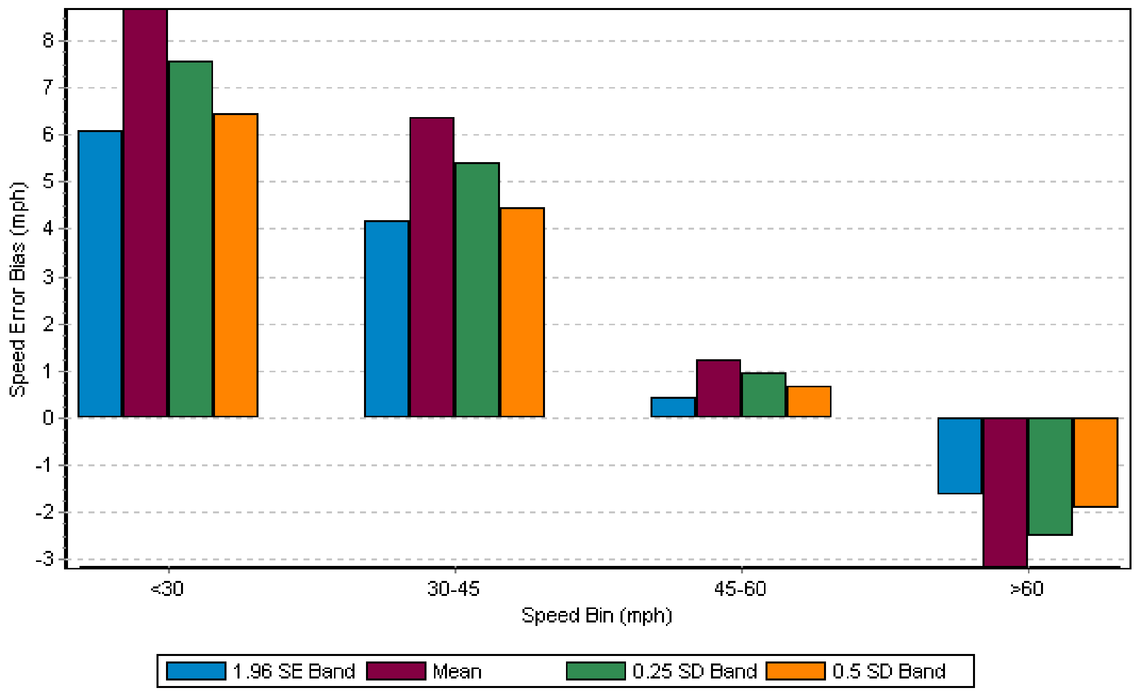


Figure 7.15
Speed error bias for freeway segments greater than one mile in New Jersey (INRIX high score, five minute shift)

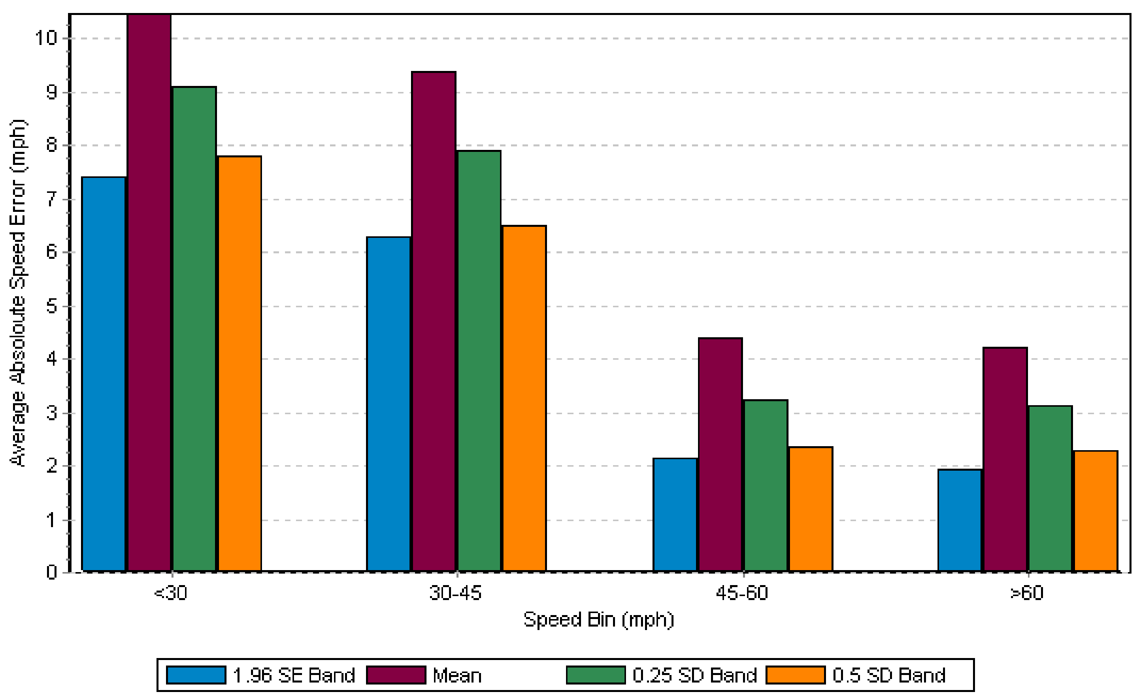


Figure 7.16
Average absolute speed error for freeway segments greater than one mile in New Jersey (INRIX high score, five minute shift)

8 Evaluation Results for the State of Virginia

8.1 *Data Collection*

Bluetooth sensor deployments in the Northern Virginia region started on the evening of Tuesday, July 22, 2008 and after some rotations of the sensors over different highway segments and directions the data collection was completed on the evening of Thursday, July 24, 2008. This initial round of data collections in Virginia was designed to cover segments of the main highways in and around the Capital Beltway area along which both recurrent and non-recurrent congestions could be expected during both peak and off-peak periods. Highways on which data collection was performed are the following: I-95 south of the beltway to VA-610 Garrisonville road, I-395 north of the mixing bowl, inside the beltway to Seminary road, I-495 east of the mixing bowl to Telegraph road, VA-650 Gallows road to GW Memorial Parkway, and I-66 west of the beltway to VA-123 Chain Bridge road.

Figures 8.1 through 8.3 present snapshots of the corridors in which Bluetooth sensors were deployed in Northern Virginia.

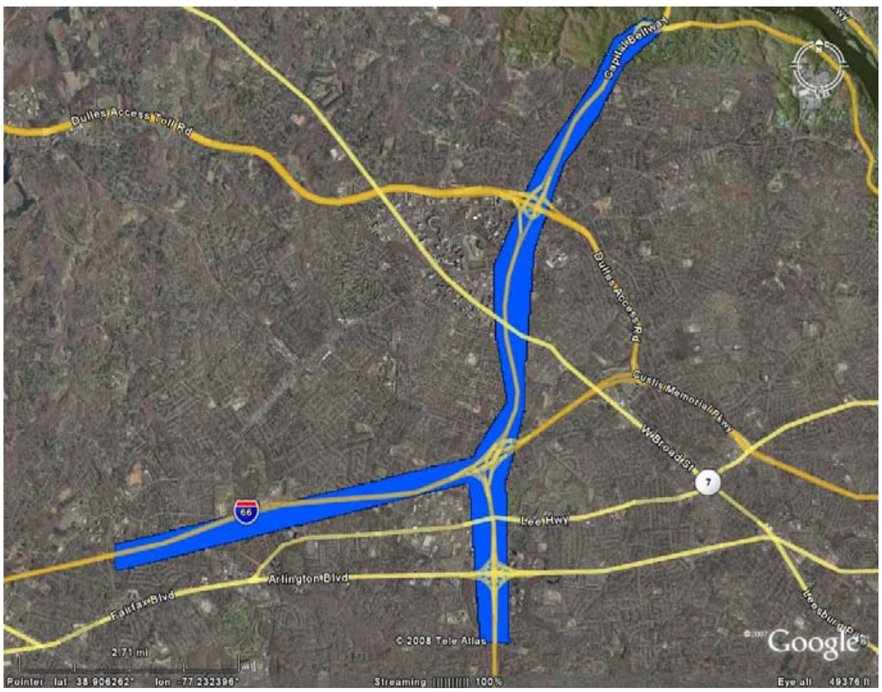


Figure 8.1
TMC segments selected for validation in Northern Virginia, west of capital beltway and I-66

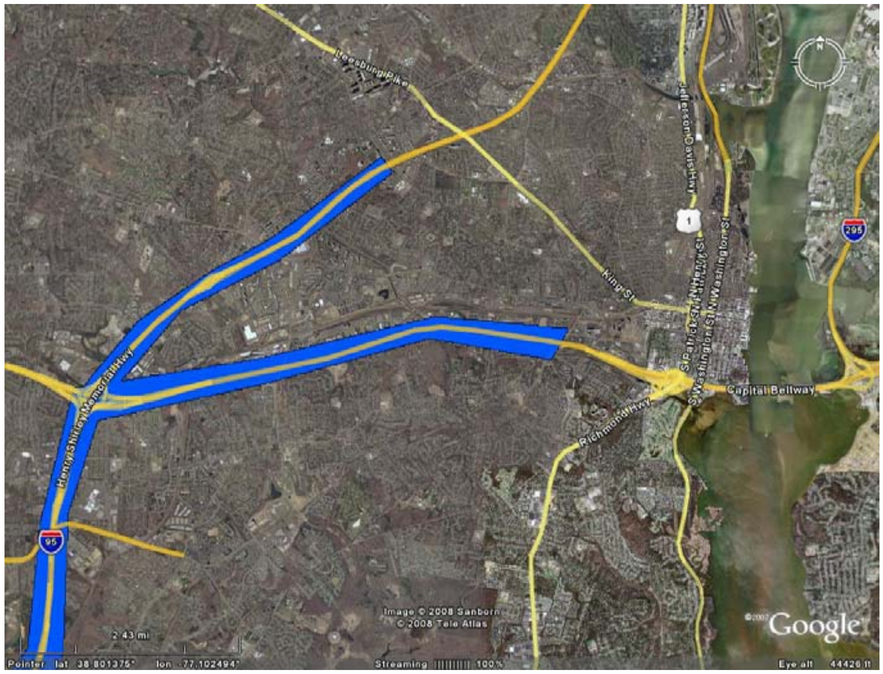


Figure 8.2
TMC segments selected for validation in Northern Virginia, south of capital beltway and I-395

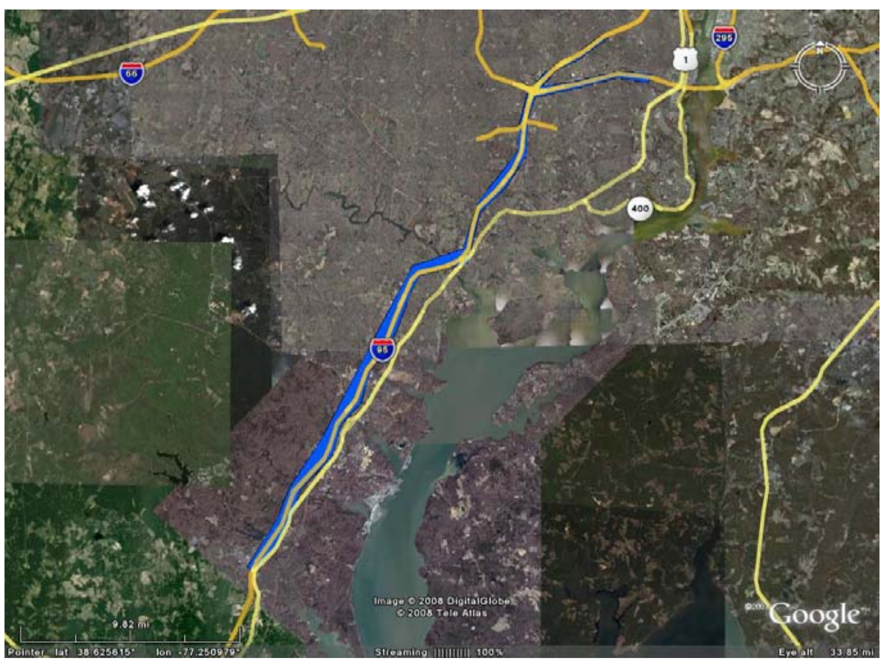


Figure 8.3
TMC segments selected for validation in Northern Virginia, I-95 south of Washington, D.C.

The coordinates of the locations at which the Bluetooth sensors were deployed throughout Northern Virginia are reported in Table D.1 in Appendix D. Table D.1 also presents the distances that have been used in estimation of Bluetooth speeds based on travel times. Table 8.1 presents a list of specific TMC segments which were selected as the validation sample in Northern Virginia. In total, results of validation on 24 TMC freeway segments are presented in this report. These segments cover a total length of over 38 miles. Out of 24 freeway segments under consideration, 18 segments are longer than one mile.

8.2 *Analysis of Results*

This section presents the data quality comparisons for Northern Virginia. First, a series of graphs showing the Bluetooth observations on one of the segments in Northern Virginia are presented. These graphs provide a qualitative basis for comparison between INRIX speed data and the estimated Bluetooth speeds.

Figure 8.4 shows every single Bluetooth speed estimate at every time interval on segment 110-04177. Figure 8.4 also highlights the observations that are deemed as outliers during the application of the filtering methodology that was explained earlier. The remaining observations are then used to obtain the mean estimate of speed at each time interval.

A 24 hour slice of data on this segment for July 24, 2008 is shown in Figure 8.5 that incorporates the mean Bluetooth speed estimate along with the 95% confidence interval band of the estimate as well as the corresponding INRIX speeds. Figure 8.5 provides a visual aid to observe the overall behavior of INRIX data compared to Bluetooth speeds.

Figures 8.6 and 8.7 demonstrate the trends of both Bluetooth and INRIX speeds over the same time period on the same segment. Figure 8.6 includes the number of Bluetooth observations used in the speed estimation for each five minute interval and Figure 8.7 shows the reported scores for INRIX speeds.

In Figure 8.8, all individual Bluetooth speed observations (outliers and non-outliers identified with different colors), the mean speed estimate and its associated 95% confidence interval band, as well as the INRIX data are presented in one place to give a better picture of the raw data as well as the final outcomes of the analysis versus the INRIX speeds.

These graphs are produced for each TMC and all graphs for the segments picked for validation in Northern Virginia are included in the CD-ROM that accompanies this report.

Table 8.1
Traffic Message Channel segments picked for validation in Virginia

TYPE	TMC	HIGHWAY	DIRECTION	STARING AT	ENDING AT	COUNTY	LENGTH (mile)
Freeways	**110+04122**	I 395	NORTHBOUND	EDSALL RD/EXIT 2	HWY 236/DUKE ST/EXIT 3	ALEXANDRIA	1.2
	110+04609	I 495	CLOCKWISE	I 66/EXIT 9	HWY 7/LEESBURG PIKE/EXIT 10	FAIRFAX	1.2
	110+04612	I 495	CLOCKWISE	HWY 267/EXIT 12	HWY 193/GEORGETOWN PIKE/EXIT 13	FAIRFAX	1.1
	110-04646	I 495	COUNTERCLOCKWISE	EISENHOWER AVE/EXIT 3	HWY 241/TELEGRAPH RD/EXIT 2	ALEXANDRIA	1.1
	110+04176	I 66	WESTBOUND	I 495/EXIT 64	HWY 243/NUTLEY ST/EXIT 62	FAIRFAX	1.3
	110+04178	I 66	WESTBOUND	VADEN DR/EXIT 62	HWY 123/EXIT 60	FAIRFAX	1.2
	110-04175	I 66	EASTBOUND	HWY 243/NUTLEY ST/EXIT 62	I 495/EXIT 64	FAIRFAX	1.4
	110-04177	I 66	EASTBOUND	HWY 123/EXIT 60	VADEN DR/EXIT 62	FAIRFAX	1.2
	110+04146	I 95	NORTHBOUND	EXIT 150	RUSSELL RD/EXIT 148	PRINCE WILLIAM	4.0
	110+04147	I 95	NORTHBOUND	HWY 234/EXIT 152	EXIT 150	PRINCE WILLIAM	1.7
	110+04148	I 95	NORTHBOUND	EXIT 150	HWY 234/EXIT 152	PRINCE WILLIAM	1.9
	110+04154	I 95	NORTHBOUND	US 1/EXIT 161	EXIT 163	FAIRFAX	1.4
	110+04155	I 95	NORTHBOUND	EXIT 163	HWY 7100/EXIT 166	FAIRFAX	2.4
	110-04145	I 95	SOUTHBOUND	RUSSELL RD/EXIT 148	US 1/HWY 610/EXIT 143	STAFFORD	4.1
	110-04146	I 95	SOUTHBOUND	EXIT 150	RUSSELL RD/EXIT 148	PRINCE WILLIAM	1.9
	110-04147	I 95	SOUTHBOUND	HWY 234/EXIT 152	EXIT 150	PRINCE WILLIAM	1.9
	110-04153	I 95	SOUTHBOUND	EXIT 163	US 1/EXIT 161	FAIRFAX	1.8
	110-04154	I 95	SOUTHBOUND	HWY 7100/EXIT 166	EXIT 163	FAIRFAX	2.6
	Sub-Total						**33.4**
	110+04123	I 395	NORTHBOUND	HWY 236/DUKE ST/EXIT 3	SEMINARY RD/EXIT 4	ALEXANDRIA	0.9
	110-04121	I 395	SOUTHBOUND	HWY 236/DUKE ST/EXIT 3	EDSALL RD/EXIT 2	FAIRFAX	0.9
	110-04122	I 395	SOUTHBOUND	SEMINARY RD/EXIT 4	HWY 236/DUKE ST/EXIT 3	ALEXANDRIA	0.8
	110+04613	I 495	CLOCKWISE	HWY 193/GEORGETOWN PIKE/EXIT 13	GW MEMORIAL PKWY/EXIT 14	FAIRFAX	0.5
	110-04647	I 495	COUNTERCLOCKWISE	VAN DORN ST/EXIT 3	EISENHOWER AVE/EXIT 3	ALEXANDRIA	0.8
	110-04648	I 495	COUNTERCLOCKWISE	I 95/EXIT 57	VAN DORN ST/EXIT 3	FAIRFAX	0.8
	Sub-Total						**4.8**
Total							**38.2**

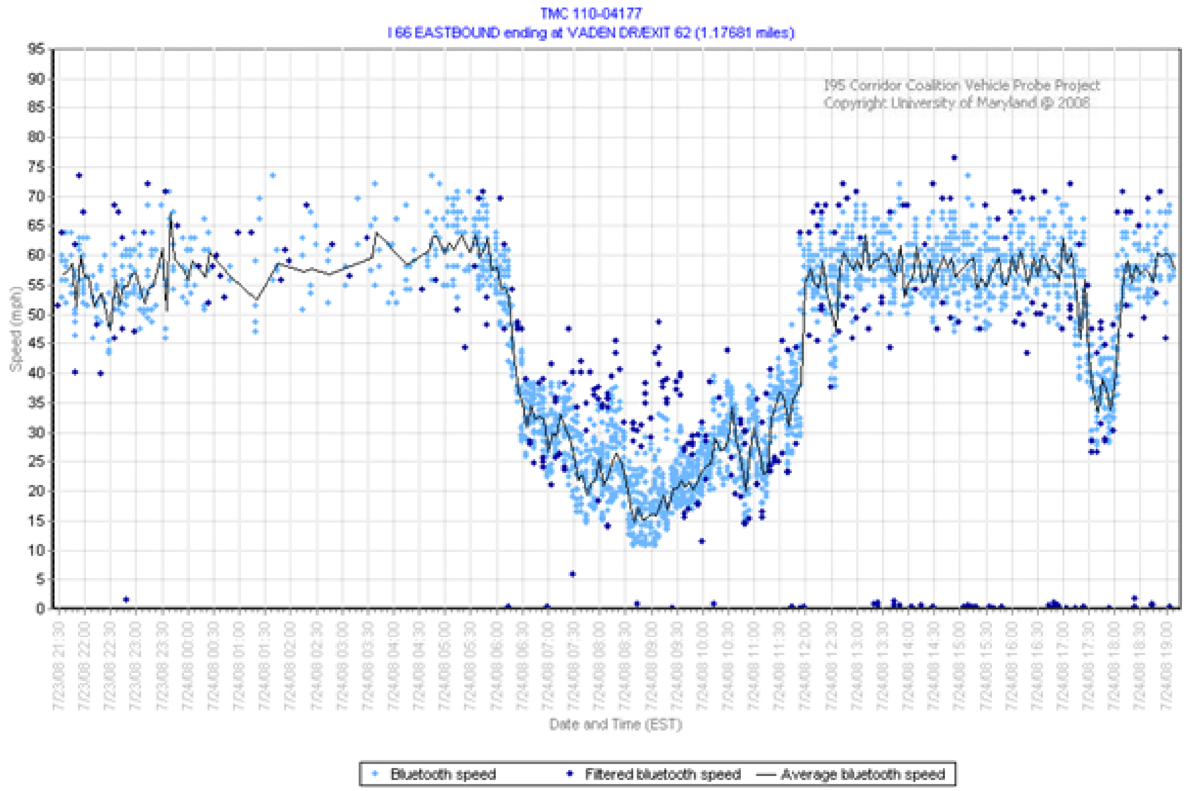


Figure 8.4
Bluetooth observations and outliers on a sample segment in Virginia (all data)

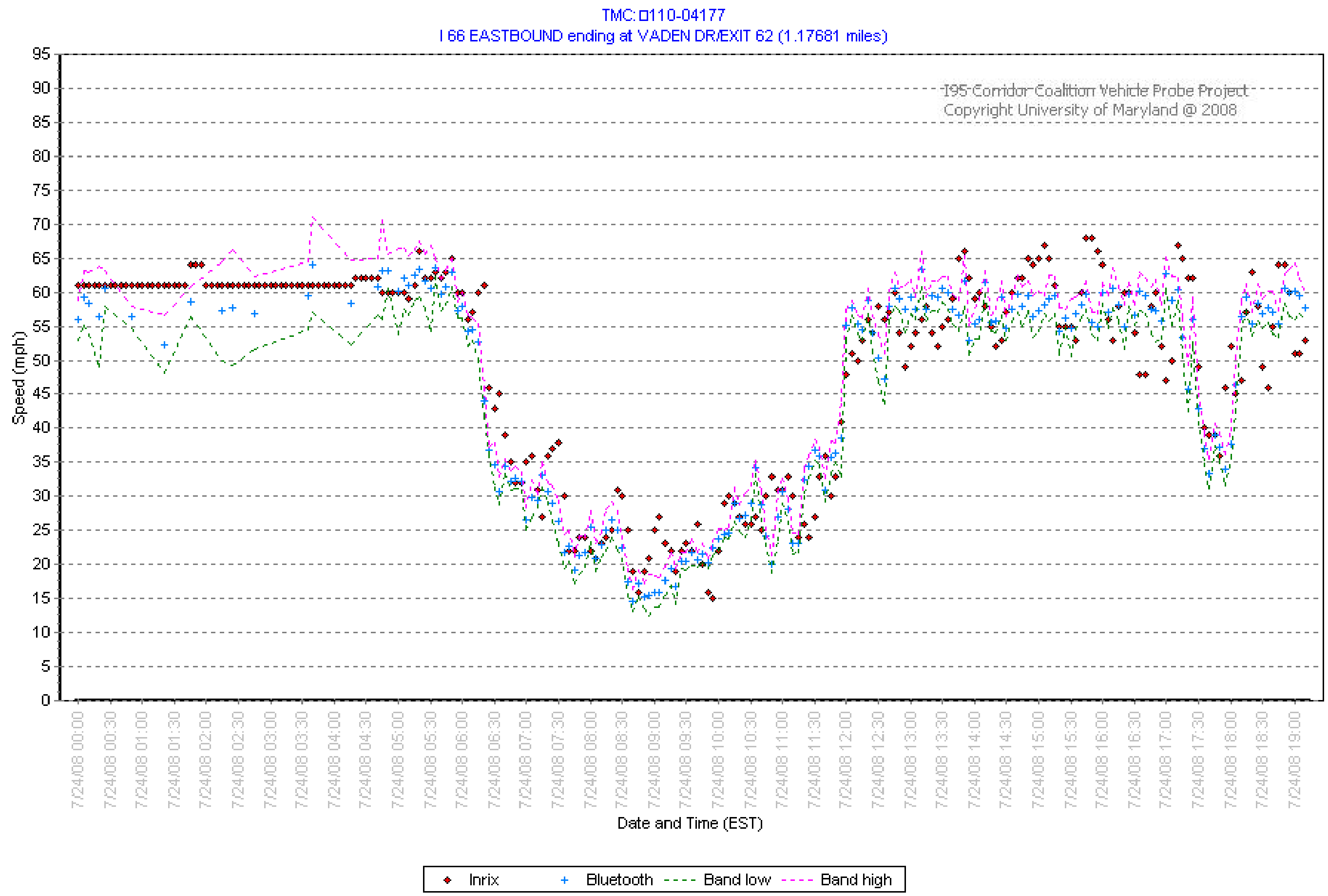


Figure 8.5
Bluetooth mean estimate and its 95% confidence band with INRIX speeds on a sample segment in Virginia, 24 July 2008 (all data)

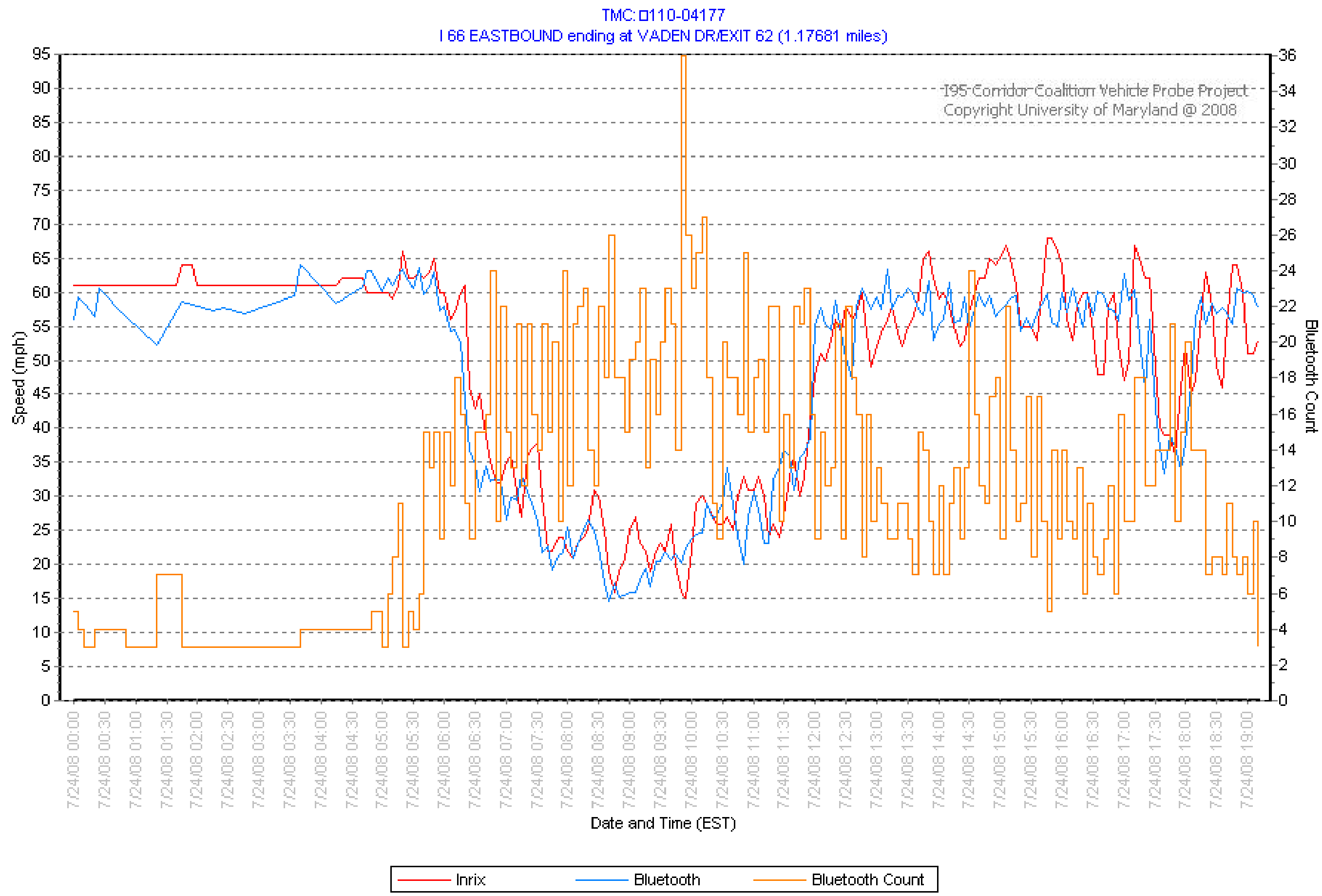


Figure 8.6
Bluetooth and INRIX speeds with number of Bluetooth observations on a sample segment in Virginia, 24 July 2008 (all data)

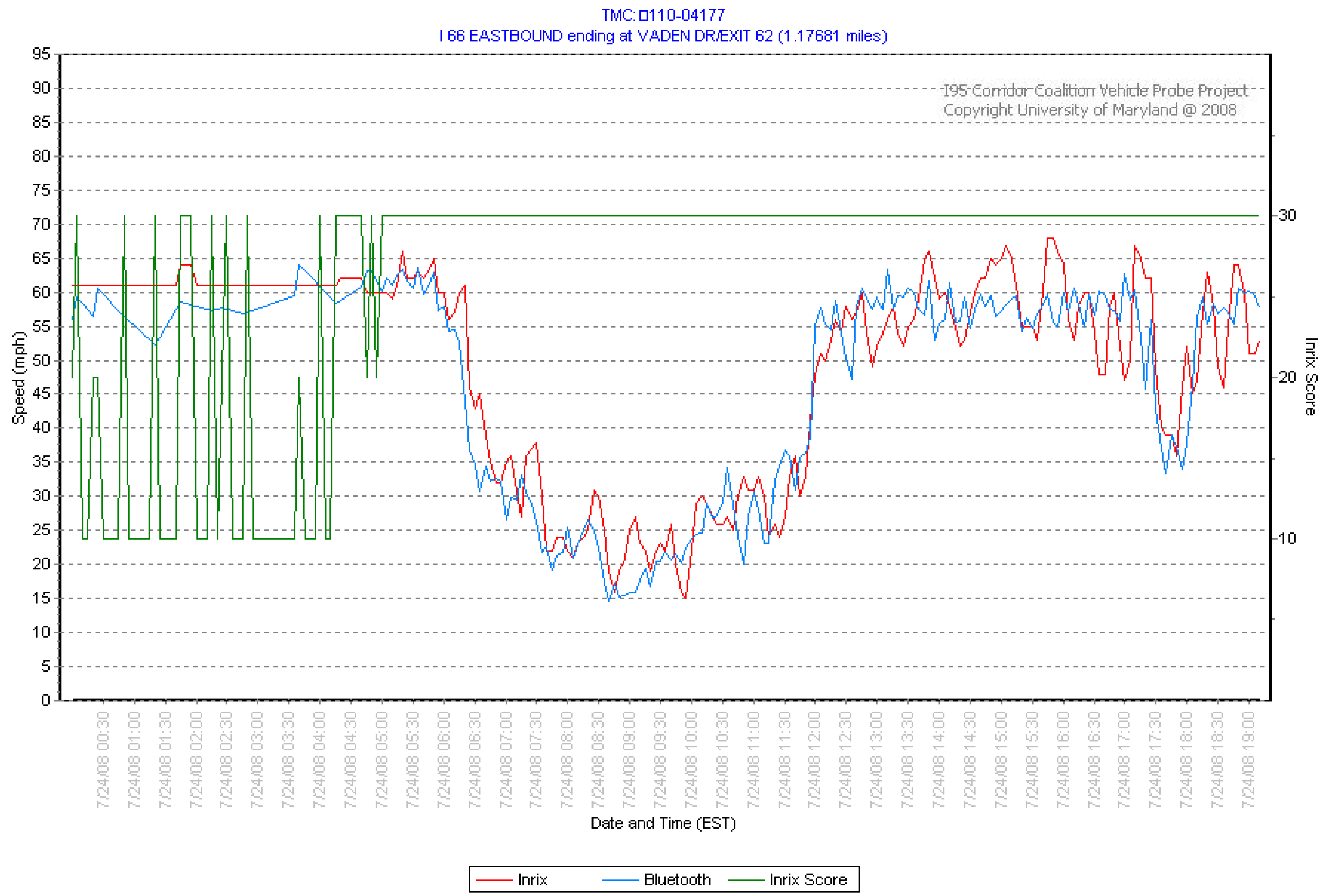


Figure 8.7
Bluetooth and INRIX speeds with the score on a sample segment in Virginia, 24 July 2008 (all data)

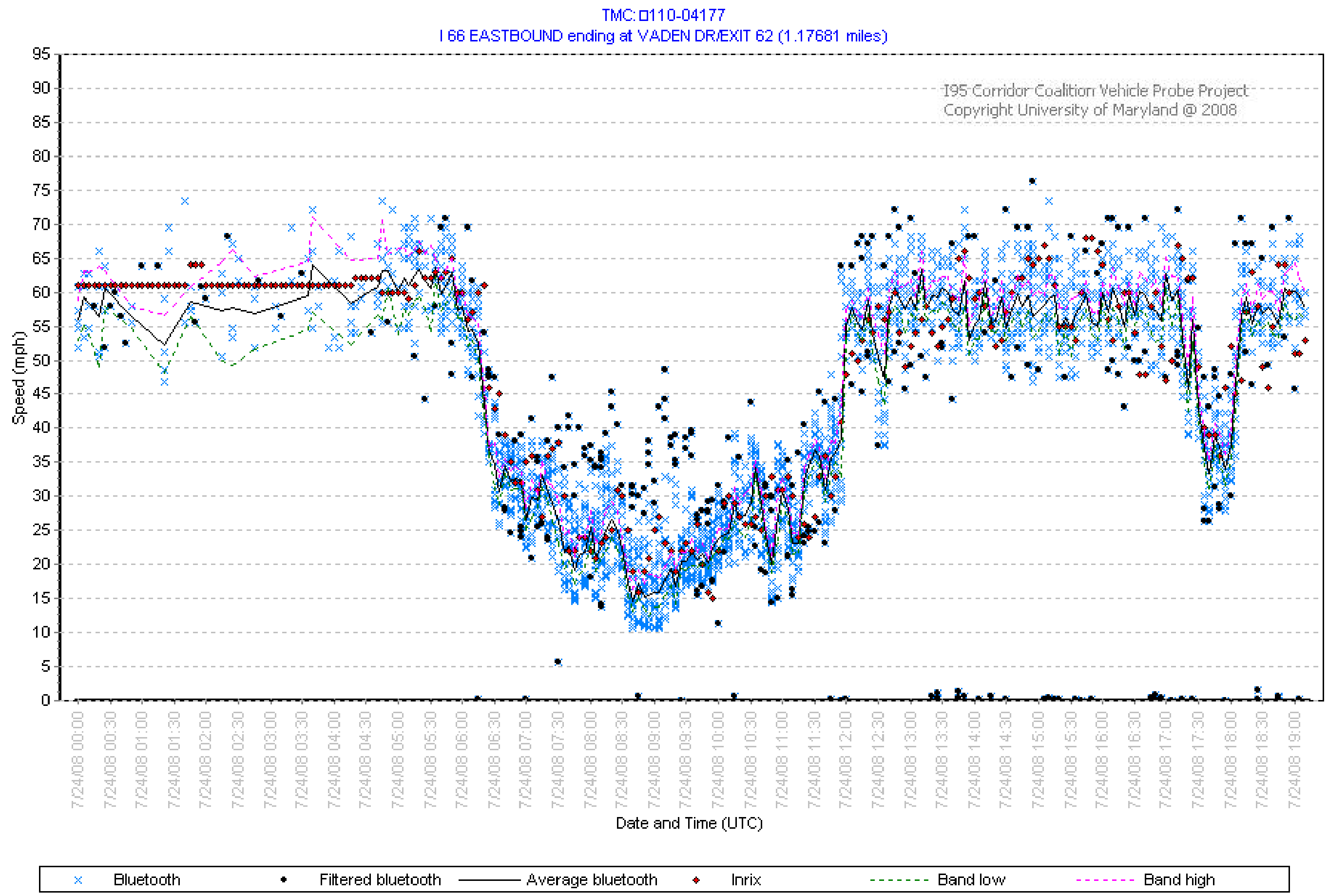


Figure 8.8
Bluetooth and INRIX speeds on a sample segment in Virginia, 24 July 2008 (all data)

Table 8.2 summarizes the data quality measures obtained as a result of comparison between Bluetooth and all reported INRIX speeds, including all scores.

The comparisons between the Bluetooth data with the corresponding INRIX speed data for which INRIX indicated high score are summarized in the Table 8.3.

In all speed bins and for all bands around the Bluetooth mean speed estimates, INRIX data passes the data quality measures set forth by the contract by a noticeable margin. Considering the high score INRIX data alone, the results of the analysis are essentially the same.

Figures 8.9 and 8.10 show the overall speed error bias for different speed bins, and the average absolute speed errors for all segments in Northern Virginia, respectively. These figures correspond to Table 8.2. Likewise, Figures 8.11 and 8.12 show the same error measures for all segments in Northern Virginia for speed data for which INRIX indicated high score (score 30 as mentioned before). Figures 8.11 and 8.12 correspond to the results exhibited in Table 8.3.

Table 8.4 shows the percentage of the time intervals that have met the data quality requirements as described in the contract for each speed bin for all TMCs in Northern Virginia. Table 8.5 presents the same information when high score INRIX data has been used in the evaluations.

In both tables 8.4 and 8.5 the columns that show the percentage falling inside the band represent the percentage of the time intervals for which INRIX provides travel time and speed data that falls inside the corresponding band as described in section 4.2.4. The columns that show the percentage within five mph of the band represent the percentage of the INRIX data that lay within five mph of the band including the data points that fall inside the corresponding band. When comparing to the mean of the Bluetooth data, numbers in the percentage equal to mean column show the percentage of the INRIX observations that are exactly equal to their corresponding Bluetooth observation and the percentage within five mph of the mean show the portion of the INRIX data that falls within five mph of the Bluetooth mean.

8.3 *Shifted INRIX Data*

In this section, results of comparisons made between Bluetooth sensor speed data and INRIX speed data that were shifted five minutes back in time in Northern Virginia are reported. Table 8.6 summarizes the data quality measures obtained as a result of comparison between Bluetooth and all reported INRIX speeds, including all scores.

The comparisons made between the Bluetooth data with the corresponding INRIX speed data for which INRIX indicated high score are summarized in the Table 8.7.

Figures 8.13 and 8.14 show the overall speed error bias for different speed bins, and the average absolute speed errors for all segments in Northern Virginia. These figures correspond to Table 8.6. Likewise, Figures 8.15 and 8.16 show the same error measures for all segments in Northern Virginia for speed data for which INRIX indicated high score (score 30 as mentioned before). Figures 8.15 and 8.16 correspond to the results exhibited in Table 8.7.

Generally speaking, the five minute shift in INRIX data does not have a major impact on the data quality measures. Again there is not much difference between speed data flagged for which INRIX reports high score and the rest of data provided by INRIX.

Table 8.2
Data quality measures for freeway segments greater than one mile in Northern Virginia (all data)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	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	2.2	4.1	2.6	5.3	2.4	4.7	2.2	4.1	200
30-45	1.4	5.7	1.7	7.4	1.6	6.6	1.5	5.8	291
45-60	0.2	2.9	0.9	5.2	0.7	4.2	0.5	3.3	1046
60+	-1.6	2.2	-2.8	4.3	-2.3	3.4	-1.9	2.7	1220

Table 8.3
Data quality measures for freeway segments greater than one mile in Northern Virginia (INRIX high score)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	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	2.2	4.1	2.6	5.3	2.4	4.7	2.2	4.1	200
30-45	1.4	5.7	1.7	7.4	1.6	6.6	1.5	5.8	291
45-60	-0.2	2.9	0.3	5.1	0.2	4.1	0.1	3.2	919
60+	-1.7	2.3	-2.9	4.4	-2.4	3.5	-1.9	2.8	1140

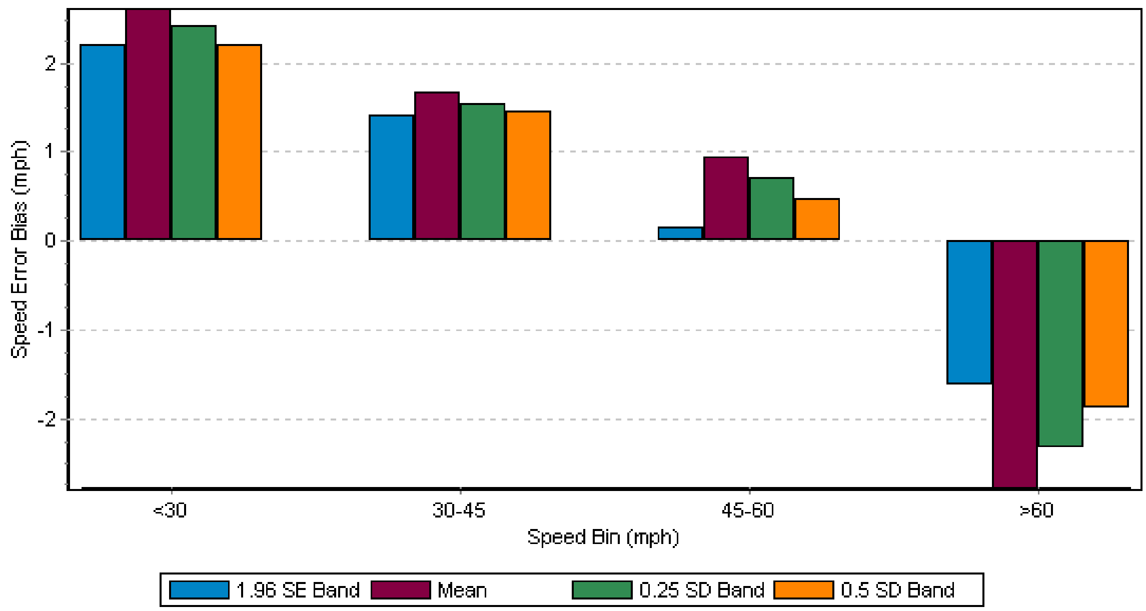


Figure 8.9
Speed error bias for freeway segments greater than one mile in Northern Virginia (all data)

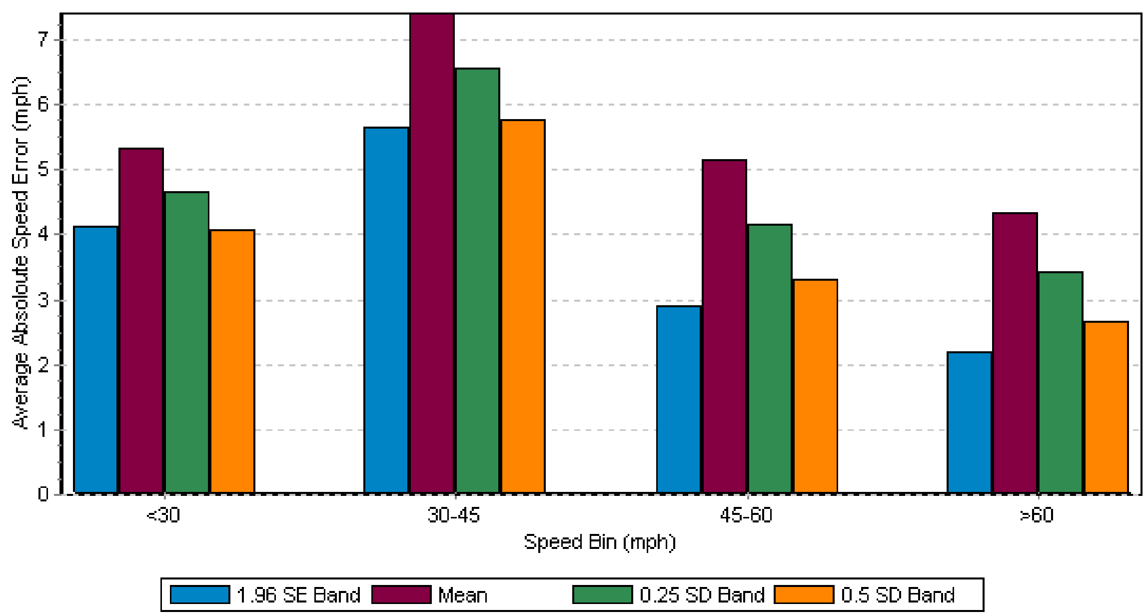


Figure 8.10
Average absolute speed error for freeway segments greater than one mile in Northern Virginia (all data)

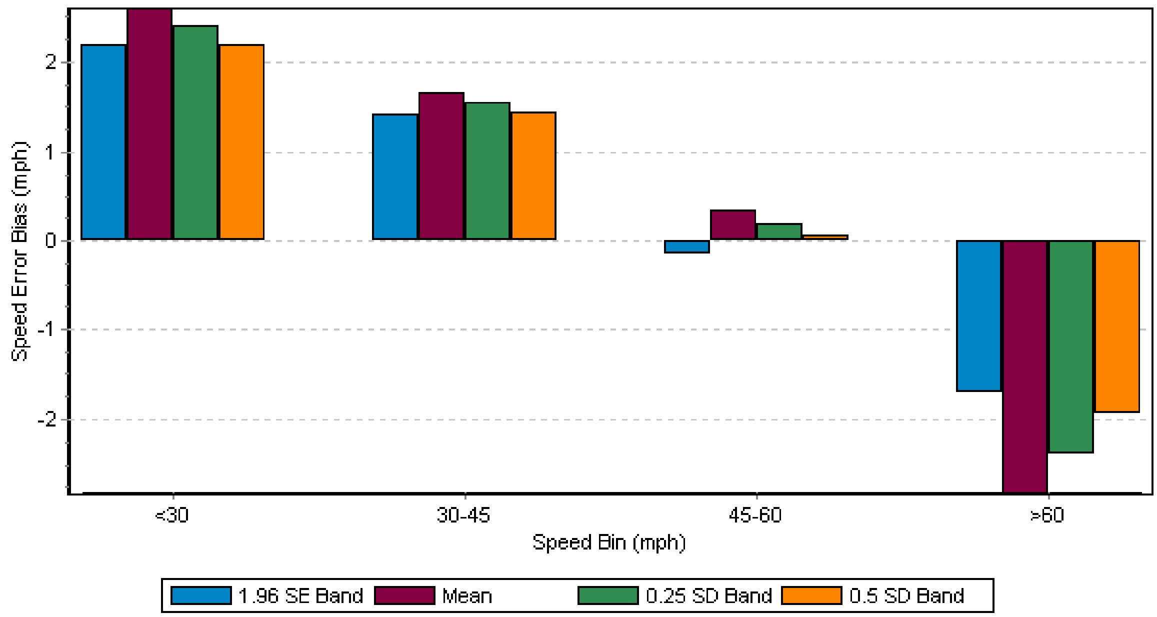


Figure 8.11
Speed error bias for freeway segments greater than one mile in Northern Virginia (INRIX high score)

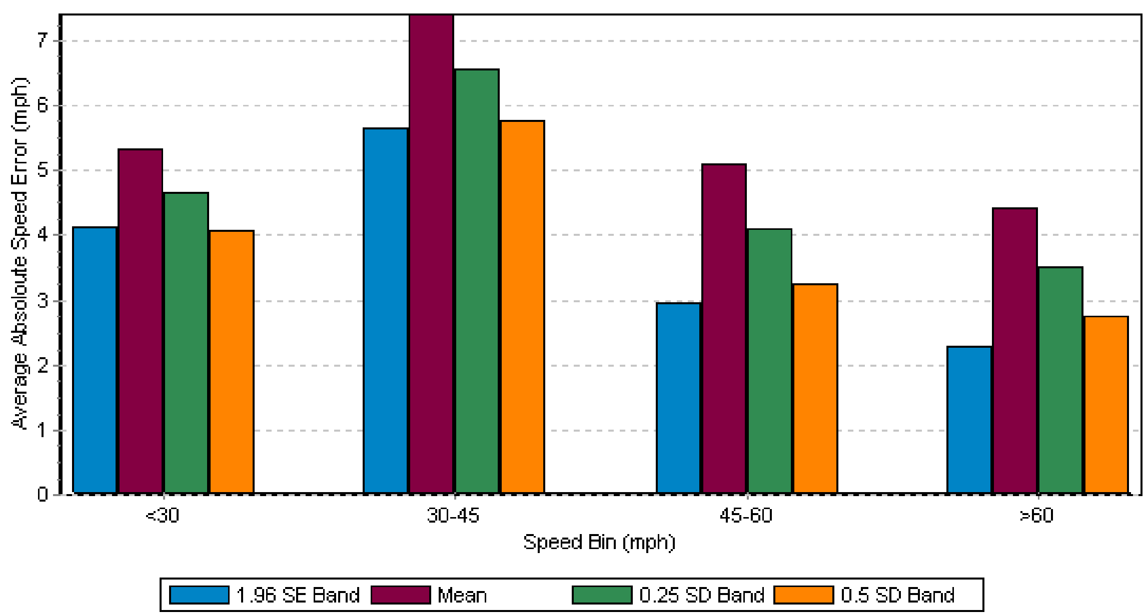


Figure 8.12
Average absolute speed error for freeway segments greater than one mile in Northern Virginia (INRIX high score)

Table 8.4
Percent observations meeting data quality criteria for freeway segments greater than one mile in Northern Virginia (all data)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Equal to Mean	Percentage within 5 mph of the Mean	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	
0-30	20%	75%	0%	69%	12%	73%	22%	75%	200
30-45	14%	56%	0%	42%	6%	49%	13%	54%	291
45-60	33%	80%	0%	58%	13%	68%	26%	76%	1046
60+	44%	84%	0%	65%	18%	74%	31%	80%	1220

Table 8.5
Percent observations meeting data quality criteria for freeway segments greater than one mile in Northern Virginia (INRIX high score)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Equal to Mean	Percentage within 5 mph of the Mean	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	
0-30	20%	75%	0%	69%	12%	73%	22%	75%	200
30-45	14%	56%	0%	42%	6%	49%	13%	54%	291
45-60	33%	79%	0%	60%	14%	69%	27%	76%	919
60+	42%	83%	0%	64%	17%	73%	30%	79%	1140

Table 8.6
Data quality measures for freeway segments greater than one mile in Northern Virginia (all data, five minute shift)

SPEED BIN	Data Quality Measures for: 1.96 SE Band: Speed Error Bias	1.96 SE Band: Average Absolute Speed Error	Mean: Speed Error Bias	Mean: Average Absolute Speed Error	0.25 SD Band: Speed Error Bias	0.25 SD Band: Average Absolute Speed Error	0.5 SD Band: Speed Error Bias	0.5 SD Band: Average Absolute Speed Error	No. of Obs.
0-30	1.6	3.3	1.9	4.5	1.7	3.9	1.5	3.3	200
30-45	1.0	5.1	1.2	6.8	1.1	6.0	1.0	5.2	291
45-60	0.4	2.8	1.2	5.0	0.9	4.0	0.7	3.2	1046
60+	-1.6	2.2	-2.8	4.3	-2.4	3.4	-1.9	2.7	1220

Table 8.7
Data quality measures for freeway segments greater than one mile in Northern Virginia (INRIX high score, five minute shift)

SPEED BIN	Data Quality Measures for: 1.96 SE Band: Speed Error Bias	1.96 SE Band: Average Absolute Speed Error	Mean: Speed Error Bias	Mean: Average Absolute Speed Error	0.25 SD Band: Speed Error Bias	0.25 SD Band: Average Absolute Speed Error	0.5 SD Band: Speed Error Bias	0.5 SD Band: Average Absolute Speed Error	No. of Obs.
0-30	1.6	3.3	1.9	4.5	1.7	3.9	1.5	3.3	200
30-45	1.0	5.1	1.2	6.8	1.1	6.0	1.0	5.2	291
45-60	0.0	2.8	0.5	4.9	0.4	3.9	0.2	3.1	905
60+	-1.7	2.3	-2.9	4.4	-2.4	3.5	-1.9	2.7	1115

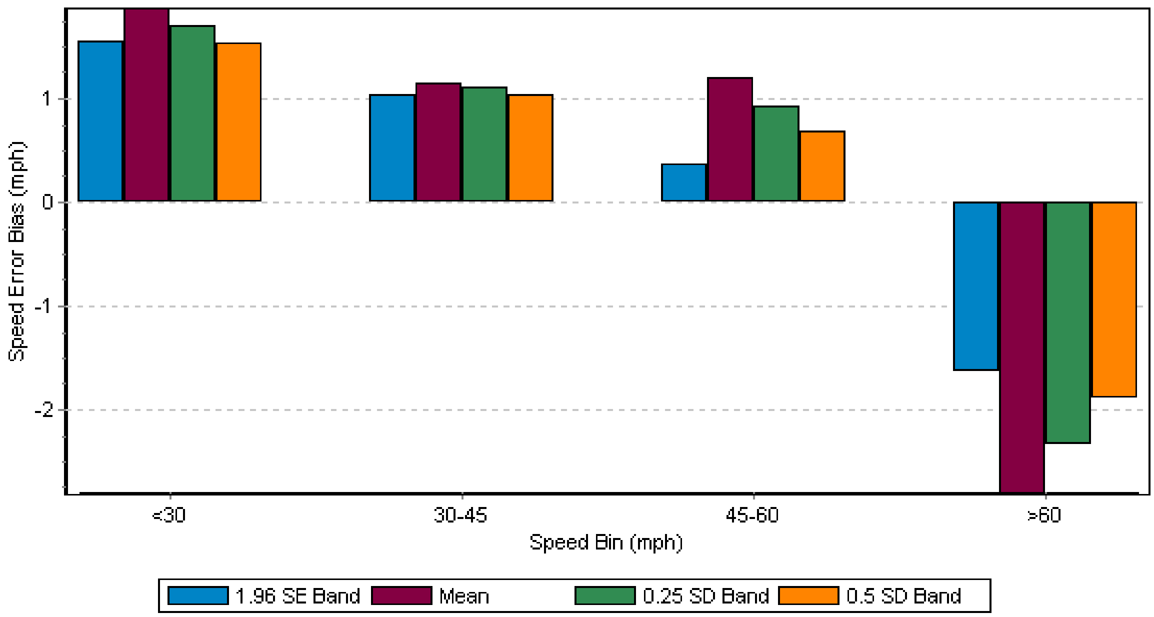


Figure 8.13
Speed error bias for freeway segments greater than one mile in Northern Virginia (all data, five minute shift)

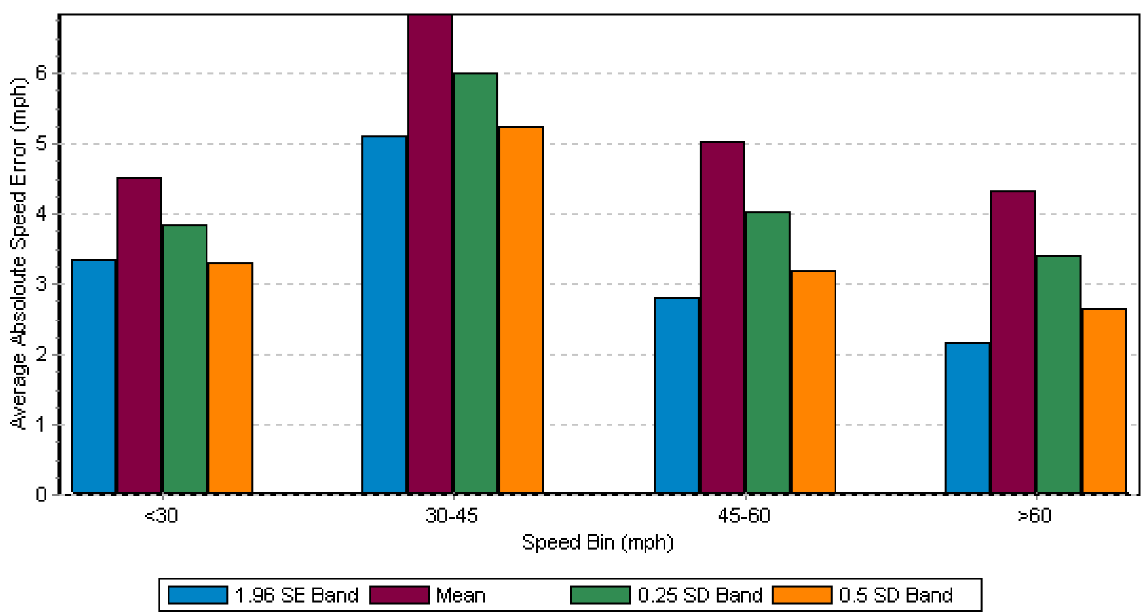


Figure 8.14
Average absolute speed error for freeway segments greater than one mile in Northern Virginia (all data, five minute shift)

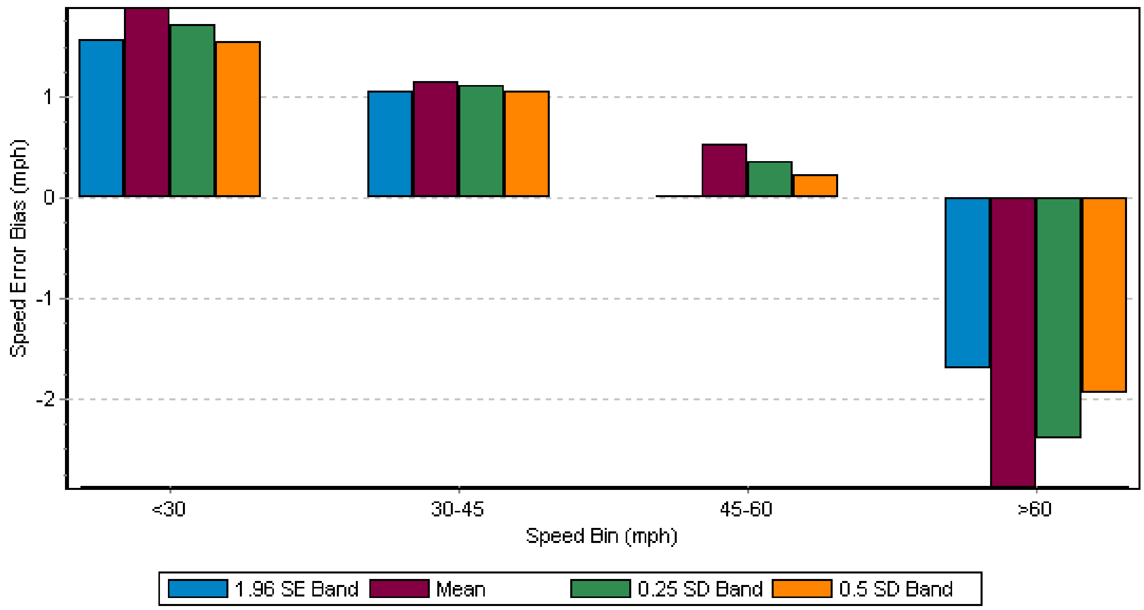


Figure 8.15
Speed error bias for freeway segments greater than one mile in Northern Virginia (INRIX high score, five minute shift)

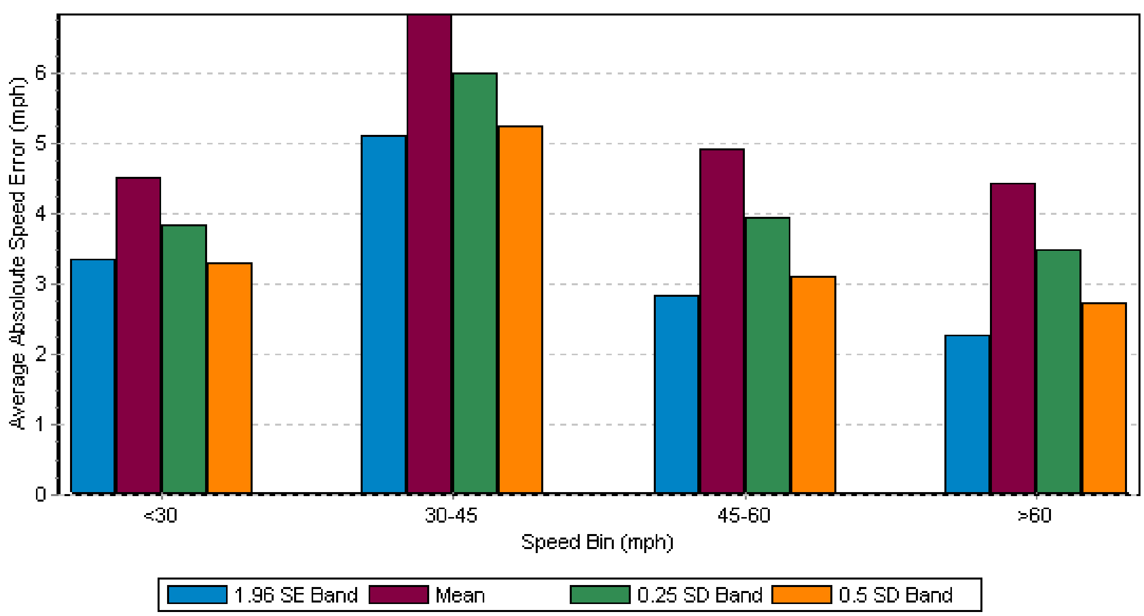


Figure 8.16
Average absolute speed error for freeway segments greater than one mile in Northern Virginia (INRIX high score, five minute shift)

Detailed data for individual TMC segments in Northern Virginia are presented in Appendix D. This appendix also presents the results of the evaluation of the INRIX data reported for the freeway segments that are less than one mile long.

9 Evaluation Results for All States

9.1 *Analysis of Results*

This section presents the data quality comparisons for all four states combined. In total, data from 98 TMC segments in the four states are used in this validation effort. 74 of these segments are freeway segments of which 54 are greater than one mile and cover more than 111 miles of freeways in the core states.

Table 9.1 summarizes the data quality measures obtained as a result of comparison between Bluetooth and all reported INRIX speeds, including all scores.

The comparisons between the Bluetooth data with the corresponding INRIX speed data for which INRIX indicated high score are summarized in the Table 9.2.

In all speed bins, INRIX data passes the data quality measures set forth by the contract when errors are measured as a distance from the 1.96 times the standard error, 0.25 and 0.5 times the standard deviation bands. However, when compared to the computed mean the INRIX data barely fails to pass the data quality requirements in less than 30 mph speeds. Considering the high score INRIX data alone, the results of the analysis are essentially the same.

Figures 9.1 and 9.2 show the overall speed error bias for different speed bins, and the average absolute speed errors for all segments in the four states, respectively. These Figures correspond to Table 9.1. Likewise, Figures 9.3 and 9.4 show the same error measures for all segments for speed data for which INRIX indicated high score (score 30 as mentioned before). Figures 9.3 and 9.4 correspond to the results exhibited in Table 9.2.

Table 9.3 shows the percentage of the time intervals that have met the data quality requirements as described in the contract for each speed bin for all TMCs in all states. Table 9.4 presents the same information when high score INRIX data has been used in the evaluations.

In both tables 9.3 and 9.4 the columns that show the percentage falling inside the band represent the percentage of the time intervals for which INRIX provides travel time and speed data that falls inside the corresponding band as described in section 4.2.4. The columns that show the percentage within five mph of the band represent the percentage of the INRIX data that lay within five mph of the band including the data points that fall inside the corresponding band. When comparing to the mean of the Bluetooth data, numbers in the percentage equal to mean column show the percentage of the INRIX observations that are exactly equal to their corresponding Bluetooth observation and the percentage within five mph of the mean show the portion of the INRIX data that falls within five mph of the Bluetooth mean.

Table 9.1
Data quality measures for freeway segments greater than one mile in all states (all data)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	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	3.8	5.9	5.2	8.1	4.6	7.1	4.1	6.2	344
30-45	2.2	6.9	3.4	9.6	2.9	8.4	2.5	7.3	636
45-60	0.2	2.3	1.0	4.7	0.7	3.7	0.5	2.8	3904
60+	-1.7	2.0	-3.2	4.3	-2.6	3.3	-2.0	2.4	14118

Table 9.2
Data quality measures for freeway segments greater than one mile in all states (INRIX high score)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	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	3.8	5.9	5.2	8.1	4.6	7.1	4.1	6.2	344
30-45	2.1	7.0	3.3	9.6	2.9	8.4	2.4	7.3	633
45-60	0.0	2.3	0.6	4.6	0.4	3.5	0.2	2.7	3549
60+	-1.7	2.0	-3.3	4.4	-2.6	3.3	-2.0	2.5	13557

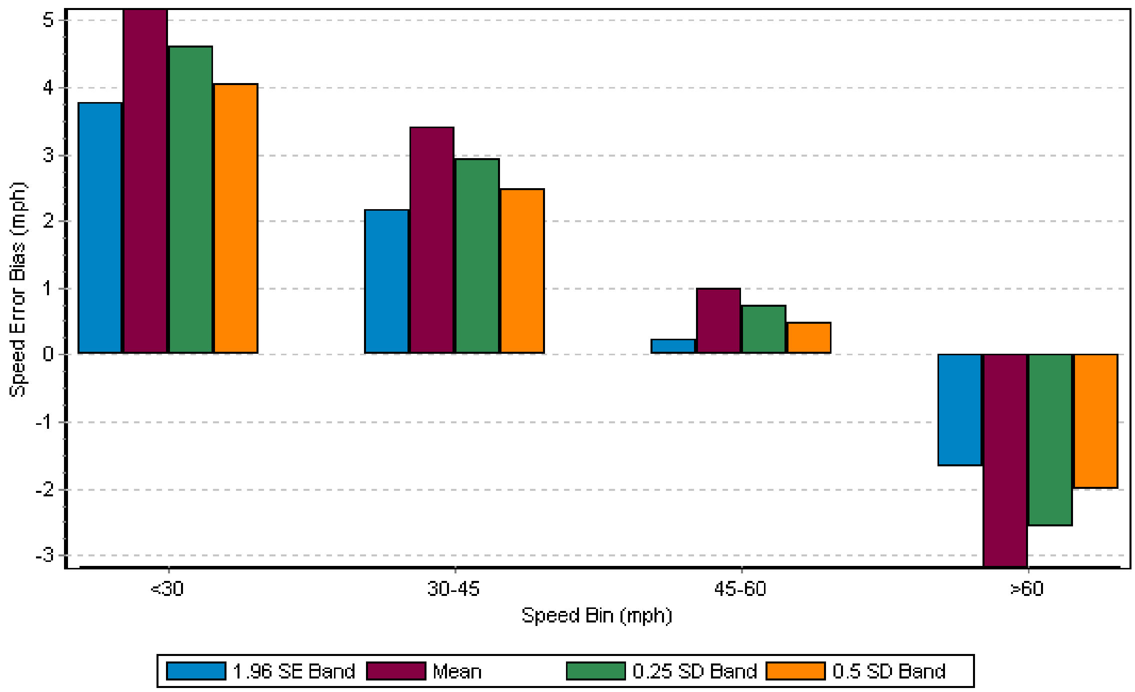


Figure 9.1
Speed error bias for freeway segments greater than one mile in all states (all data)

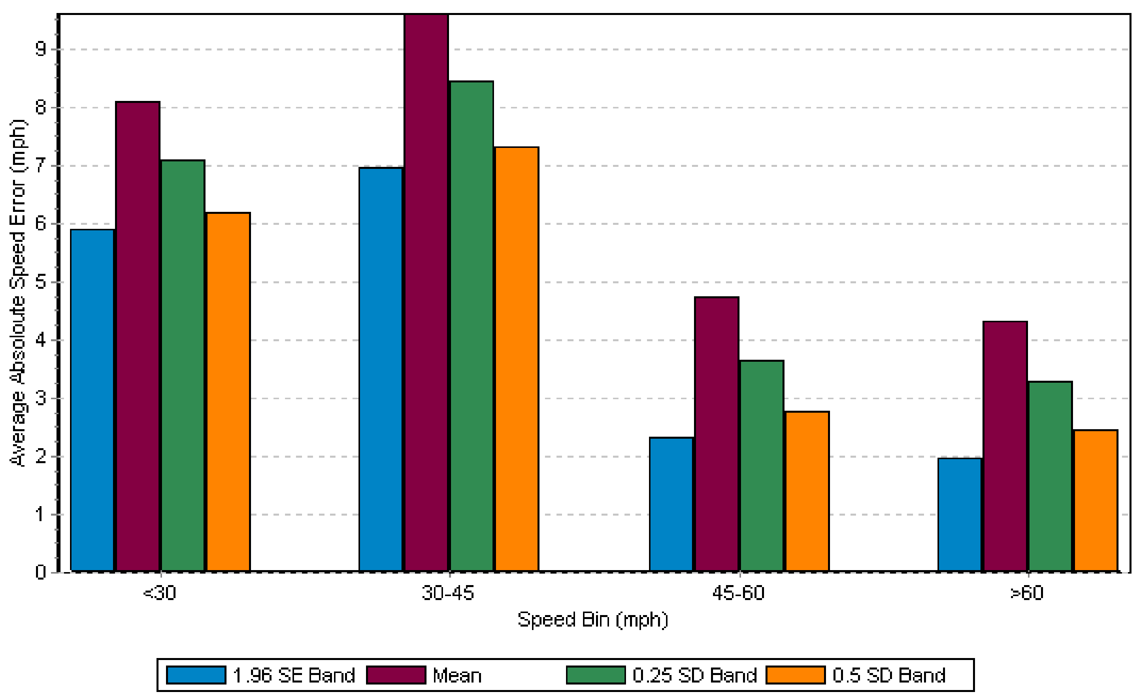


Figure 9.2
Average absolute speed error for freeway segments greater than one mile in all states (all data)

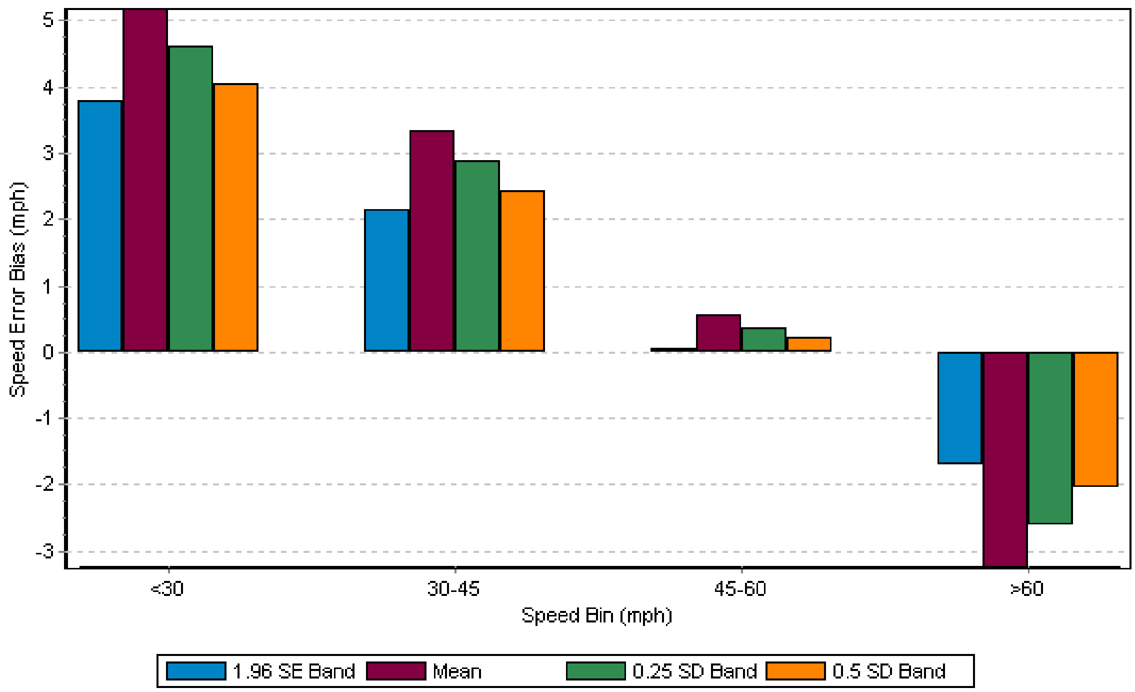


Figure 9.3
Speed error bias for freeway segments greater than one mile in all states (INRIX high score)

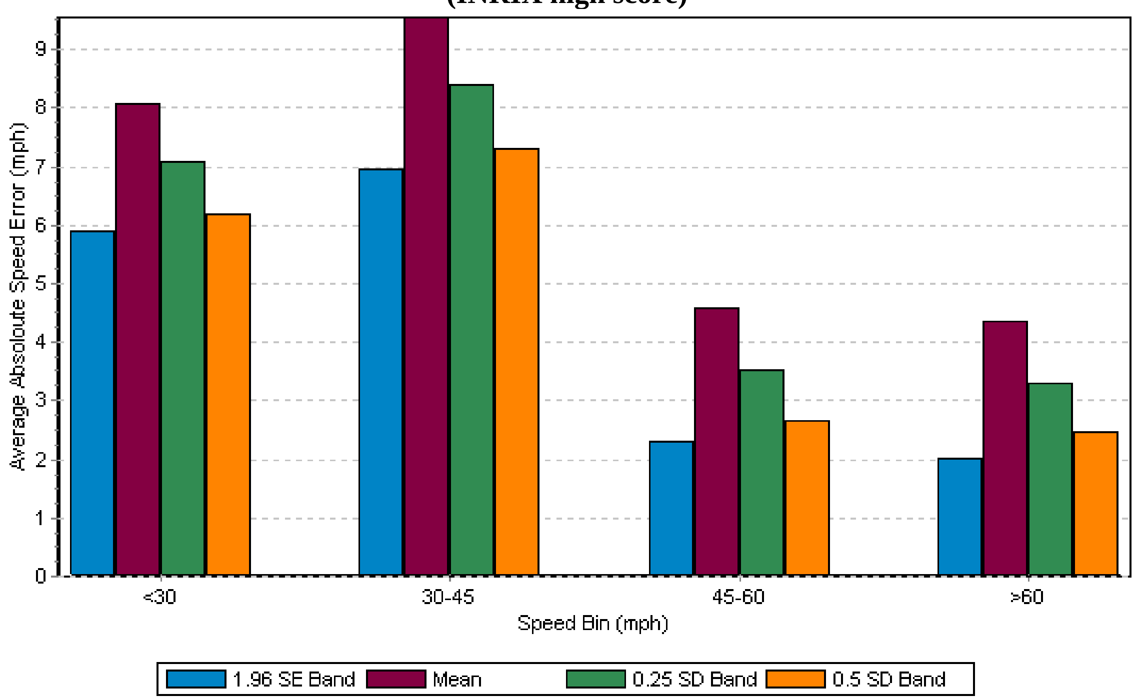


Figure 9.4
Average absolute speed error for freeway segments greater than one mile in all states (INRIX high score)

Table 9.3
Percent observations meeting data quality criteria for freeway segments greater than one mile in all states (all data)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Equal to Mean	Percentage within 5 mph of the Mean	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	
0-30	17%	63%	0%	56%	9%	60%	18%	62%	344
30-45	14%	48%	0%	35%	5%	41%	13%	46%	636
45-60	41%	84%	0%	62%	16%	73%	32%	80%	3904
60+	43%	87%	0%	66%	17%	76%	33%	84%	14118

Table 9.4
Percent observations meeting data quality criteria for freeway segments greater than one mile in all states (INRIX high score)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Equal to Mean	Percentage within 5 mph of the Mean	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	Percentage Falling Inside the Band	Percentage Falling within 5 mph of the Band	
0-30	17%	63%	0%	56%	9%	60%	18%	62%	344
30-45	14%	48%	0%	35%	5%	41%	13%	46%	633
45-60	42%	85%	0%	65%	17%	74%	34%	82%	3549
60+	42%	87%	0%	65%	16%	76%	32%	83%	13557

9.2 *Shifted INRIX Data*

In this section, results of comparisons made between Bluetooth sensor speed data and the INRIX speed data that are shifted five minutes back in time in all four states are reported. Table 9.5 summarizes the data quality measures obtained as a result of comparison between Bluetooth and all reported INRIX speeds, including all scores.

The comparisons made between the Bluetooth data with the corresponding INRIX speed data for which INRIX indicated high score are summarized in the Table 9.6.

Figures 9.5 and 9.6 show the overall speed error bias for different speed bins, and the average absolute speed errors for all segments which have been subject to validation. These figures correspond to Table 9.5. Likewise, Figures 9.7 and 9.8 show the same error measures for all segments in all states for speed data for which INRIX indicated high score (score 30 as mentioned before). Figures 9.7 and 9.8 correspond to the results exhibited in Table 9.6.

Generally speaking, the five minute shift in INRIX data does not have a major impact on the data quality measures. Also, it is notable that the five minute shifted speed data for which INRIX reports high score is meeting the contract requirements for data quality based on the 1.96 times the standard error and the 0.5 times the standard deviation bands.

Detailed data for individual TMC segments in all states are presented in the appendixes that have the detailed data for the state in which the TMC segments lie. Appendix E presents the results of the evaluation of the INRIX data reported for freeway segments that are less than one mile long for all states combined.

Table 9.5
Data quality measures for freeway segments greater than one mile in all states (all data, five minute shift)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	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	2.8	4.9	4.0	7.0	3.6	6.0	3.1	5.2	344
30-45	1.4	5.8	2.5	8.4	2.1	7.3	1.7	6.2	635
45-60	0.3	2.2	1.1	4.6	0.9	3.5	0.6	2.6	3897
60+	-1.7	1.9	-3.2	4.3	-2.5	3.2	-2.0	2.4	14096

Table 9.6
Data quality measures for freeway segments greater than one mile in all states (INRIX high score, five minute shift)

SPEED BIN	Data Quality Measures for								No. of Obs.
	1.96 SE Band		Mean		0.25 SD Band		0.5 SD Band		
	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	2.8	4.9	4.0	7.0	3.6	6.0	3.1	5.2	344
30-45	1.4	5.8	2.5	8.4	2.0	7.2	1.6	6.2	633
45-60	0.1	2.1	0.6	4.4	0.5	3.3	0.3	2.5	3492
60+	-1.7	2.0	-3.2	4.3	-2.6	3.3	-2.0	2.4	13415

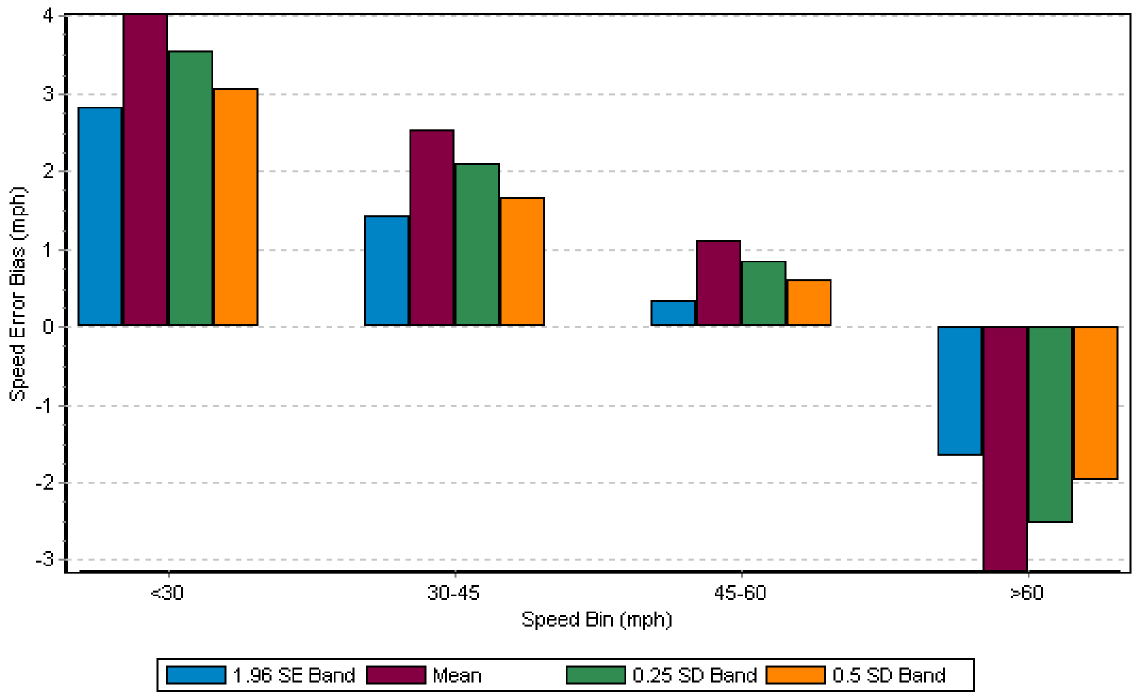


Figure 9.5
Speed error bias for freeway segments greater than one mile in all states (all data, five minute shift)

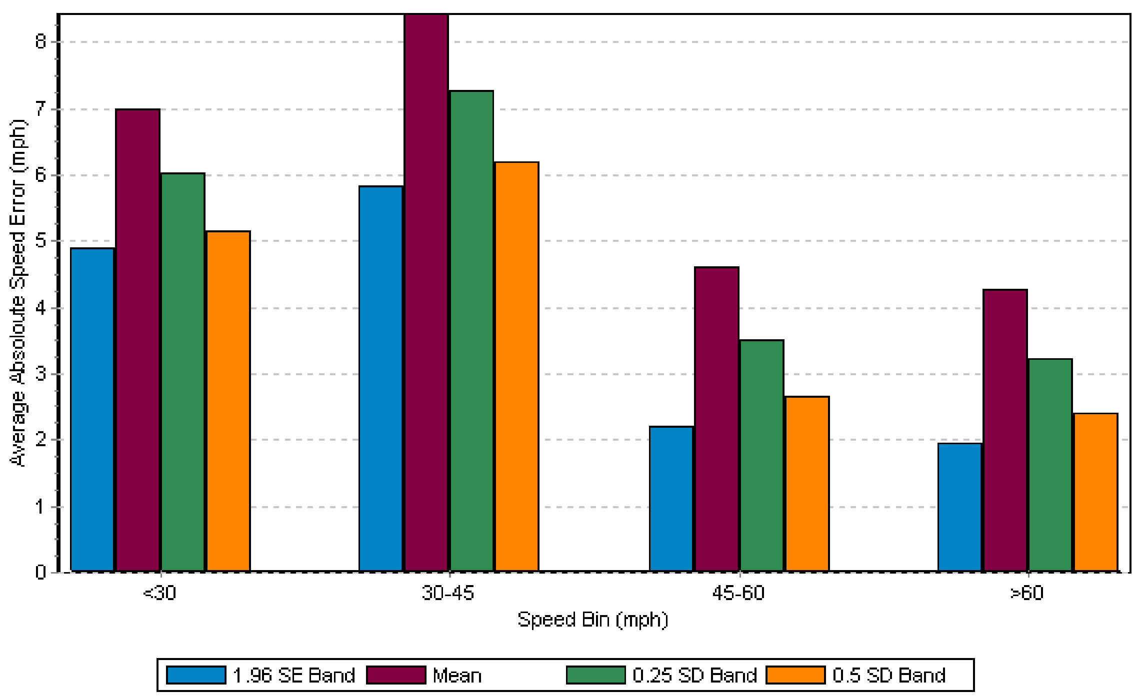


Figure 9.6
Average absolute speed error for freeway segments greater than one mile in all states (all data, five minute shift)

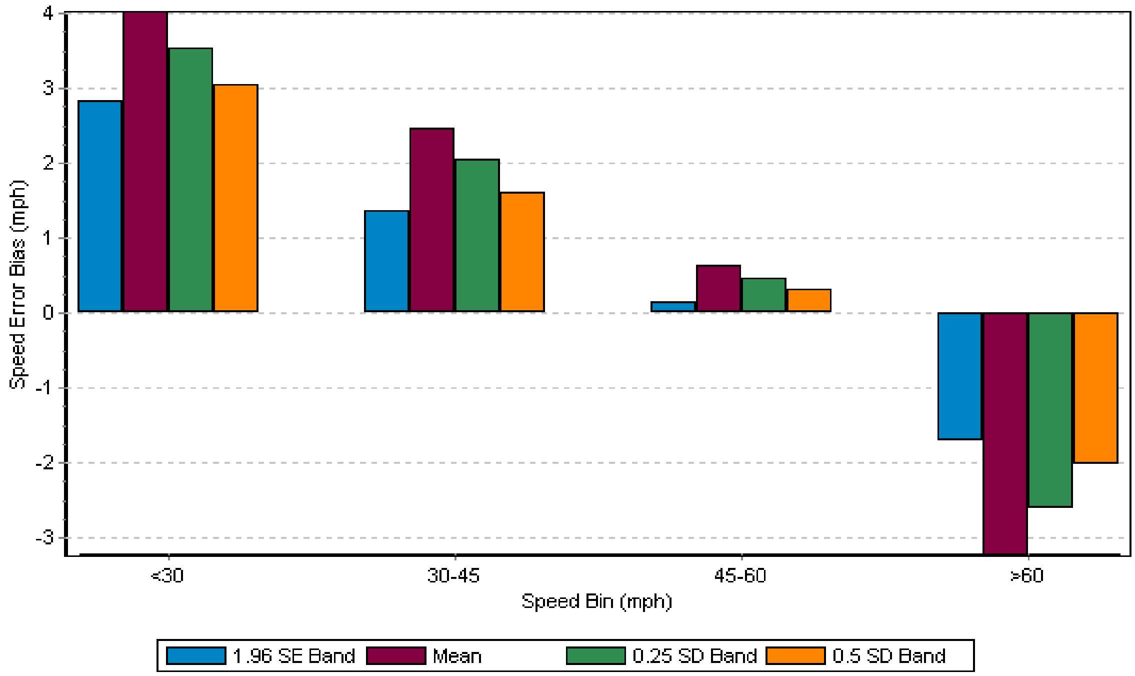


Figure 9.7
Speed error bias for freeway segments greater than one mile in all states
(INRIX high score, five minute shift)

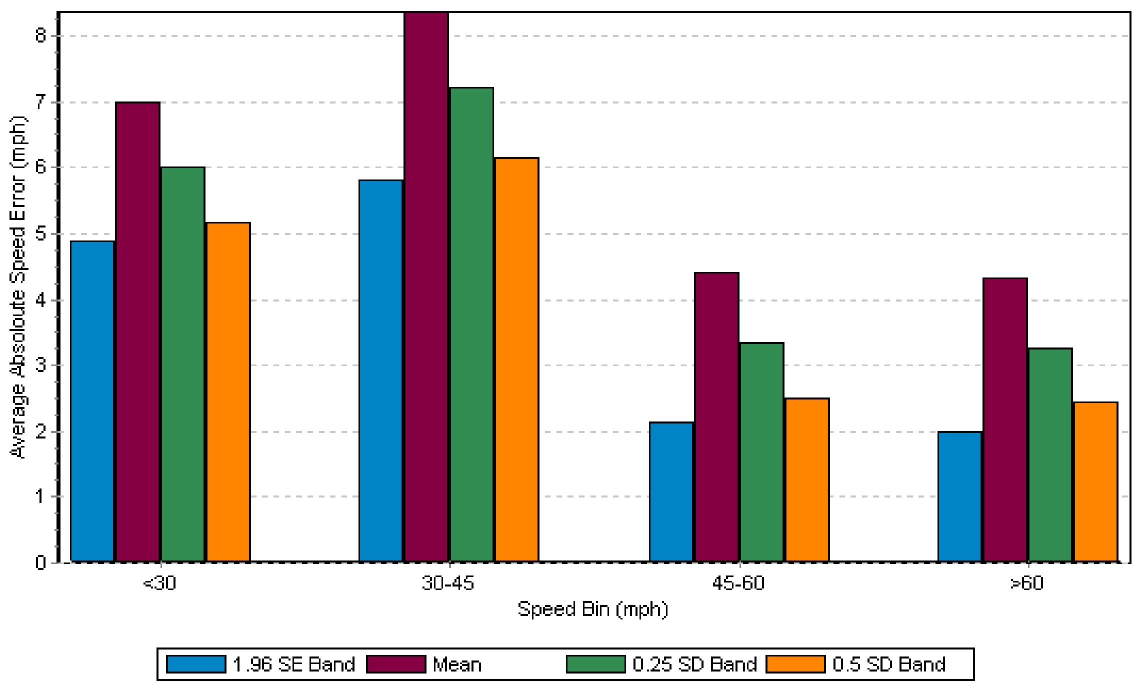


Figure 9.8
Average absolute speed error for freeway segments greater than one mile in all states
(INRIX high score, five minute shift)

10 Conclusions

This report describes the data collection and validation analysis of the speed data provided by INRIX to the I-95 Corridor Coalition members through the Vehicle Probe Project over the course of the summer and fall of 2008. This validation effort concentrated on the four states of Maryland, Virginia (Northern parts only), Delaware and New Jersey. A new traffic data collection technique, based on the reception of Bluetooth signals from passing vehicles, was used to support this validation effort to collect "Ground Truth" data.

The results presented, are based on the five-minute space-mean speed validation performed on a sample of roadways in the four states. It was determined that roadway segments greater than one mile in length provide the most accurate speed measurement results. Therefore, only roadway segments greater than one mile in length were included in the analysis. The contract specified analysis of results using four speed ranges (speed bins): 0 mph to 30 mph; 30 mph to 45 mph; 45 mph to 60 mph; and, greater than 60 mph.

The contract also specified the allowable maximum for the absolute average speed error and speed error bias in each of the speed ranges to be 10 mph and 5 mph, respectively. The evaluation results are presented in terms of these requirements.

The contract specified a maximum data lag of eight minutes. Although the exact method for quantifying data lag is still under investigation, the UMD attempted to assess the impact of any data lag by shifting the INRIX data five minutes in time and recalculating the AASE and SEB accuracy metrics. The difference in the AASE and SEB error metrics with and without out the five-minute shift were insignificant, showing only a marginal improvement in accuracy of generally less than one mph. Furthermore, the small improvements observed did not appear to impact the lower speed bins.

Scores provided by INRIX as part of their "data feed" were intended to serve as indicators of the data quality. The segment score of 30 (high) is based on real-time data for that particular segment; the segment score of 20 (medium) is based on real-time data across multiple segments and/or based on a combination of expected real-time data; and, a segment score of 10 (low) is based primarily on historical data. The validation process revealed that the score was not a significant indicator of the data quality and, as previously stated, should be used only as an indication of the manner in which the reported data has been calculated.

The analyses performed thus far suggest that the speed data provided by INRIX is generally of good quality. Quality of the data provided by INRIX improves with increase in speed. Also, the results consistently indicate that at speeds below 45 mph range INRIX is over-estimating the speeds and at speeds over 60 mph their data feed is under-estimating the actual speeds. The observations presented in this document are noted to assist the end user as they design particular applications for the data.