

I-95 Corridor Coalition Vehicle Probe Project: HERE, INRIX and TOMTOM Data Validation

Report for Pennsylvania (#11)
Arterial Validation: US-22

Data Collection: November 14 – November 26, 2018
Report Date: April 2019



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Acknowledgements:

The research team would like to express its gratitude for the assistance it received from the state highway officials in Pennsylvania during the data collection phase of the validation effort.

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Executive Summary

Wireless re-identification traffic monitoring (WRTM) technology (Bluetooth and/or Wi-Fi) is used to evaluate the quality of speeds reported by probe data vendors on selected validation road segments. WRTM equipment is deployed at strategic locations along these segments and identifies – and later re-identifies – unique signals emitted by in-vehicle electronic equipment via Bluetooth, Wi-Fi and other technologies, thus allowing direct measurement of travel times from a sample of vehicles. Prior research indicates that this sampling approach is capable of accurately characterizing actual travel times (speeds)¹; therefore, WRTM data serves as the ground-truth data source against which reported probe speeds are compared. The following bullets summarize key information about the data collection effort, while ES Table 1 provides a summary description of the study area:

Study area

- Harrisburg, PA (see Figure 1)
- Arterial segments along US-22
- Number of validation segments: 24
- Directional miles: 37

WRTM sensors

- Re-identification technology: Bluetooth & Wi-Fi
- Number deployed: 20

Data collection:

- Dates: November 14-26, 2018
- Effective five-minute travel time samples observed: 12,057

ES Table 1 -- Arterial Corridor Description			
Corridor Name	Number of Lanes	AADT	Speed Limit
US-22	2 to 5 lanes	16,000	35 to 55 mph

¹ Ali Haghani, Masoud Hamedi, Kaveh Farokhi Sadabadi, I-95 Corridor Coalition Vehicle Probe Project: Validation of INRIX Data July-September 2008, January 2010 ([link](#))

The core analysis conducted in this report involves comparing reported probe speeds to (a) the mean WRTM speed, and (b) the 95% confidence interval speed for each 5-minute time interval, known as the SEM Band. These comparisons are quantified in terms of two error metrics: Average Absolute Speed Error (AASE) and Speed Error Bias (SEB) metrics – which are calculated separately for four different speed bins. Based on probe vendor contract specifications, AASE values are to be less than 10 mph, while SEB values are to be less than 5 mph when compared with the SEM Band.

The overall error metrics calculated across all validation segments are summarized in ES Tables 2-4 and are discussed in further detail later in the report. The columns relevant to contract specifications are outlined in red, and error metric values are colored green or red to indicate whether the value is within contract specifications.

ES Table 2 – HERE Summary					
Speed Bin	Average Absolute Speed Error (<10mph)		Speed Error Bias (<5mph)		Number of 5 Minute Samples
	Comparison with SEM Band	Comparison with Mean	Comparison with SEM Band	Comparison with Mean	
0-15 MPH	3.5	9.05	3.46	8.93	1041
15-25 MPH	1.16	5.19	1.08	4.58	3032
25-35 MPH	2.04	6.2	0.86	1.62	2586
>35 MPH	1.89	5.95	-0.75	-1	5398
All Speeds	1.88	6.08	0.42	1.82	12057

- **AASE:** Within specifications (< 10 mph) in all speed bins
- **SEB:** Within specifications (< 5 mph) in all speed bins

ES Table 3 – INRIX Summary					
Speed Bin	Average Absolute Speed Error (<10mph)		Speed Error Bias (<5mph)		Number of 5 Minute Samples
	Comparison with SEM Band	Comparison with Mean	Comparison with SEM Band	Comparison with Mean	
0-15 MPH	3.68	9.1	3.65	8.9	1041
15-25 MPH	1.55	5.98	1.25	4.79	3032
25-35 MPH	2.36	6.61	1.2	2.62	2586
>35 MPH	2.08	6.16	-1.01	-1.33	5398
All Speeds	2.14	6.46	0.43	1.94	12057

- **AASE:** Within specifications (< 10 mph) in all speed bins
- **SEB:** Within specifications (< 5 mph) in all speed bins

ES Table 4 – TOMTOM Summary					
Speed Bin	Average Absolute Speed Error (<10mph)		Speed Error Bias (<5mph)		Number of 5 Minute Samples
	Comparison with SEM Band	Comparison with Mean	Comparison with SEM Band	Comparison with Mean	
0-15 MPH	2.23	7.32	2.21	7.24	1041
15-25 MPH	0.86	4.85	0.7	3.85	3021
25-35 MPH	1.12	4.83	0.4	1.56	2584
>35 MPH	1.23	4.78	-0.68	-1.12	5387
All Speeds	1.2	5.03	0.15	1.43	12033

- **AASE:** Within specifications (< 10 mph) in all speed bins
- **SEB:** Within specifications (< 5 mph) in all speed bins

Introduction

The University of Maryland (UMD), acting on behalf of the I-95 Corridor Coalition, was given the responsibility of evaluating the quality of Vehicle Probe Project (VPP) data at the inception of the project in 2009. To assess the quality of travel time and speed data, UMD developed a methodology using wireless re-identification traffic monitoring (WRTM) technology, which is documented in detail in the previously-referenced full report: I-95 Corridor Coalition Vehicle Probe Project: Validation of INRIX Data.

At a high level, WRTM equipment is deployed at strategic locations along selected road segments and identifies – and later re-identifies – unique signals emitted by in-vehicle electronic equipment via Bluetooth, Wi-Fi and other technologies, thus allowing direct measurement of travel times from a sample of vehicles. Initial research conducted by UMD shows that this sampling approach is capable of accurately characterizing travel times (speeds); therefore, WRTM data serves as the ground-truth data source against which reported probe speeds are compared.

In 2014, the project moved to a second phase (VPPII), during which a probe data marketplace was created. Currently there are three data vendors that provide travel time and speed data through this marketplace: HERE, INRIX, and TomTom. The purpose of this report, which is produced on a regular basis, is to continue to rigorously assess the accuracy of speeds reported by each vendor on various road segments from I-95 Corridor Coalition member states.

Probe Data Vendors

Three probe data vendors are evaluated in this report: HERE, INRIX, and TomTom. Each vendor provides travel time and speed data along the road segments and time periods of interest, which are subsequently compared to ground truth WRTM observations in order to assess data accuracy.

Specifically, each vendor reports travel time and speed data in one-minute intervals either along road segments defined by the WRTM sensor locations (i.e., validation segmentation) or Traffic Message Channel (TMC) segments. In the latter case the TMC-based speeds must first be transformed to equivalent speeds on validation segments before a direct comparison can be made.

Methodology

The primary means of evaluating the vendor data is through the standard validation analysis, which is thoroughly documented in the original report (I-95 Corridor Coalition Vehicle Probe Project: Validation of INRIX Data July-September 2008) and summarized below. Additionally, a supplemental slowdown or latency analysis may be conducted depending on the type of road segment being evaluated; the slowdown analysis quantifies how well probe data captures congestion events on arterials, while the latency analysis quantifies the time lag between ground truth and probe data on freeways.

Standard validation analysis

Overview

The standard validation analysis consists of comparing ground truth (i.e., WRTM) speeds against vendor speeds over five-minute intervals and quantifying the discrepancy in terms of two error metrics defined in the contract specifications.

Obtain vendor speed data along validation road segments

Road segments used for validation are defined based on WRTM sensor locations – often resulting in different segment definitions than those typically reported by the probe vendors. Accordingly, vendors may either report speeds directly on the validation road segmentation used for evaluation, or report speeds based on standard Traffic Message Channel (TMC) segments. In the latter case, equivalent vendor speeds must be obtained for the geometry specified by the WRTM sensors, which is accomplished via a trajectory reconstruction algorithm. This algorithm is described in another report² and works by (a) identifying the portions of vendor road segments that correspond to the validation segment, and (b) using the speeds reported on the vendor’s segments during multiple time intervals to calculate the equivalent speed.

Filter and aggregate ground truth data

Raw travel time (speed) observations are first filtered to remove outliers. The filtering step is necessary because WRTM sensors sometimes re-identify vehicles that stop between sensors or record travel times from pedestrians or non-motorized vehicles that are not representative of actual traffic conditions. After the outlier observations are removed, the remaining representative observations are aggregated for each segment over five-minute intervals, and intervals with too few observations or excessive variation are discarded.

The remaining intervals are deemed suitable for evaluation of vendor probe data and are summarized in terms of (a) space-mean speed and (b) confidence band. The space-mean speed

² Ali Haghani, Masoud Hamed, Kaveh Farokhi Sadabadi, Estimation of Travel Times for Multiple TMC Segments, prepared for I-95 Corridor Coalition, February 2010 ([link](#))

captures average ground truth traffic behavior, while the confidence band accounts for the uncertainty associated with a heterogeneous mixture of drivers, vehicles, and road characteristics.

Several statistical measures were initially evaluated to define the width of this uncertainty band, all of which are described and reported in the original report. Ultimately, the standard error of the mean (SEM) measure was selected due to its simplicity and sensitivity to both variability and number of observations used for calculations. The SEM is calculated as the standard deviation (SD) of the calculated error (the difference between the ground truth data and the vendor data) divided by the square root of the number of ground truth data points (n) taken for a given time. In other words, $SEM = \frac{SD_{GT}}{\sqrt{n}}$. The confidence band based on this statistic (i.e., the SEM band) narrows when there is a higher degree of confidence in the ground truth data (i.e., more observations or less variation) and widens when there is less confidence, serving as a proxy for a 95% confidence interval of ground truth speeds.

Compute Error Metrics

A statistical analysis of the data is conducted for four defined speed bins, where each five-minute interval is associated with a speed bin based on its corresponding ground truth space-mean speed (0-15 mph, 15-30 mph, 30-45 mph, 45+ mph for arterials; 0-30 mph, 30-45 mph, 45-60 mph, 60+ mph for freeways). Reported probe speeds are compared to both the space-mean and SEM band ground truth speed for each five-minute time interval, and the discrepancies are quantified in terms of two error metrics: Average Absolute Speed Error (AASE) and Speed Error Bias (SEB), which are reported separately for each speed bin. According to contract specifications, AASE and SEB values must be within 10 mph and 5 mph, respectively, when compared with the SEM band.

AASE is calculated by summing up the absolute difference between probe vendor speeds (S_P) and ground truth speeds (S_{GT}) for each time interval and taking the average over n observations. That is, $AASE = \frac{1}{n} \sum_{i=1}^n |S_P - S_{GT}|$. Because the absolute value is used, positive and negative errors cannot cancel, and the result is always positive. Speed Error Bias is calculated similarly, with the difference that the absolute value of the errors is not taken. In other words, $SEB = \frac{1}{n} \sum_{i=1}^n S_P - S_{GT}$. Thus, positive and negative errors can cancel each other out, and the resulting value can provide insight into whether there is a consistent positive or negative error.

Data Collection

Travel time samples were collected along 24 directional validation road segments in Harrisburg, PA between November 14 and November 26, 2018. These validation segments are located along US-22, and are defined based on WRTM sensor locations, which are shown in Figure 1.

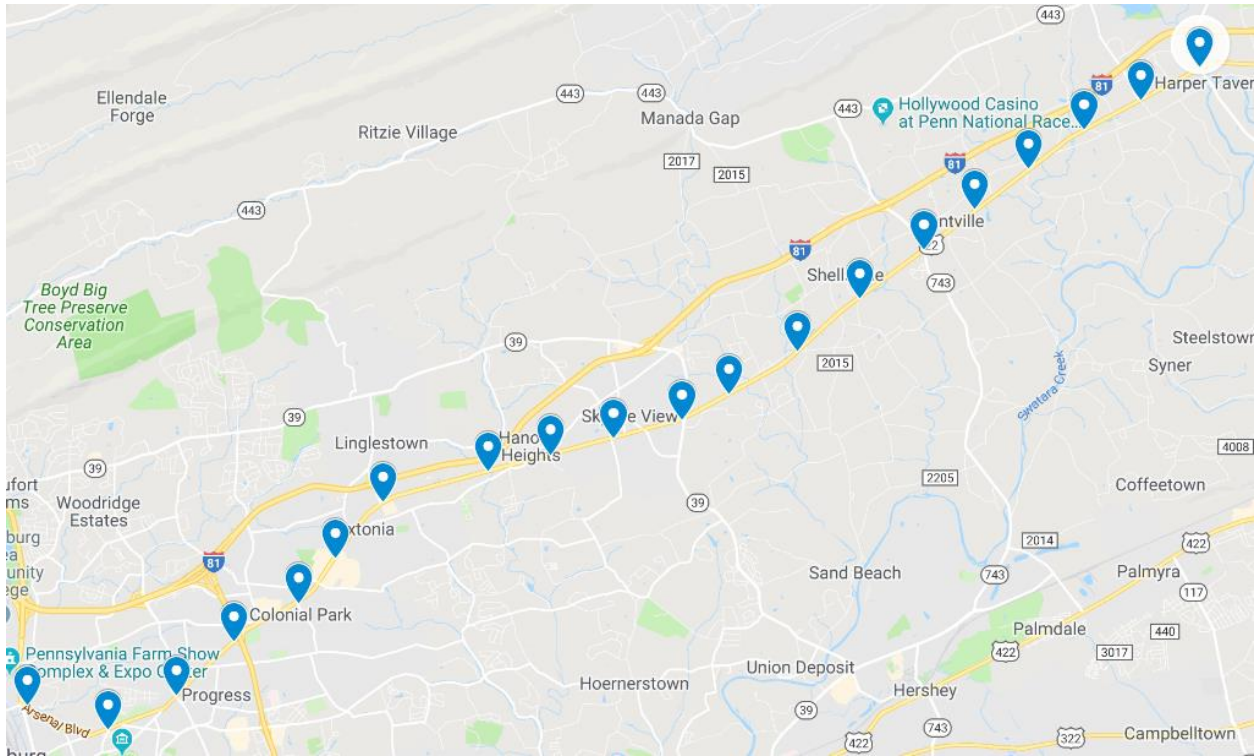


Figure 1 – WRTM Sensor locations

Table 1 contains the summary information for each data collection segment, including WRTM sensor latitude/longitudes and an active map link, which can be followed to view each data collection segment in detail. Please note that the configuration of the test segments is often such that the endpoint of one segment coincides with the start point of the next segment, so that one WRTM sensor covers both data collection segments.

Table 1 - Validation Segment Attributes

Segment (Map Link)	DESCRIPTION						Deployment	
	Highway Direction	Starting at Ending at	Lane (Min) Lane (Max)	Signals Signal/mile	AADT	Access Points Speed Limit	Begin Lat/Lon End Lat/Lon	Length (mile)
	Arterial							
A1 PA11-0001	US-22 Eastbound	N Cameron St Parkway Dr	1 2	3 2.34	7,070 19,642	9 35	40.28291 -76.88009 40.27854 -76.85861	1.28
A2 PA11-0002	US-22 Eastbound	Parkway Dr Progress Ave	1 2	3 2.92	11,913 11,913	13 35	40.27854 -76.85861 40.28473 -76.84167	1.03
A3 PA11-0003	US-22 Eastbound	Progress Ave Capital Beltway	2 3	4 3.84	16256 19959	13 40	40.28473 -76.84167 40.29507 -76.82725	1.04
A4 PA11-0004	US-22 Eastbound	Capital Beltway Prince St	2 4	4 3.96	27913 29219	7 40	40.29507 -76.82725 40.30281 -76.81115	1.01
A5 PA11-0005	US-22 Eastbound	Prince St Paxton Towne Centre Dr	4 5	5 6.12	25,047 29,219	7 40	40.30281 -76.81115 40.31156 -76.80107	0.82
A6 PA11-0006	US-22 Eastbound	Paxton Towne Centre Dr N Mountain Rd	2 3	5 5.15	16851 25,047	6 40	40.31156 -76.80107 40.32214 -76.78920	0.97
A7 PA11-0007	US-22 Eastbound	N Mountain Rd N Oak Grove Rd	2 4	4 1.69	13,069 16,851	10 45	40.32214 -76.78920 40.33165 -76.74618	2.36
A8 PA11-0008	US-22 Eastbound	N Oak Grove Rd N Hershay Rd	2 3	4 2.09	12,368 13,069	12 50	40.33165 -76.74618 40.33899 -76.71122	1.91
A9 PA11-0009	US-22 Eastbound	N Hershay Rd N Hill Dr	2 3	1 0.35	13,069 13,069	8 50	40.33899 -76.71122 40.36209 -76.66735	2.83
A10 PA11-0010	US-22 Eastbound	N Hill Dr Laudermilch Rd	2 4	0 0.00	13,069 16,851	2 55	40.36209 -76.66735 40.37160 -76.65050	1.10
A11 PA11-0011	US-22 Eastbound	Laudermilch Rd Coon Circle Rd	2 4	1 0.58	13,069 13,069	6 55	40.38681 -76.62435 40.38681 -76.62435	1.73
A12 PA11-0012	US-22 Eastbound	Coon Circle Rd Fisher Ave	2 4	0 0.00	13,069 13,069	7 55	40.38681 -76.62435 40.40667 -76.58074	2.68

Segment (Map Link)	DESCRIPTION						Deployment		
	Highway Direction	Starting at Ending at	Lane (Min) Lane (Max)	Signals Signal/mile	AADT	Access Points Speed Limit	Begin Lat/Lon End Lat/Lon	Length (mile)	
	Arterial								
A13 PA11-0013	US-22 Westbound	Fisher Ave Coon Circle Rd	2 3	0 0.00	13,069 13,069	9 55	40.40667 -76.58074 40.38689 -76.62444	2.68	
A14 PA11-0014	US-22 Westbound	Coon Circle Rd Laudermilch Rd	2 3	0 0.00	13,069 16,851	6 55	40.38689 -76.62444 40.37172 -76.65055	1.73	
A15 PA11-0015	US-22 Westbound	Laudermilch Rd N Hill Dr	2 3	1 0.91	13,069 13,069	4 55	40.37172 -76.65055 40.36221 -76.66732	1.10	
A16 PA11-0016	US-22 Westbound	N Hill Dr N Hershay Rd	2 3	1 0.35	13,069 16,851	6 50	40.36221 -76.66732 40.33911 -76.71123	2.83	
A17 PA11-0017	US-22 Westbound	N Hershay Rd N Oak Grove Rd	2 3	4 2.10	13,069 13,069	5 50	40.33911 -76.71123 40.33177 -76.74612	1.91	
A18 PA11-0018	US-22 Westbound	N Oak Grove Rd N Mountain Rd	2 4	4 1.69	13,069 13,069	10 45	40.33177 -76.74612 40.32224 -76.78928	2.37	
A19 NC08-0019	US-22 Westbound	N Mountain Rd Paxton Towne Centre Dr	2 4	5 5.15	13,069 16,851	7 40	40.32224 -76.78928 40.31167 -76.80118	0.97	
A20 PA11-0020	US-22 Westbound	Paxton Towne Centre Dr Prince St	2 4	5 6.12	16,851 25,049	9 40	40.31167 -76.80118 40.30290 -76.81121	0.82	
A21 PA11-0021	US-22 Westbound	Prince St Capital Beltway	4 2	4 3.95	25,049 29,219	13 40	40.30290 -76.81121 40.29514 -76.82732	1.01	
A22 PA11-0022	US-22 Westbound	Capital Beltway S Progress Ave	2 3	4 3.83	28,606 29,225	12 40	40.29514 -76.82732 40.28473 -76.84166	1.04	
A23 PA11-0023	US-22 Westbound	S Progress Ave Parkway Dr	1 2	3 2.98	16,256 19,959	9 35	40.28473 -76.84166 40.27854 -76.85862	1.00	
A24 PA11-0024	US-22 Westbound	Parkway Dr N Cameron St	1 2	3 2.35	7,070 19,959	7 35	40.27854 -76.85862 40.28291 -76.88009	1.3	

Validation Results

Standard Validation Results

HERE

Table 2 summarizes the standard error metrics computed between ground truth (i.e., WRTM) and HERE speeds. Both Average Absolute Speed Error (AASE) and Speed Error Bias (SEB) are within specifications for all speed bins.

Table 2 – HERE data quality measures

Speed Bin	Average Absolute Speed Error (<10mph)		Speed Error Bias (<5mph)		Number of 5 Minute Samples
	Comparison with SEM Band	Comparison with Mean	Comparison with SEM Band	Comparison with Mean	
0-15	3.5	9.05	3.46	8.93	1041
15-25	1.16	5.19	1.08	4.58	3032
25-35	2.04	6.2	0.86	1.62	2586
>35	1.89	5.95	-0.75	-1	5398
All Speeds	1.88	6.08	0.42	1.82	12057

Table 3 shows the percentage of time the HERE data falls within 5mph of the mean and SEM band for each speed bin.

Table 3 – Percent of HERE observations meeting data quality criteria

Speed Bin	Data Quality Measures for				Number of 5 Minute Samples
	SEM Band		Mean		
	Percent inside band	Percent within 5mph of band	Percent equal to mean	Percent within 5mph of mean	
0-15	35	71	-	22	1041
15-25	70	92	-	57	3032
25-35	59	85	-	51	2586
35+	57	85	-	50	5398

Table 4 reports the standard error metrics on individual validation segments. Note that some segments and time bins only have a few observations, and thus may not be representative of the overall performance in each speed bin.

Table 4 – HERE data quality measures by validation segment

Path	Sensor distance	Speed Bin	Data Quality Measures for				No. of Obs.
			1.96 SEM Band		Mean		
			Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
PA11-0001	1.28	0-15	6.71	6.71	8.67	8.67	9
		15-25	0.54	0.76	2.79	2.79	35
		25-35	-0.51	0.91	-1.1	-1.1	81
		35+	-6.47	6.47	-8.75	-8.75	4
PA11-0002	1.03	0-15	4.55	4.56	8.27	8.27	73
		15-25	1.57	1.84	3.53	3.53	101
		25-35	-1.23	1.23	-3.24	-3.24	14
		35+	-	-	-	-	-
PA11-0003	1.04	0-15	1.96	1.98	5.26	5.26	36
		15-25	0.35	0.46	3.58	3.58	262
		25-35	-1.11	1.16	-3.43	-3.43	397
		35+	-5.16	5.16	-11.06	-11.06	57
PA11-0004	1.01	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	-	-	-	-	-
		35+	-	-	-	-	-
PA11-0005	0.82	0-15	2.79	2.79	10.68	10.68	226
		15-25	0.66	0.69	4.84	4.84	430
		25-35	-0.78	1.01	-3.03	-3.03	149
		35+	-4	4	-9.49	-9.49	28
PA11-0006	0.97	0-15	3.84	3.84	9.68	9.68	155
		15-25	0.88	0.9	4.47	4.47	556
		25-35	-0.74	0.79	-2.79	-2.79	188
		35+	-3.68	3.68	-9.13	-9.13	21
PA11-0007	2.36	0-15	-	-	-	-	-
		15-25	1.3	1.3	5.88	5.88	17
		25-35	1.32	1.41	6.61	6.61	103
		35+	-0.56	0.98	-1.07	-1.07	387
PA11-0008	1.91	0-15	5.76	5.76	10.46	10.46	13
		15-25	2.86	3.2	10.83	10.83	39
		25-35	1.92	1.92	7.94	7.94	127
		35+	-0.49	0.9	-1.13	-1.13	220
PA11-0009	2.83	0-15	0.57	0.73	0.81	0.81	18
		15-25	2.23	4.58	2.27	2.27	21
		25-35	4.59	6.01	8.31	8.31	27
		35+	-2.26	2.43	-5.06	-5.06	449
PA11-0010	1.10	0-15	0.82	1.61	1.68	1.68	49
		15-25	8.57	8.57	14.57	14.57	30
		25-35	7.66	7.7	15.6	15.6	211
		35+	1.2	1.61	6.46	6.46	426

Path	Sensor distance	Speed Bin	Data Quality Measures for				No. of Obs.
			1.96 SEM Band		Mean		
			Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
PA11-0011	1.73	0-15	-	-	-	-	-
		15-25	0.93	1.07	4.68	4.68	6
		25-35	5.36	6.19	8.25	8.25	15
		35+	-0.12	0.85	-0.51	-0.51	518
PA11-0012	2.68	0-15	-	-	-	-	-
		15-25	2.2	2.2	5.19	5.19	4
		25-35	4.7	5.48	6.3	6.3	16
		35+	-1.49	1.79	-3.13	-3.13	517
PA11-0013	2.68	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	3.95	3.95	7.78	7.78	12
		35+	-1.88	2.09	-3.98	-3.98	575
PA11-0014	1.73	0-15	22.32	22.32	23.52	23.52	1
		15-25	9.05	9.05	12.95	12.95	15
		25-35	8.69	8.7	15.81	15.81	63
		35+	2.25	2.45	7.11	7.11	563
PA11-0015	1.10	0-15	-	-	-	-	-
		15-25	8.59	8.59	9.7	9.7	1
		25-35	2.49	4.14	5.99	5.99	22
		35+	-2.18	2.24	-4.97	-4.97	616
PA11-0016	2.83	0-15	16.74	16.74	20.31	20.31	4
		15-25	9.56	9.56	15.03	15.03	17
		25-35	6.08	6.08	10.9	10.9	20
		35+	1.03	1.64	4.06	4.06	442
PA11-0017	1.91	0-15	-	-	-	-	-
		15-25	5.76	5.76	9.33	9.33	9
		25-35	0.31	0.31	10.61	10.61	22
		35+	-2.34	2.48	-5.32	-5.32	303
PA11-0018	2.37	0-15	-	-	-	-	-
		15-25	2.67	2.75	10.23	10.23	33
		25-35	2.4	2.42	7.06	7.06	212
		35+	0.07	0.4	0.16	0.16	168
PA11-0019	0.97	0-15	3.68	3.68	8.15	8.15	149
		15-25	1.15	1.2	4.51	4.51	541
		25-35	-0.8	0.9	-2.88	-2.88	175
		35+	-4.6	4.61	-9.76	-9.76	41
PA11-0020	0.82	0-15	3.23	3.23	9.28	9.28	254
		15-25	0.46	0.51	3.23	3.23	393
		25-35	-0.65	0.78	-3.16	-3.16	160
		35+	-4.58	4.58	-13.9	-13.9	11
PA11-0021	1.01	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	-	-	-	-	-
		35+	-	-	-	-	-
PA11-0022	1.04	0-15	5.42	5.42	10.73	10.73	42
		15-25	0.95	1.07	3.57	3.57	405
		25-35	-0.87	1.08	-2.98	-2.98	232
		35+	-6.39	6.39	-13.14	-13.14	21

Path	Sensor distance	Speed Bin	Data Quality Measures for				No. of Obs.
			1.96 SEM Band		Mean		
			Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
PA11-0023	1.01	0-15	6.91	6.91	12.09	12.09	8
		15-25	0.63	0.63	6.59	6.59	56
		25-35	-0.57	0.72	-1.6	-1.6	243
		35+	-3.51	3.51	-7.8	-7.8	17
PA11-0024	1.28	0-15	10.25	10.25	15.57	15.57	4
		15-25	1.79	1.79	7.42	7.42	61
		25-35	0.04	0.39	1.62	1.62	97
		35+	-2.68	2.68	-6.71	-6.71	14

INRIX

Table 5 summarizes the standard error metrics computed between ground truth (i.e., WRTM) and INRIX speeds. Both Average Absolute Speed Error (AASE) and Speed Error Bias (SEB) are within specifications for all speed bins.

Table 5– INRIX data quality measures

Speed Bin	Average Absolute Speed Error (<10mph)		Speed Error Bias (<5mph)		Number of 5 Minute Samples
	Comparison with SEM Band	Comparison with Mean	Comparison with SEM Band	Comparison with Mean	
0-15	3.68	9.1	3.65	8.9	1041
15-25	1.55	5.98	1.25	4.79	3032
25-35	2.36	6.61	1.2	2.62	2586
>35	2.08	6.16	-1.01	-1.33	5398
All Speeds	2.14	6.46	0.43	1.94	12057

Table 6 shows the percentage of time the INRIX data falls within 5mph of the mean and SEM band for each speed bin.

Table 6– Percent of INRIX observations meeting data quality criteria

Speed Bin	Data Quality Measures for				Number of 5 Minute Samples.
	SEM Band		Mean		
	Percent inside band	Percent within 5mph of band	Percent equal to mean	Percent within 5mph of mean	
0-15	37	69	-	28	1041
15-25	63	89	-	49	3032
25-35	58	82	-	50	2586
35+	55	84	-	49	5398

Table 7 reports the standard error metrics on individual validation segments. Note that some segments and time bins only have a few observations, and thus may not be representative of the overall performance in each speed bin.

Table 7– INRIX data quality measures by validation segment

Path	Sensor distance	Speed Bin	Data Quality Measures for				No. of Obs.
			1.96 SEM Band		Mean		
			Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
PA11-0001	1.28	0-15	7.95	7.95	9.91	9.91	9
		15-25	0.58	1.28	2.4	4.56	35
		25-35	-0.52	0.82	-1.28	2.45	81
		35+	-7.24	7.24	-9.52	9.52	4
PA11-0002	1.03	0-15	4.46	4.59	7.57	8.02	73
		15-25	1.24	1.59	3.5	4.24	101
		25-35	-1.17	1.17	-2.46	3.02	14
		35+	-	-	-	-	-
PA11-0003	1.04	0-15	2.73	3	6.24	6.87	36
		15-25	0.95	1.04	5.86	6.27	262
		25-35	-0.5	0.74	-1.45	3.49	397
		35+	-3.69	3.69	-9.25	9.25	57
PA11-0004	1.01	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	-	-	-	-	-
		35+	-	-	-	-	-
PA11-0005	0.82	0-15	2.74	2.74	10.18	10.32	226
		15-25	0.49	0.61	4.22	5.32	430
		25-35	-1.23	1.3	-4.06	5	149
		35+	-5.52	5.52	-11.09	11.09	28
PA11-0006	0.97	0-15	4.5	4.54	10.11	10.27	155
		15-25	1.12	1.36	4.57	5.72	556
		25-35	-0.8	0.84	-2.33	4.5	188
		35+	-4.12	4.12	-10.01	10.01	21
PA11-0007	2.36	0-15	-	-	-	-	-
		15-25	1.26	1.26	3.82	7.05	17
		25-35	1.28	1.6	6.27	8.11	103
		35+	-0.62	1.3	-0.84	5.06	387
PA11-0008	1.91	0-15	4.41	4.63	8.8	9.29	13
		15-25	2.51	2.51	9.14	9.31	39
		25-35	2.69	2.79	8.41	9.03	127
		35+	-0.77	1.32	-0.66	4.92	220
PA11-0009	2.83	0-15	0.96	0.96	1.37	1.37	18
		15-25	0.77	2.68	0.96	4.19	21
		25-35	3.03	5.51	4.31	8.78	27
		35+	-2.56	2.69	-5.14	6.06	449
PA11-0010	1.10	0-15	1.56	1.62	2.73	2.9	49
		15-25	5.79	5.79	10.62	10.75	30
		25-35	7.47	7.78	15.02	15.72	211
		35+	1.17	1.9	6.13	8.28	426

Path	Sensor distance	Speed Bin	Data Quality Measures for				No. of Obs.
			1.96 SEM Band		Mean		
			Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
PA11-0011	1.73	0-15	-	-	-	-	-
		15-25	0.84	1.58	5.16	6.22	6
		25-35	6.89	7.8	9.57	11.39	15
		35+	-0.76	1.54	-1.71	4.56	518
PA11-0012	2.68	0-15	-	-	-	-	-
		15-25	1.93	1.93	6.4	6.4	4
		25-35	6.41	8.94	8.25	12.05	16
		35+	-1.04	1.49	-2.17	4.91	517
PA11-0013	2.68	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	6.56	8.1	10.68	13.72	12
		35+	-1.83	2.24	-3.51	5.23	575
PA11-0014	1.73	0-15	6.19	6.19	7.39	7.39	1
		15-25	6.98	7.41	9.28	9.89	15
		25-35	6.89	7.23	13.13	13.78	63
		35+	0.97	2.2	4.4	7.35	563
PA11-0015	1.10	0-15	-	-	-	-	-
		15-25	18.5	18.5	19.61	19.61	1
		25-35	5.61	7.27	9.07	12.76	22
		35+	-2.22	2.33	-4.78	6.36	616
PA11-0016	2.83	0-15	14.03	14.03	17.43	17.43	4
		15-25	7.13	7.13	10.33	11.64	17
		25-35	4.78	4.78	8.42	9.21	20
		35+	0.62	1.83	3.24	6.18	442
PA11-0017	1.91	0-15	-	-	-	-	-
		15-25	4.51	4.51	8.1	8.32	9
		25-35	0	0	10.05	10.51	22
		35+	-3.41	3.55	-6.97	8.33	303
PA11-0018	2.37	0-15	-	-	-	-	-
		15-25	2.89	3.17	9.6	10.22	33
		25-35	2.73	2.78	7.3	7.74	212
		35+	0.1	0.65	0.59	4.21	168
PA11-0019	0.97	0-15	2.86	2.89	6.48	6.83	149
		15-25	0.69	1.44	2.95	5.03	541
		25-35	-1.31	1.49	-3.07	4.78	175
		35+	-5.08	5.08	-10.92	10.92	41
PA11-0020	0.82	0-15	3.9	3.9	10.11	10.2	254
		15-25	0.73	0.99	3.88	5.39	393
		25-35	-0.62	0.86	-2.3	4.22	160
		35+	-5.11	5.11	-14.36	14.36	11
PA11-0021	1.01	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	-	-	-	-	-
		35+	-	-	-	-	-
PA11-0022	1.04	0-15	5.5	5.5	11	11	42
		15-25	2.02	2.16	5.49	6.28	405
		25-35	-0.2	1.42	-0.88	5.03	232
		35+	-3.93	3.93	-8.72	9.22	21

Path	Sensor distance	Speed Bin	Data Quality Measures for				No. of Obs.
			1.96 SEM Band		Mean		
			Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
PA11-0023	1.01	0-15	7.15	7.15	12.34	12.34	8
		15-25	2.23	2.23	10.19	10.32	56
		25-35	1.08	2.07	2.47	4.93	243
		35+	-2.16	2.34	-4.36	5.31	17
PA11-0024	1.28	0-15	16.37	16.37	22.14	22.14	4
		15-25	4.43	4.43	12.05	12.1	61
		25-35	1.58	1.88	6.86	7.54	97
		35+	-0.13	0.93	-0.29	3.48	14

TOMTOM

Table 8 summarizes the standard error metrics computed between ground truth (i.e., WRTM) and TOMTOM speeds. Both Average Absolute Speed Error (AASE) and Speed Error Bias (SEB) are within specifications for all speed bins.

Table 8 – TOMTOM data quality measures

Speed Bin	Average Absolute Speed Error (<10mph)		Speed Error Bias (<5mph)		Number of 5 Minute Samples
	Comparison with SEM Band	Comparison with Mean	Comparison with SEM Band	Comparison with Mean	
0-15	2.23	7.32	2.21	7.24	1041
15-25	0.86	4.85	0.7	3.85	3021
25-35	1.12	4.83	0.4	1.56	2584
>35	1.23	4.78	-0.68	-1.12	5387
All Speeds	1.2	5.03	0.15	1.43	12033

Table 9 shows the percentage of time the TOMTOM data falls within 5 mph of the mean and SEM band for each speed bin.

Table 9 – Percent of TOMTOM observations meeting data quality criteria

Speed Bin	Data Quality Measures for				Number of 5 Minute Samples.
	SEM Band		Mean		
	Percent inside band	Percent within 5mph of band	Percent equal to mean	Percent within 5mph of mean	
0-15	49	84	-	40	1041
15-25	72	95	-	58	3021
25-35	69	91	-	64	2584
35+	65	91	-	60	5387

Table 10 reports the standard error metrics on individual validation segments. Note that some segments and time bins only have a few observations, and thus may not be representative of the overall performance in each speed bin.

Table 10 – TOMTOM data quality measures by validation segment

Path	Sensor distance	Speed Bin	Data Quality Measures for				No. of Obs.
			1.96 SEM Band		Mean		
			Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
PA11-0001	1.28	0-15	5.83	5.83	7.8	7.8	9
		15-25	2.9	2.9	7.2	7.5	35
		25-35	0.34	0.49	1.77	2.55	81
		35+	-3.37	3.37	-5.65	5.65	4
PA11-0002	1.03	0-15	2.91	2.94	6.34	6.46	73
		15-25	1.3	1.61	3.73	4.38	101
		25-35	-0.68	0.68	-2.52	2.64	14
		35+	-	-	-	-	-
PA11-0003	1.04	0-15	3.37	3.37	7.74	7.74	36
		15-25	1.17	1.2	6.83	6.97	261
		25-35	-0.15	0.27	0.09	2.7	396
		35+	-2.78	2.78	-8.07	8.07	57
PA11-0004	1.01	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	-	-	-	-	-
		35+	-	-	-	-	-
PA11-0005	0.82	0-15	2.51	2.51	10.26	10.26	226
		15-25	0.57	0.63	4.84	5.54	428
		25-35	-0.71	0.73	-2.88	3.74	149
		35+	-4.52	4.52	-10.14	10.14	28
PA11-0006	0.97	0-15	1.73	1.73	6.23	6.27	155
		15-25	0.15	0.44	1.21	3.28	555
		25-35	-1.28	1.28	-4.53	4.96	188
		35+	-6.08	6.08	-12.04	12.04	21
PA11-0007	2.36	0-15	-	-	-	-	-
		15-25	1.18	1.18	5.7	6.37	17
		25-35	2.01	2.01	8.44	8.9	103
		35+	-0.2	0.65	0.38	3.92	385
PA11-0008	1.91	0-15	1.16	1.16	4.32	4.64	13
		15-25	1.93	1.95	8.88	9.01	39
		25-35	1.33	1.38	7.27	7.52	127
		35+	-0.48	0.69	-0.76	3.73	219
PA11-0009	2.83	0-15	1.7	2.03	2.05	2.47	18
		15-25	0.04	0.95	0.21	2.32	21
		25-35	-0.59	1.51	0.57	5.26	27
		35+	-2.04	2.1	-4.95	5.4	449
PA11-0010	1.10	0-15	0.69	0.76	1.76	1.93	49
		15-25	2.31	2.38	6.41	6.92	30
		25-35	3.91	3.92	10.83	10.98	211
		35+	-0.05	0.55	2.02	4.53	425

Path	Sensor distance	Speed Bin	Data Quality Measures for				No. of Obs.
			1.96 SEM Band		Mean		
			Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
PA11-0011	1.73	0-15	-	-	-	-	-
		15-25	0.49	0.49	4.12	4.12	6
		25-35	0.93	1.87	1.64	4.48	15
		35+	-0.3	0.83	-0.75	3.44	517
PA11-0012	2.68	0-15	-	-	-	-	-
		15-25	1.55	1.55	4.71	4.71	4
		25-35	0.36	1.33	0.92	3.49	16
		35+	-0.42	0.94	-0.85	4.13	516
PA11-0013	2.68	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	0.97	1.31	2.98	4.55	12
		35+	-0.85	1.17	-2.17	3.93	575
PA11-0014	1.73	0-15	0	0	-0.35	0.35	1
		15-25	2.33	2.41	4.41	4.82	15
		25-35	2.88	3.35	7.84	8.78	63
		35+	0.64	1.24	3.61	5.79	561
PA11-0015	1.10	0-15	-	-	-	-	-
		15-25	6.92	6.92	8.03	8.03	1
		25-35	-0.53	0.7	1.55	4.99	22
		35+	-1.35	1.51	-3.45	5.27	615
PA11-0016	2.83	0-15	3.46	3.46	6.51	6.51	4
		15-25	0.54	0.89	2.76	4.34	17
		25-35	0.61	0.83	2.64	3.33	20
		35+	0.33	0.93	1.91	4.62	441
PA11-0017	1.91	0-15	-	-	-	-	-
		15-25	3.38	3.38	6.83	6.83	9
		25-35	-0.03	0.1	10.91	12.68	22
		35+	-1.61	1.77	-4.22	6.02	302
PA11-0018	2.37	0-15	-	-	-	-	-
		15-25	1.54	1.74	9.43	9.78	33
		25-35	1.76	1.79	5.81	6.21	212
		35+	-0.05	0.3	-0.18	3.21	168
PA11-0019	0.97	0-15	0.88	0.92	4.37	4.53	149
		15-25	0.26	0.56	2.1	3.45	538
		25-35	-0.62	0.76	-2	3.69	175
		35+	-4.41	4.41	-9.77	9.77	41
PA11-0020	0.82	0-15	2.53	2.53	8.32	8.35	254
		15-25	0.42	0.52	3.09	4.37	392
		25-35	-0.39	0.45	-2.39	3.73	159
		35+	-4.7	4.7	-13.5	13.5	11
PA11-0021	1.01	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	-	-	-	-	-
		35+	-	-	-	-	-
PA11-0022	1.04	0-15	4.07	4.07	9.08	9.1	42
		15-25	1.13	1.15	5.01	5.24	402
		25-35	-0.4	0.43	-1.76	2.82	232
		35+	-4.37	4.37	-11.31	11.31	21

Path	Sensor distance	Speed Bin	Data Quality Measures for				No. of Obs.
			1.96 SEM Band		Mean		
			Speed Error Bias	Average Absolute Speed Error	Speed Error Bias	Average Absolute Speed Error	
PA11-0023	1.01	0-15	2.69	2.76	6.38	7.27	8
		15-25	0.65	0.65	7.37	7.45	56
		25-35	-0.4	0.5	-1.07	2.28	243
		35+	-3.81	3.81	-8.26	8.26	17
PA11-0024	1.28	0-15	5.04	5.04	10.81	10.81	4
		15-25	2.38	2.38	8.75	8.84	61
		25-35	0.2	0.25	3.45	4.05	97
		35+	-1.92	1.92	-5.23	5.23	14