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

Report for Massachusetts (#01)
Freeway Validation

Data Collection: January – February 2020
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1. Table of Contents

List of Tables

List of Figures

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

- I-93 (SB) and I-90 (EB) towards downtown Boston (see Figure 1)
- Number of freeway validation segments: 17
- Directional miles: 34

WRTM sensors

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

Data collection:

- Dates: January 22 – February 03, 2020
- Effective five-minute travel time samples observed: 47,958

ES Table 1 -- Freeway Corridor Description

Corridor Name	Number of Lanes	AADT (both directions)	Speed Limit
I-93 (Southbound)	3-4 lanes	174,000	55-65 mph
I-90 (Eastbound)	2-4 lanes	121,000	55-65 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)

ES Tables 2-4 summarize each vendor's error metrics using the "traditional analysis", which involves comparing reported probe speeds to (a) the mean WRTM speed, and (b) the 95% confidence band of WRTM mean speed for each 5-minute time interval. These comparisons are quantified in terms of two error metrics: Average Absolute Speed Error (AASE) and Speed Error Bias (SEB), which are calculated separately for four different speed bins. 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 (AASE <= 10 mph, SEB <= 5 mph).

ES Table 2 – HERE Traditional Analysis 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	
0-30	1.66	2.57	1.2	1.56	2451
30-45	3.05	4.87	0.48	0.96	2036
45-60	2.5	5.56	1.17	2.91	8678
60+	1.23	3.86	0.04	-0.04	34651
All Speeds	1.56	4.15	0.32	0.62	47816

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

ES Table 3 – INRIX Traditional Analysis 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	
0-30	2.56	3.6	2.39	3.2	2451
30-45	3.89	5.85	2.87	4.05	2036
45-60	2.72	5.9	2.05	4.4	8678
60+	1.12	3.67	0.37	0.85	34651
All Speeds	1.61	4.16	0.89	1.75	47816

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

ES Table 4 – TomTom Traditional Analysis 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	
0-30	0.81	1.66	0.31	0.52	2451
30-45	1.35	3.13	0.62	1.47	2036
45-60	1.99	5	1.7	3.79	8678
60+	0.89	3.4	0.02	-0.36	34651
All Speeds	1.1	3.59	0.36	0.51	47816

- **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 (link).

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 traditional validation analysis, which is documented in the original report (I-95 Corridor Coalition Vehicle Probe Project: Validation of INRIX Data July-September 2008) and summarized below. Additionally, supplemental analyses may be conducted depending on the road type being evaluated and

observed data characteristics. The most common supplemental analysis is the slowdown analysis, which evaluates probe data quality during major congestion events on arterials.

Traditional validation analysis

Overview

The traditional 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 report[2] 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 around the mean. The space-mean speed captures average ground truth traffic behavior, while the confidence band accounts for sample size and variation in the observed speeds.

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

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

(SD) of the WRTM speeds divided by the square root of the number WRTM data points (n) taken for a given time. In other words, SEM $= \frac{SD_{WRTM}}{\sqrt{n}}$. 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 17 directional freeway validation segments near downtown Boston, Massachusetts from January 22 – February 03, 2020. These validation segments are located along I-93 Southbound (from I-95 to downtown) and I-93 Eastbound (from I-495 to downtown), and are defined based on WRTM sensor locations, which are shown in Figure 1.

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.

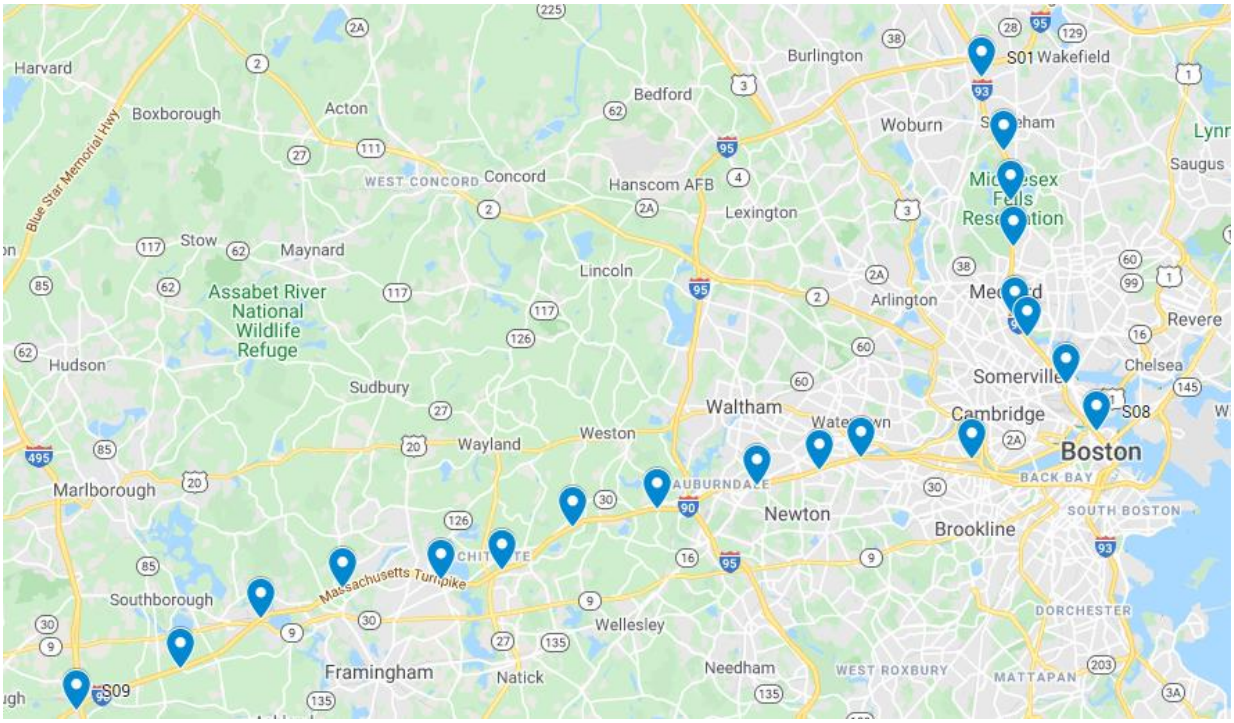

Figure 1 – WRTM Sensor locations

Table 1 - Validation Segment Attributes

Segment (Map Link)	DESCRIPTION					Deployment		
	Highway / Direction	Starting at / Ending at	Lane (Min) / Lane (Max)	AADT	Access Points / Speed Limit	Begin Lat/Lon / End Lat/Lon		Length (mi)
Freeway								
A1	I-93	Yankee Division Highway	4	186659	3	42.49623	-71.11834	1.95
MA01-0001	Southbound	Fallon Road	4		65	42.46960	-71.10792	
A2	I-93	Fallon Road	4	180782	0	42.46960	-71.10792	1.35
MA01-0002	Southbound	Fellsway	4		65	42.45125	-71.10418	
A3	I-93	Fellsway	4	184264	1	42.45125	-71.10418	1.15
MA01-0003	Southbound	Fellsway West	4		65	42.43478	-71.10285	
A4	I-93	Fellsway West	4	178369	6	42.43478	-71.10285	2.39
MA01-0004	Southbound	Mystic Ave	4		55	42.40178	-71.09600	
A5	I-93	Mystic Ave	3	155951	2	42.40178	-71.09600	1.56
MA01-0005	Southbound	Cambridge street	4		55	42.38438	-71.07699	
A6	I-93	Cambridge street	3	153059	2	42.38438	-71.07699	1.51
MA01-0006	Southbound	Nashua Street	4		55	42.36697	-71.06154	
A7	I-90	I-495	3	116224	0	42.26529	-71.56703	2.85
MA01-0007	Eastbound	Woodland Road	4		65	42.28036	-71.51540	
A8	I-90	Woodland Road	3	118920	2	42.28036	-71.51540	2.41
MA01-0008	Eastbound	MA 9	3		65	42.29842	-71.47596	
A9	I-90	MA 9	3	124367	0	42.29842	-71.47596	2.30
MA01-0009	Eastbound	Edgell Road	3		65	42.30968	-71.43496	
A10	I-90	Edgell Road	3	128046	1	42.30968	-71.43496	2.58
MA01-0010	Eastbound	Cochituate Road	4		65	42.31287	-71.38636	
A11	I-90	Cochituate Road	3	130780	3	42.31287	-71.38636	1.66
MA01-0011	Eastbound	North Main Street	3		65	42.31624	-71.35629	
A12	I-90	North Main Street	3	117842	0	42.31624	-71.35629	2.13
MA01-0012	Eastbound	Winter Street	3		65	42.33191	-71.32137	

Segment (Map Link)	DESCRIPTION					Deployment		
	Highway Direction	Starting at Ending at	Lane (Min) Lane (Max)	AADT	Access Points Speed Limit	Begin Lat/Lon End Lat/Lon		Length (mi)
A13	I-90	Winter Street	3	109485	2	42.33191	-71.32137	2.22
MA01-0013	Eastbound	Ridheway Road	4		65	42.33852	-71.27948	
A14	I-90	Ridheway Road	2	113121	2	42.33852	-71.27948	2.71
MA01-0014	Eastbound	Washington Street	4		65	42.34744	-71.22966	
A15	I-90	Washington Street	3	116600	1	42.34744	-71.22966	1.63
MA01-0015	Eastbound	Lewis Terrace	3		65	42.35313	-71.19888	
A16	I-90	Lewis Terrace	3	129835	2	42.35313	-71.19888	1.11
MA01-0016	Eastbound	Center Street	3		65	42.35760	-71.17808	
A17	I-90	Center Street	3	129835	0	42.35760	-71.17808	2.81
MA01-0017	Eastbound	Cambridge Street	4		65	42.35718	-71.12365	

Validation Results

Traditional 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	
0-30	1.66	2.57	1.2	1.56	2451
30-45	3.05	4.87	0.48	0.96	2036
45-60	2.5	5.56	1.17	2.91	8678
60+	1.23	3.86	0.04	-0.04	34651
All Speeds	1.56	4.15	0.32	0.62	47816

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	
0-30	34%	89%	-	84%	2451
30-45	32%	78%	-	64%	2036
45-60	44%	80%	-	55%	8678
60+	58%	93%	-	72%	34651

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.
			Avg. Absolute Speed Error		Speed Error Bias		
			SEM Band	Mean	SEM Band	Mean	
MA01-0001	1.95	0-30	0.96	1.97	0.53	0.37	15*
		30-45	1.17	1.94	0.46	0.53	180
		45-60	1.68	4.03	1.23	2.9	262
		60+	0.95	3.37	-0.27	-0.48	2751
MA01-0002	1.35	0-30	0.8	1.38	0.27	0.39	81
		30-45	1.18	2.42	0.14	-0.12	35
		45-60	1.7	3.82	0.3	0.62	266
		60+	0.91	3.47	0.09	0.07	2834
MA01-0003	1.15	0-30	0.62	1.23	-0.51	-0.96	176
		30-45	4	5.33	-2.91	-3.96	35
		45-60	3.86	8.36	3.05	7.22	657
		60+	1.34	4.13	0.47	1.58	2350
MA01-0004	2.39	0-30	0.81	1.38	0.79	1.24	271
		30-45	1.56	3.16	1.26	1.86	66
		45-60	1.08	3.9	0.95	3.2	517
		60+	0.56	2.87	-0.04	0.07	2062
MA01-0005	1.56	0-30	0.31	1.08	0.12	0.24	313
		30-45	1.47	3.86	-0.14	-0.41	83
		45-60	1.04	3.56	-0.85	-2.02	684
		60+	1.56	5.3	-1.48	-4.82	1687
MA01-0006	1.51	0-30	0.66	1.97	0.46	0.97	471
		30-45	1.35	3.54	1.02	2.41	614
		45-60	0.77	3.07	-0.1	-0.04	1530
		60+	3.09	10.43	-3.09	-10.43	19
MA01-0007	2.85	0-30	8.89	9.53	8.89	9.53	9*
		30-45	6.61	8.27	2.99	3.93	16*
		45-60	4.56	8.94	3.68	7.8	195
		60+	1.41	3.85	0.87	2.33	2726
MA01-0008	2.41	0-30	7.12	8.35	7.12	8.35	11*
		30-45	4.99	7.51	3.73	5.79	18*
		45-60	4.58	7.05	-2.37	-2.58	28*
		60+	1.17	3.65	-0.97	-2.46	2793
MA01-0009	2.30	0-30	2.03	2.59	0.67	0.81	75
		30-45	5.27	6.52	4.99	5.95	30*
		45-60	5.33	9.01	5.26	8.81	337
		60+	2.96	5.78	2.86	5.41	2240
MA01-0010	2.58	0-30	1.07	1.74	-0.9	-1.3	90
		30-45	1.7	2.63	-1.69	-2.47	46
		45-60	1.84	4.04	0.21	0.89	59
		60+	1.2	3.64	-0.71	-2.07	2568
MA01-0011	1.66	0-30	5.99	6.78	5.86	6.56	97
		30-45	9.47	12.48	8.77	11.37	80
		45-60	4.56	8.79	2.68	5.75	168
		60+	1.27	3.99	-0.11	0.14	2638

Path	Sensor distance	Speed Bin	Data Quality Measures for				No. of Obs.
			Avg. Absolute Speed Error		Speed Error Bias		
			SEM Band	Mean	SEM Band	Mean	
MA01-0012	2.13	0-30	1.67	2.51	-0.38	-0.65	42
		30-45	3.28	4.35	-2.24	-2.73	96
		45-60	3.13	5.35	-1.19	-0.78	137
		60+	1.1	3.67	-0.74	-1.99	2636
MA01-0013	2.22	0-30	4.93	6.57	4.74	6.16	86
		30-45	4.23	6.15	2	2.56	77
		45-60	4.81	9.07	4.32	8.3	1121
		60+	2.08	5.57	1.92	5.08	1617
MA01-0014	2.71	0-30	0.89	1.59	0.21	0.24	244
		30-45	1.42	3.18	-1.1	-1.9	87
		45-60	1.79	4.15	-0.22	0.25	215
		60+	0.76	3.35	-0.64	-2.31	1442
MA01-0015	1.63	0-30	4.38	5.62	4.28	5.46	309
		30-45	4.27	5.8	4.09	5.41	212
		45-60	1.76	5	0.89	3.1	794
		60+	0.58	3.18	-0.05	0.12	1169
MA01-0016	1.11	0-30	2.52	3.77	0.94	0.96	51
		30-45	5.85	7.97	-4.14	-5.16	318
		45-60	3.49	6.63	-0.5	1.25	1115
		60+	0.83	3.3	-0.3	-0.41	1384
MA01-0017	2.81	0-30	0.69	1.24	0.22	0.32	110
		30-45	0.94	1.8	0.37	0.52	43
		45-60	1.03	2.9	0.59	1.39	593
		60+	0.57	2.65	-0.22	-0.9	1735

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	
0-30	2.56	3.6	2.39	3.2	2451
30-45	3.89	5.85	2.87	4.05	2036
45-60	2.72	5.9	2.05	4.4	8678
60+	1.12	3.67	0.37	0.85	34651
All Speeds	1.61	4.16	0.89	1.75	47816

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	
0-30	21%	83%	0%	77%	2451
30-45	22%	71%	0%	54%	2036
45-60	38%	78%	0%	51%	8678
60+	60%	94%	0%	73%	34651

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.
			Avg. Absolute Speed Error		Speed Error Bias		
			SEM Band	Mean	SEM Band	Mean	
MA01-0001	1.95	0-30	2.48	3.7	2.3	3.28	15*
		30-45	3.78	4.62	3.26	3.73	180
		45-60	2.79	5.3	2.3	4.23	262
		60+	0.74	3	-0.12	-0.02	2751
MA01-0002	1.35	0-30	1.67	2.29	0.56	0.58	81
		30-45	3.35	4.77	-1.21	-1.57	35
		45-60	3.66	6.1	0.69	2.25	266
		60+	1.17	3.6	0.06	1.01	2834
MA01-0003	1.15	0-30	1.41	2.04	1.07	1.22	176
		30-45	6.28	7.69	3.83	4.23	35
		45-60	5.03	9.95	4.7	9.47	657
		60+	1.59	4.63	1.41	3.85	2350
MA01-0004	2.39	0-30	1.28	1.9	1.17	1.64	271
		30-45	4.6	6.28	3.75	4.42	66
		45-60	1.98	5.25	1.8	4.71	517
		60+	0.42	2.63	0.21	1.18	2062
MA01-0005	1.56	0-30	1.11	2.07	1.02	1.71	313
		30-45	2.83	5.44	1.5	2.3	83
		45-60	0.47	2.71	-0.25	-0.78	684
		60+	1.34	5.13	-1.3	-4.84	1687
MA01-0006	1.51	0-30	2.16	3.92	2.07	3.56	471
		30-45	2.17	4.75	1.96	4.21	614
		45-60	0.54	2.61	0.23	1	1530
		60+	1.95	8.43	-1.95	-8.43	19*
MA01-0007	2.85	0-30	9.88	10.52	9.88	10.52	9*
		30-45	8.34	10.02	5.44	6.4	16*
		45-60	5.4	10.31	4.97	9.69	195
		60+	1.62	4.25	1.33	3.38	2726
MA01-0008	2.41	0-30	5.27	6.5	5.27	6.5	11*
		30-45	3.92	6.46	3.15	5.19	18*
		45-60	5.04	7.91	-0.29	-0.13	28
		60+	0.69	2.92	-0.38	-1.18	2793
MA01-0009	2.30	0-30	5.74	6.33	5.37	5.75	75
		30-45	10.25	11.53	9	9.81	30*
		45-60	6.18	9.96	6.07	9.73	337
		60+	3.31	6.26	3.27	6.11	2240
MA01-0010	2.58	0-30	1.31	1.96	1.01	1.43	90
		30-45	3.64	4.73	2.51	2.68	46
		45-60	3.62	5.96	2.04	3.17	59
		60+	0.76	2.95	-0.21	-1.02	2568
MA01-0011	1.66	0-30	6.68	7.51	6.67	7.45	97
		30-45	10.46	13.47	10.14	12.94	80
		45-60	5.12	9.25	4.35	8.01	168
		60+	1.15	3.75	0.24	0.91	2638

Path	Sensor distance	Speed Bin	Data Quality Measures for				No. of Obs.
			Avg. Absolute Speed Error		Speed Error Bias		
			SEM Band	Mean	SEM Band	Mean	
MA01-0012	2.13	0-30	2.48	3.36	2.4	3.11	42
		30-45	3.2	4.32	1.22	1.27	96
		45-60	3.22	5.5	0.67	1.66	137
		60+	0.73	3.14	-0.42	-1.42	2636
MA01-0013	2.22	0-30	9.05	10.74	8.99	10.65	86
		30-45	5.24	7.18	4.24	5.54	77
		45-60	5.2	9.64	4.93	9.26	1121
		60+	2.11	5.69	2.08	5.48	1617
MA01-0014	2.71	0-30	1.51	2.22	1.46	2.04	244
		30-45	2.81	4.46	2.36	2.78	87
		45-60	1.82	4.52	1.27	2.8	215
		60+	0.53	2.78	-0.32	-1.12	1442
MA01-0015	1.63	0-30	3.75	4.95	3.69	4.79	309
		30-45	4.4	5.94	3.81	4.69	212
		45-60	1.97	5.34	0.98	3.46	794
		60+	0.48	2.76	-0.03	0.23	1169
MA01-0016	1.11	0-30	3.78	5.08	2.38	2.84	51
		30-45	4.53	6.59	1.92	2.44	318
		45-60	2.7	6.06	1.42	3.99	1115
		60+	0.59	2.94	-0.1	0.27	1384
MA01-0017	2.81	0-30	1.86	2.47	1.83	2.37	110
		30-45	4.4	5.32	4.16	4.65	43
		45-60	1.38	3.5	1.12	2.87	593
		60+	0.29	2.07	-0.03	-0.05	1735

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	
0-30	0.81	1.66	0.31	0.52	2451
30-45	1.35	3.13	0.62	1.47	2036
45-60	1.99	5	1.7	3.79	8678
60+	0.89	3.4	0.02	-0.36	34651
All Speeds	1.1	3.59	0.36	0.51	47816

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	
0-30	42%	99%	0%	95%	2451
30-45	40%	95%	0%	83%	2036
45-60	45%	85%	0%	58%	8678
60+	62%	96%	0%	76%	34651

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.
			Avg. Absolute Speed Error		Speed Error Bias		
			SEM Band	Mean	SEM Band	Mean	
MA01-0001	1.95	0-30	0.43	1.46	-0.14	-0.24	15*
		30-45	0.84	1.58	-0.01	-0.06	180
		45-60	2.2	4.91	1.66	4.16	262
		60+	0.71	2.89	-0.45	-1.14	2751
MA01-0002	1.35	0-30	1.12	1.66	0.95	1.24	81
		30-45	0.49	1.61	-0.01	-0.09	35
		45-60	1.19	3.37	0.6	1.41	266
		60+	0.39	2.51	0.13	0.21	2834
MA01-0003	1.15	0-30	0.59	1.16	0.28	0.5	176
		30-45	0.71	1.78	0.68	1.17	35
		45-60	3.01	7.77	2.97	7.66	657
		60+	0.5	2.79	0.08	0.76	2350
MA01-0004	2.39	0-30	0.76	1.31	0.53	0.79	271
		30-45	0.8	2.3	0.64	1.61	66
		45-60	1.28	4.57	1.27	4.46	517
		60+	0.25	2.15	-0.2	-0.69	2062
MA01-0005	1.56	0-30	0.54	1.33	0.4	0.73	313
		30-45	1.04	3.4	0.13	0.35	83
		45-60	0.34	2.41	-0.29	-1.77	684
		60+	2.28	6.98	-2.28	-6.98	1687
MA01-0006	1.51	0-30	0.28	1.45	0.17	-0.02	471
		30-45	1.31	3.77	1.29	3.51	614
		45-60	0.35	2.33	-0.14	-0.36	1530
		60+	4.8	13.19	-4.8	-13.19	19*
MA01-0007	2.85	0-30	1.75	2.33	0.79	1.14	9*
		30-45	0.64	2.09	0.44	1.21	16*
		45-60	6.94	11.88	6.93	11.83	195
		60+	1.88	4.67	1.76	4.15	2726
MA01-0008	2.41	0-30	0.69	1.47	-0.52	-0.74	11*
		30-45	1.26	2.96	0.46	0.87	18*
		45-60	1.06	2.99	0.02	0.07	28
		60+	0.58	2.82	-0.37	-1.54	2793
MA01-0009	2.30	0-30	2.02	2.59	-0.65	-0.67	75
		30-45	2.61	3.87	2.01	2.61	30*
		45-60	6.85	10.73	6.85	10.69	337
		60+	2.56	5.51	2.55	5.42	2240
MA01-0010	2.58	0-30	1.26	1.85	-0.38	-0.38	90
		30-45	1.78	2.81	-1	-1.14	46
		45-60	1.98	4.13	0.6	1.8	59
		60+	0.84	3.12	-0.46	-1.65	2568
MA01-0011	1.66	0-30	1.12	1.88	0.06	0.2	97
		30-45	4.13	6.98	3.72	6.02	80
		45-60	3.55	7.91	3.49	7.73	168
		60+	0.45	2.99	-0.17	-1.28	2638

Path	Sensor distance	Speed Bin	Data Quality Measures for				No. of Obs.
			Avg. Absolute Speed Error		Speed Error Bias		
			SEM Band	Mean	SEM Band	Mean	
MA01-0012	2.13	0-30	1.66	2.48	-1.15	-1.52	42
		30-45	1.04	2.03	-0.73	-1.28	96
		45-60	0.98	3.13	0.59	1.7	137
		60+	0.69	3.15	-0.48	-1.8	2636
MA01-0013	2.22	0-30	1.7	3.21	1.28	2.43	86
		30-45	2.28	4.22	2.23	4.02	77
		45-60	4.78	9.27	4.75	9.23	1121
		60+	1.02	4.23	0.99	3.99	1617
MA01-0014	2.71	0-30	0.77	1.49	0.06	0.18	244
		30-45	0.45	1.68	-0.11	0.11	87
		45-60	1.7	4.49	1.42	3.43	215
		60+	0.3	2.41	-0.19	-0.88	1442
MA01-0015	1.63	0-30	1.05	2.1	0.92	1.74	309
		30-45	0.94	2.27	0.75	1.56	212
		45-60	0.55	2.69	0.32	1.81	794
		60+	0.68	3.62	-0.68	-3.62	1169
MA01-0016	1.11	0-30	0.69	1.67	-0.59	-1.07	51
		30-45	1.62	3.41	-0.75	-1.4	318
		45-60	1.71	4.95	1.16	3.91	1115
		60+	0.35	2.35	-0.33	-1.16	1384
MA01-0017	2.81	0-30	1.06	1.64	0.23	0.32	110
		30-45	1.49	2.34	1.12	1.46	43
		45-60	0.65	2.49	0.65	2.42	593
		60+	0.57	2.73	-0.57	-2.63	1735