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

Report for Georgia (#4)
Arterial Validation: US-80, GA-21, W/E Bay St.

Data Collection: October 23 – November 4, 2018
Report Date: April 2019

Prepared by:
Zachary Vander Laan, Sara Zahedian
University of Maryland, College Park

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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

- Savannah, GA near port of Savannah (see Figure 1)
- Arterial segments along US-80, GA-21, W/E Bay St chosen due to high freight volumes
- Number of validation segments: 28
- Directional miles: 41

WRTM sensors

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

Data collection:

- Dates: October 23 – November 4, 2018
- Total hours of data collection: 400 (across all sensors)
- Effective five-minute travel time samples observed: 37,759

ES Table 1 -- Arterial Corridor Description

Corridor Name	Number of Lanes	AADT	Speed Limit
US-80	2 to 4 lanes	11,000	35 to 45 mph
GA-21	2 to 5 lanes	16,000	45 to 50 mph
W Bay St	1 to 4 lanes	10,000	35 to 40 mph
E Bay St	2 to 4 lanes	10,000	30 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	1.64	3.9	1.44	3.06	1587
15-25 MPH	1.49	5.15	1.03	3.48	5316
25-35 MPH	1.15	5.33	0.33	2.66	11125
>35 MPH	1.58	4.88	-1.38	-2.74	19731
All Speeds	1.44	5.01	-0.42	-0.03	37759

- **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	1.94	4.47	1.74	3.78	1581
15-25 MPH	1.7	5.52	1.3	4.08	5310
25-35 MPH	1.79	6.47	1	4.08	11114
>35 MPH	1.55	5.03	-1.13	-1.7	19709
All Speeds	1.66	5.5	-0.04	1.05	37714

- **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	1.27	3.42	1.21	3.1	1587
15-25 MPH	1.46	5.42	0.96	3.84	5297
25-35 MPH	1.08	4.97	0.45	2.89	11090
>35 MPH	1.02	4.21	-0.73	-1.26	19605
All Speeds	1.11	4.57	-0.06	0.87	37579

- **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 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. The space-mean speed

[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)

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, $\text{SEM} = \frac{SD_{GT}}{\sqrt{n}}$. 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, $\text{AASE} = \frac{1}{n}\sum_{i=1}^{n}|S_P - S_{GT}|$. 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, $\text{SEB} = \frac{1}{n}\sum_{i=1}^{n} S_P - S_{GT}$. 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.

Slowdown analysis (optional on arterials)

The slowdown analysis is an offshoot of the traditional analysis, developed to provide a more intuitive measure of probe data's ability to capture congestion events. **The definition of a slowdown in this context is when traffic speeds (as identified by ground truth WRTM sensors) decrease by at least 15 mph for a period of one hour or more**.

An analyst visually compares ground truth and vendor speeds for each slowdown event, focusing on how well the vendor data captures the magnitude and duration of the speed reduction. Each slowdown is ultimately classified as 'Fully Captured', 'Partially Captured', or 'Failed to Capture' according to the following rules:

- A **Fully Captured slowdown** indicates that the probe data accurately characterized both the reduction in speed, and duration of the slowdown. The error in speed reduction or duration cannot exceed 20%.
- A **Partially Captured slowdown** indicates that the probe data reported a significant disruption to traffic, but the extent of speed reduction or duration of time were in error by more than 20%.
- **Failed to Capture** indicates that the probe data either completely missed the slowdown, or the extent of speed reduction or duration of the event were significant in error such that the slowdown would not be interpreted as a significant disruption to traffic.

Data Collection

Travel time samples were collected along 28 directional validation road segments in Savannah, GA between October 23 and November 4, 2018. These validation segments are located along US-80, GA-21, W Bay St and E Bay St, and are defined based on WRTM sensor locations, which are shown in Figure 1. The locations were chosen because the corridors are important arterial freight routes near the Port of Savannah.

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	GA-21	I-95	2	3	26300	6	32.18958	-81.19424	2.09
GA04-0001	Southbound	Sonny Dixon Interchange	5	1.44		45	32.16144	-81.18364	
A2	GA-21	Sonny Dixon Interchange	2	2	26600	2	32.16144	-81.18364	1.10
GA04-0002	Southbound	Crossgate Rd	4	1.81		50	32.14624	-81.17794	
A3	GA-21	Crossgate Rd	2	1	34000	5	32.14624	-81.17794	1.44
GA04-0003	Southbound	Bourne Ave	5	0.70		45	32.12655	-81.17006	
A4	GA-21	Bourne Ave	2	4	39000	20	32.12655	-81.17006	2.12
GA04-0004	Southbound	Minus Ave	4	1.89		45	32.10296	-81.14878	
A5	GA-21	Minus Ave	2	4	39000	25	32.10313	-81.14861	2.12
GA04-0005	Northbound	Bourne Ave	5	1.89		45	32.12663	-81.16987	
A6	GA-21	Bourne Ave	2	1	34000	9	32.12663	-81.16987	1.44
GA04-0006	Northbound	Crossgate Rd	4	0.70		45	32.14631	-81.17774	
A7	GA-21	Crossgate Rd	2	2	26600	4	32.14631	-81.17774	1.10
GA04-0007	Northbound	Sonny Dixon Interchange	4	1.81		50	32.16151	-81.18352	
A8	GA-21	Sonny Dixon Interchange	2	3	26300	10	32.16151	-81.18352	2.08
GA04-0008	Northbound	I-95	5	1.44		45	32.18967	-81.19398	
A9	US-80	Douglas Ct	2	0	21100	9	32.13052	-81.29362	1.06
GA04-0009	Eastbound	Patrick Ave	2	0.00		45	32.12517	-81.27664	
A10	US-80	Patrick Ave	2	2	21100	11	32.12517	-81.27664	1.20
GA04-0010	Eastbound	Collins St	4	1.67		45	32.11906	-81.25743	
A11	US-80	Collins St	2	5	23200	16	32.11906	-81.25743	1.46
GA04-0011	Eastbound	Continental Blvd	4	3.44		35	32.11130	-81.23486	
A12	US-80	Continental Blvd	2	3	23200	20	32.11130	-81.23486	2.69
GA04-0012	Eastbound	Dean Forest Rd	4	1.12		45	32.09260	-81.19659	
A13	US-80	Dean Forest Rd	2	0	21700	18	32.09260	-81.19659	2.25
GA04-0013	Eastbound	Chatham Pkwy	4	0.00		45	32.08690	-81.15940	
A14	US-80	Chatham Pkwy	2	3	21400	9	32.08690	-81.15940	1.16
GA04-0014	Eastbound	Burnsed Blvd	4	2.58		45	32.09655	-81.14314	

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								
A15	W Bay St	Burnsed Blvd	2	4	21400	12	32.09655	-81.14314	0.77
GA04-0015	Eastbound	Augusta Ave (Route 80)	3	5.17		35	32.09224	-81.13232	
A16	W Bay St	Augusta Ave (Route 80)	1	4	21694	13	32.09224	-81.13232	1.27
GA04-0016	Eastbound	Lathrop Ave	3	3.15		35	32.08646	-81.11180	
A17	W Bay St	Lathrop Ave	2	4	20000	5	32.08646	-81.11180	1.06
GA04-0017	Eastbound	Jefferson St	3	3.79		40	32.08181	-81.09463	
A18	E Bay St	Jefferson St	2	11	21000	13	32.08181	-81.09463	0.98
GA04-0018	Eastbound	President St	4	11.26		30	32.07544	-81.08107	
A19	E Bay St	President St	2	11	21000	15	32.07548	-81.08092	0.98
GA04-0019	Westbound	Jefferson St	3	11.18		30	32.08181	-81.09463	
A20	W Bay St	Jefferson St	2	4	20000	7	32.08181	-81.09463	1.06
GA04-0020	Westbound	Lathrop Ave	4	3.79		40	32.08646	-81.11180	
A21	W Bay St	Lathrop Ave	1	4	21085	12	32.08646	-81.11180	1.27
GA04-0021	Westbound	Augusta Ave (Route 80)	3	3.16		35	32.09224	-81.13232	
A22	W Bay St	Augusta Ave (Route 80)	2	4	21400	11	32.09224	-81.13232	0.78
GA04-0022	Westbound	Burnsed Blvd	4	5.10		40	32.09668	-81.14321	
A23	US-80	Burnsed Blvd	2	3	21400	12	32.09668	-81.14321	1.17
GA04-0023	Westbound	Chatham Pkwy	4	2.58		45	32.08690	-81.15940	
A24	US-80	Chatham Pkwy	2	1	21700	19	32.08690	-81.15940	2.25
GA04-0024	Westbound	Dean Forest Rd	4	0.44		45	32.09260	-81.19659	
A25	US-80	Dean Forest Rd	2	3	23200	20	32.09260	-81.19659	2.70
GA04-0025	Westbound	Continental Blvd	4	1.11		50	32.11152	-81.23485	
A26	US-80	Continental Blvd	2	5	23200	17	32.11152	-81.23485	1.42
GA04-0026	Westbound	Collins St	3	3.52		45	32.11906	-81.25743	
A27	US-80	Collins St	2	2	21100	14	32.11906	-81.25743	1.20
GA04-0027	Westbound	Patrick Ave	3	1.67		45	32.12517	-81.27664	
A28	US-80	Patrick Ave	2	0	21100	7	32.12517	-81.27664	1.06
GA04-0028	Westbound	Douglas Ct	2	0.00		45	32.13052	-81.29362	

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	1.64	3.9	1.44	3.06	1587
15-25	1.49	5.15	1.03	3.48	5316
25-35	1.15	5.33	0.33	2.66	11125
>35	1.58	4.88	-1.38	-2.74	19731
All Speeds	1.44	5.01	-0.42	-0.03	37759

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	53	90	-	76	1587
15-25	57	90	-	60	5316
25-35	65	92	-	52	11125
35+	61	88	-	61	19731

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	Standard TMC length	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	
GA04-0001	1.02	1.02	0-15	-	-	-	-	-
			15-25	4.04	4.04	23.67	23.67	2*
			25-35	1.4	1.4	9.88	9.88	19*
			35+	-1.66	1.79	-3.36	4.99	2139
GA04-0002	1.00	1.00	0-15	-	-	-	-	-
			15-25	9.57	9.57	18.15	18.15	9*
			25-35	1.92	1.92	8.61	8.64	694
			35+	-0.96	1.28	-0.66	4.86	1595
GA04-0003	1.51	1.51	0-15	3.45	3.45	5.48	5.48	14*
			15-25	4.41	4.43	9.09	9.15	89
			25-35	1.23	1.26	6.31	6.48	722
			35+	-0.63	0.95	-0.97	4.27	1333
GA04-0004	1.14	1.14	0-15	15.21	15.21	20	20	13*
			15-25	4.88	4.88	12.92	12.92	88
			25-35	0.89	1.02	4.49	4.89	467
			35+	-0.54	0.83	-0.93	3.01	1355
GA04-0005	0.81	0.81	0-15	13.62	13.62	21.11	21.11	7*
			15-25	3.44	3.44	13.06	13.06	231
			25-35	0.75	0.77	5.02	5.3	827
			35+	-0.64	0.74	-1.65	3.63	577
GA04-0006	0.37	0.37	0-15	0.59	0.68	1.94	2.26	6*
			15-25	3.83	3.83	12.18	12.3	87
			25-35	1.15	1.2	6.54	6.86	868
			35+	-0.46	0.87	0.24	4.33	1232
GA04-0007	0.28	0.28	0-15	1.97	1.97	2.57	2.74	15*
			15-25	6.36	6.36	11.97	11.97	3*
			25-35	1.01	1.2	5.91	6.2	365
			35+	-1.18	1.45	-2.1	4.7	1887
GA04-0008	0.59	0.59	0-15	1.1	1.16	2.5	2.64	91
			15-25	1.72	1.95	4.47	5.1	100
			25-35	0.6	0.84	3.46	4.31	423
			35+	-1.12	1.28	-2.68	4.41	1621
GA04-0009	0.86	0.86	0-15	10.36	10.36	12.56	12.56	3*
			15-25	6.25	6.25	12.27	12.27	2*
			25-35	1.55	1.8	6.38	7.97	10*
			35+	-3.88	3.89	-8.07	8.29	1203
GA04-0010	1.32	1.32	0-15	9.57	9.57	11.38	11.38	9*
			15-25	-1.76	1.76	-0.88	4.32	3*
			25-35	0.56	0.56	3.91	4.1	174
			35+	-0.98	0.98	-3.56	4.01	350
GA04-0011	1.34	1.34	0-15	7.92	7.92	17.96	17.96	14*

Path	Standard TMC length	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	
			15-25	3.03	3.03	8.35	8.35	201
			25-35	0.73	0.83	2.91	3.51	585
			35+	-0.34	0.34	-2.03	2.93	85
GA04-0012	1.35	1.35	0-15	27.46	27.46	29.91	29.91	1*
			15-25	3.24	3.24	10.51	10.54	54
			25-35	1.16	1.17	5.4	5.48	604
			35+	-0.34	0.61	-0.92	3.14	753
GA04-0013	1.02	1.02	0-15	-	-	-	-	-
			15-25	0.51	0.51	17.79	17.79	5*
			25-35	1.22	1.22	7.51	7.51	135
			35+	-0.36	0.63	-0.41	3.11	1414
GA04-0014	1.20	1.20	0-15	-	-	-	-	-
			15-25	0.88	0.88	5.51	5.74	153
			25-35	-0.34	0.57	-0.99	3.33	957
			35+	-2.7	2.7	-7.83	7.91	280
GA04-0015	1.15	1.15	0-15	2.32	2.32	9.12	9.12	17*
			15-25	-0.06	0.13	0.79	2.71	216
			25-35	-2.91	2.91	-7.11	7.23	924
			35+	-8.84	8.84	-14.78	14.78	292
GA04-0016	1.16	1.16	0-15	3.67	3.67	8.64	8.64	85
			15-25	1.7	1.74	4.34	4.69	947
			25-35	-0.03	0.39	-0.5	3.49	120
			35+	-0.95	0.95	-9.09	9.09	10*
GA04-0017	1.20	1.20	0-15	3.69	3.69	6.02	6.02	80
			15-25	0.47	0.74	1.26	2.9	544
			25-35	-1.41	1.47	-3.98	4.62	184
			35+	-6.27	6.27	-10.49	10.49	29*
GA04-0018	1.02	1.02	0-15	0.2	0.54	0.6	1.92	536
			15-25	-0.84	0.95	-2.37	3.05	401
			25-35	-4.2	4.2	-8.37	8.37	21*
			35+	-	-	-	-	-
GA04-0019	1.35	1.35	0-15	0.22	0.48	0.53	1.73	504
			15-25	-1.27	1.38	-2.95	3.5	504
			25-35	-3.65	3.65	-7.4	7.4	74
			35+	-8.85	8.85	-13.18	13.18	1*
GA04-0020	1.34	1.34	0-15	3.6	3.6	5.57	5.57	51
			15-25	0.79	0.91	1.87	3.16	518
			25-35	-0.81	1.01	-2.16	4.36	150
			35+	-2.86	2.86	-8.06	8.06	10*
GA04-0021	1.31	1.31	0-15	2.14	2.14	8.27	8.27	46
			15-25	0.51	0.68	1.46	3.09	377
			25-35	-0.79	0.83	-4.46	5.33	114
			35+	-3.14	3.14	-12.17	12.17	15*
GA04-0022	0.90	0.90	0-15	2.42	2.42	10.78	10.78	49
			15-25	0.39	0.45	2.88	3.81	407
			25-35	-0.5	0.54	-3.53	4.5	267
			35+	-5.46	5.46	-14.58	14.58	21*
GA04-0023	0.59	0.59	0-15	0.16	0.16	16.24	16.24	2*

Path	Standard TMC length	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	
			15-25	1.53	1.53	7.81	7.81	191
			25-35	-0.06	0.32	0.87	3.22	805
			35+	-1.85	1.86	-6.19	6.41	316
GA04-0024	0.28	0.28	0-15	30.81	30.81	31.9	31.9	3*
			15-25	5.04	5.04	15.41	15.41	29*
			25-35	1.69	1.7	7.04	7.14	621
			35+	-0.04	0.43	0.86	3.26	815
GA04-0025	0.39	0.39	0-15	2.18	2.18	3.92	3.97	26*
			15-25	1.09	1.27	7.3	7.67	76
			25-35	0.04	0.26	1.99	3.21	283
			35+	-1.79	1.81	-4.56	5.05	873
GA04-0026	0.81	0.81	0-15	10.08	10.08	19.96	19.96	12*
			15-25	1.42	1.49	10.6	10.76	71
			25-35	0.44	0.57	2.19	3.01	619
			35+	-1.21	1.21	-3.82	4	119
GA04-0027	1.16	1.16	0-15	8.24	8.24	16.46	16.46	3*
			15-25	4.39	4.39	13.47	13.47	6*
			25-35	0.82	0.87	3.38	3.6	79
			35+	-1.98	1.99	-5.69	5.87	360
GA04-0028	1.53	1.53	0-15	-	-	-	-	-
			15-25	9.78	9.78	15.31	15.31	2*
			25-35	1.8	1.8	7.65	8.4	14*
			35+	-2.9	2.93	-6.46	6.73	1046

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	1.94	4.47	1.74	3.78	1581
15-25	1.7	5.52	1.3	4.08	5310
25-35	1.79	6.47	1	4.08	11114
>35	1.55	5.03	-1.13	-1.7	19709
All Speeds	1.66	5.5	-0.04	1.05	37714

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	45	88	-	1581	1581
15-25	56	88	-	5310	5310
25-35	56	86	-	11114	11114
35+	62	88	-	19709	19709

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	Standard TMC length	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	
GA04-0001	2.09	2.09	0-15	-	-	-	-	-
			15-25	5.56	5.56	24.7	24.7	2*
			25-35	2.63	2.63	11.32	11.32	19*
			35+	-1.48	1.77	-2.56	5.13	2137
GA04-0002	1.10	1.10	0-15	-	-	-	-	-
			15-25	10.03	10.03	18.77	18.77	9*
			25-35	3.68	3.69	11.41	11.46	694
			35+	-0.61	1.2	1.08	5.35	1593
GA04-0003	1.44	1.44	0-15	6.69	6.69	9.31	9.31	14*
			15-25	5.53	5.53	10.4	10.4	89
			25-35	2.3	2.35	8.12	8.32	721
			35+	-0.57	1.18	-0.14	4.91	1332
GA04-0004	2.12	2.12	0-15	14.26	14.26	19.05	19.05	13*
			15-25	5.52	5.52	13.71	13.71	88
			25-35	1.82	1.99	6.04	6.51	466
			35+	-0.58	1.13	-0.52	3.56	1354
GA04-0005	2.12	2.12	0-15	8.32	8.32	15.81	15.81	7*
			15-25	3.79	3.79	13.31	13.37	231
			25-35	1.2	1.33	5.77	6.33	827
			35+	-0.8	1.05	-1.21	4.27	575
GA04-0006	1.44	1.44	0-15	0.36	0.88	1.47	2.56	6*
			15-25	5.8	6	14.16	14.65	85
			25-35	2.51	2.57	9.14	9.36	867
			35+	-0.38	1.04	1.14	4.96	1232
GA04-0007	1.10	1.10	0-15	2.71	2.71	4.38	4.38	15*
			15-25	8.75	8.75	14.36	14.36	3*
			25-35	2.38	2.51	8.51	8.75	365
			35+	-0.97	1.37	-1.18	4.94	1883
GA04-0008	2.08	2.08	0-15	1.15	1.16	2.53	2.61	91
			15-25	1.37	1.47	3.68	4.18	100
			25-35	1.69	1.95	6.41	7.1	423
			35+	-0.52	1.15	-0.38	4.52	1619
GA04-0009	1.06	1.06	0-15	1.53	2.18	2.32	4.45	3*
			15-25	4.25	4.25	2.12	7.48	2*
			25-35	0.73	2.81	5.43	10.01	10*
			35+	-3.29	3.3	-7.09	7.45	1203
GA04-0010	1.20	1.20	0-15	11.87	11.87	14.66	14.66	9*
			15-25	-0.39	0.39	2.27	4.43	3*
			25-35	0.74	0.84	3.72	4.63	173
			35+	-1.11	1.2	-3.32	4.39	349
GA04-0011	1.46	1.46	0-15	10.88	10.88	20.98	20.98	14*

Path	Standard TMC length	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	
			15-25	4.07	4.07	9.25	9.34	201
			25-35	1.52	1.64	4.47	4.96	584
			35+	-0.26	0.42	-1.42	2.87	85
GA04-0012	2.69	2.69	0-15	23.9	23.9	26.35	26.35	1*
			15-25	2.94	2.94	9.56	9.58	54
			25-35	1.63	1.69	5.63	6.06	603
			35+	-0.46	0.85	-0.46	3.77	752
GA04-0013	2.25	2.25	0-15	-	-	-	-	-
			15-25	1.48	1.48	18.34	18.34	5*
			25-35	1.97	2.01	8.49	8.7	135
			35+	-0.23	0.93	0.46	3.73	1412
GA04-0014	1.16	1.16	0-15	-	-	-	-	-
			15-25	1.65	1.87	6.81	7.78	153
			25-35	0.07	0.83	1.18	4.08	956
			35+	-2.01	2.11	-6.04	6.74	280
GA04-0015	0.77	0.77	0-15	2.74	2.74	9.91	9.91	17*
			15-25	-0.31	0.61	2.08	4.71	216
			25-35	-2.61	2.63	-5.89	6.47	922
			35+	-7.53	7.53	-13.28	13.28	292
GA04-0016	1.27	1.27	0-15	2.99	2.99	7.53	7.56	85
			15-25	1.15	1.35	3.04	3.92	945
			25-35	-0.46	0.67	-3.11	3.67	120
			35+	-3.46	3.46	-13.69	13.69	10*
GA04-0017	1.06	1.06	0-15	3.63	3.68	5.68	5.94	80
			15-25	0.85	1.27	2.19	3.71	544
			25-35	-0.92	1.13	-2.84	4.03	184
			35+	-6.17	6.17	-10.33	10.33	29*
GA04-0018	0.98	0.98	0-15	0.69	0.97	1.76	2.72	536
			15-25	-0.18	0.77	-0.47	2.8	401
			25-35	-2.81	2.81	-6.18	6.19	21*
			35+	-	-	-	-	-
GA04-0019	0.98	0.98	0-15	0.67	1	1.58	2.6	504
			15-25	-0.53	0.95	-1.28	2.97	503
			25-35	-2.89	2.89	-6.18	6.27	74
			35+	-5.38	5.38	-9.71	9.71	1*
GA04-0020	1.06	1.06	0-15	3.05	3.12	5.25	5.39	45
			15-25	0.9	1.21	2.39	3.82	518
			25-35	-1.07	1.16	-3.07	4.03	150
			35+	-3.81	3.81	-9.66	9.66	10*
GA04-0021	1.27	1.27	0-15	2.36	2.36	8.21	8.21	46
			15-25	0.79	0.96	2.01	3.63	376
			25-35	-0.74	0.74	-4.59	4.7	114
			35+	-3.28	3.28	-13.2	13.2	15*
GA04-0022	0.78	0.78	0-15	2.85	2.85	12.07	12.07	49
			15-25	0.77	0.84	4.41	5.09	407
			25-35	-0.4	0.48	-2.67	4.05	266
			35+	-5.17	5.17	-14.21	14.21	21*

Path	Standard TMC length	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	
GA04-0023	1.17	1.17	0-15	4.82	4.82	22.3	22.3	2*
			15-25	2.1	2.17	8.36	8.66	191
			25-35	0.14	0.63	2.24	4.35	804
			35+	-2.11	2.18	-5.93	6.39	315
GA04-0024	2.25	2.25	0-15	30.14	30.14	31.23	31.23	3*
			15-25	3.79	3.79	13.98	13.98	29
			25-35	2	2.22	6.81	7.55	621
			35+	-0.08	0.89	1	4.19	814
GA04-0025	2.70	2.70	0-15	1.91	1.91	3.82	3.88	26*
			15-25	1.68	1.81	8.32	8.67	76
			25-35	0.83	1.03	4.44	5.3	283
			35+	-1.2	1.42	-2.58	4.31	871
GA04-0026	1.42	1.42	0-15	10.75	10.75	20.69	20.69	12*
			15-25	2.38	2.38	12.35	12.35	71
			25-35	0.79	1.04	2.98	3.82	619
			35+	-1.22	1.22	-3.5	3.75	119
GA04-0027	1.20	1.20	0-15	3.39	3.39	11.61	11.61	3*
			15-25	4.99	4.99	14.43	14.43	6*
			25-35	1.38	1.5	5.01	5.61	79
			35+	-1.63	1.67	-4.35	5.16	360
GA04-0028	1.06	1.06	0-15	-	-	-	-	-
			15-25	8.59	8.59	14.11	14.11	2*
			25-35	2.14	2.74	7.61	10.75	14*
			35+	-2.24	2.3	-5.1	5.74	1046

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	1.27	3.42	1.21	3.1	1587
15-25	1.46	5.42	0.96	3.84	5297
25-35	1.08	4.97	0.45	2.89	11090
>35	1.02	4.21	-0.73	-1.26	19605
All Speeds	1.11	4.57	-0.06	0.87	37579

Table 9 shows the percentage of time the TOMTOM data falls within 5mph 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	61	93	-	81	1587
15-25	56	90	-	55	5297
25-35	68	92	-	59	11090
35+	68	93	-	67	19605

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	Standard TMC length	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	
GA04-0001	2.09	2.09	0-15	-	-	-	-	-
			15-25	4.88	4.88	24.38	24.38	2*
			25-35	1.54	1.54	10.17	10.17	19*
			35+	-1.43	1.57	-2.78	4.78	2126
GA04-0002	1.10	1.10	0-15	-	-	-	-	-
			15-25	7.34	7.34	15.31	15.31	9*
			25-35	1.63	1.65	7.28	7.48	694
			35+	-0.55	0.96	0.41	4.64	1582
GA04-0003	1.44	1.44	0-15	1.82	1.82	3.37	3.37	14*
			15-25	1.01	1.18	3.79	4.25	88
			25-35	0.36	0.64	3.56	4.47	718
			35+	-0.95	1.06	-2.48	4.31	1326
GA04-0004	2.12	2.12	0-15	8.68	8.68	13.01	13.01	13*
			15-25	4.28	4.28	12.42	12.46	88
			25-35	1.72	1.79	6.29	6.5	467
			35+	-0.06	0.59	1	3.01	1345
GA04-0005	2.12	2.12	0-15	9.49	9.49	16.98	16.98	7*
			15-25	2.5	2.5	11.49	11.54	231
			25-35	0.52	0.57	3.98	4.53	825
			35+	-0.76	0.8	-2.22	3.51	572
GA04-0006	1.44	1.44	0-15	0.01	0.23	0.38	1	6*
			15-25	3.22	3.29	11.39	11.66	87
			25-35	1.1	1.26	6.44	6.88	864
			35+	-0.49	0.76	-0.05	4.06	1224
GA04-0007	1.10	1.10	0-15	0.2	0.2	0.92	1.02	15*
			15-25	9.77	9.77	15.38	15.38	3*
			25-35	2.57	2.74	8.28	8.68	364
			35+	-0.47	0.96	0.15	4.47	1877
GA04-0008	2.08	2.08	0-15	0.13	0.36	0.64	1.34	91
			15-25	0.91	1.05	3.51	4.05	100
			25-35	2.72	2.89	8.82	9.16	422
			35+	0.2	0.63	2.13	4.03	1613
GA04-0009	1.06	1.06	0-15	0	0	0.04	1.11	3*
			15-25	2.28	3.52	-0.82	7.72	2*
			25-35	0.27	2.13	4.82	9.07	10*
			35+	-1.53	1.56	-4.31	5.05	1196
GA04-0010	1.20	1.20	0-15	5.89	6.15	6.95	7.56	9*
			15-25	0	0	2.4	2.79	3*
			25-35	1.35	1.41	6.01	6.17	174
			35+	-0.5	0.65	-1.62	3.27	346
GA04-0011	1.46	1.46	0-15	6.14	6.14	15.74	15.74	14*

Path	Standard TMC length	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	
			15-25	1.18	1.18	5.44	5.48	201
			25-35	-0.22	0.45	-0.64	2.47	582
			35+	-2.58	2.58	-7.18	7.18	82
GA04-0012	2.69	2.69	0-15	26.4	26.4	28.85	28.85	1*
			15-25	1.87	1.94	8.28	8.53	54
			25-35	0.92	0.93	4.41	4.67	604
			35+	-0.37	0.61	-1.13	3.24	742
GA04-0013	2.25	2.25	0-15	-	-	-	-	-
			15-25	0.5	0.5	18.38	18.38	5*
			25-35	1.86	1.86	8.73	8.73	135
			35+	-0.16	0.45	0.39	2.84	1408
GA04-0014	1.16	1.16	0-15	-	-	-	-	-
			15-25	1.38	1.38	7.33	7.34	151
			25-35	-0.1	0.32	0.58	2.73	955
			35+	-2.01	2.01	-7.08	7.08	279
GA04-0015	0.77	0.77	0-15	3.09	3.09	11.76	11.86	17*
			15-25	0.64	0.71	7.5	7.89	214
			25-35	-0.33	0.42	-0.04	3.14	920
			35+	-2.8	2.8	-7.87	7.87	291
GA04-0016	1.27	1.27	0-15	3.52	3.52	8.22	8.22	85
			15-25	2.3	2.33	5.34	5.6	942
			25-35	0.18	0.38	0.44	3.19	120
			35+	-0.57	0.57	-8.16	8.16	9*
GA04-0017	1.06	1.06	0-15	1.38	1.5	3.28	3.66	80
			15-25	0.17	0.51	0.8	2.38	544
			25-35	-1.87	1.87	-5.13	5.15	183
			35+	-9.9	9.9	-14.29	14.29	25*
GA04-0018	0.98	0.98	0-15	0.35	0.39	1.34	1.64	536
			15-25	-0.76	0.76	-2.73	2.74	397
			25-35	-7.96	7.96	-12.84	12.84	18*
			35+	-	-	-	-	-
GA04-0019	0.98	0.98	0-15	0.29	0.37	0.95	1.41	504
			15-25	-1.67	1.67	-4.03	4.03	502
			25-35	-10.28	10.28	-14.21	14.21	69
			35+	-18.67	18.67	-23	23	1*
GA04-0020	1.06	1.06	0-15	4.35	4.35	6.52	6.52	51
			15-25	0.67	0.72	2.25	2.94	516
			25-35	-0.88	0.88	-3.61	3.79	148
			35+	-6.48	6.48	-12.78	12.78	9*
GA04-0021	1.27	1.27	0-15	2.63	2.63	9.3	9.33	46
			15-25	1.04	1.1	3.62	4.24	376
			25-35	-0.27	0.27	-2.46	3.63	114
			35+	-1.54	1.54	-10.51	10.51	15*
GA04-0022	0.78	0.78	0-15	3.98	3.98	13.87	13.87	49
			15-25	1.21	1.24	6.14	6.37	407
			25-35	-0.08	0.15	-0.56	2.78	265
			35+	-3.17	3.17	-11.77	11.77	21*

Path	Standard TMC length	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	
GA04-0023	1.17	1.17	0-15	0.46	0.46	17.43	17.43	2*
			15-25	1.69	1.69	8.19	8.19	191
			25-35	0.04	0.31	1.12	2.99	805
			35+	-1.77	1.77	-6.47	6.47	311
GA04-0024	2.25	2.25	0-15	28.73	28.73	29.83	29.83	3*
			15-25	2.63	2.63	11.76	11.77	29*
			25-35	1.1	1.17	5.2	5.62	620
			35+	-0.26	0.53	-0.5	3.1	811
GA04-0025	2.70	2.70	0-15	0.79	0.86	2.5	2.73	26*
			15-25	1.03	1.06	8.15	8.33	76
			25-35	0.82	0.9	5.12	5.52	283
			35+	-0.56	0.73	-1.2	3.34	871
GA04-0026	1.42	1.42	0-15	6.05	6.05	14.31	14.31	12*
			15-25	-0.11	0.23	4.51	5.64	71
			25-35	-1.47	1.49	-3.66	4.01	619
			35+	-5.55	5.55	-9.71	9.71	118
GA04-0027	1.20	1.20	0-15	6.22	6.22	14.44	14.44	3*
			15-25	5.35	5.35	14.33	14.33	6*
			25-35	0.71	1.39	2.87	4.9	79
			35+	-1.96	2.01	-4.97	5.63	360
GA04-0028	1.06	1.06	0-15	-	-	-	-	-
			15-25	11.1	11.1	16.62	16.62	2*
			25-35	1.38	1.38	9.9	10.1	14*
			35+	-0.4	0.55	-1.57	3.17	1045

Slowdown Analysis Results

HERE

Table 11 summarizes the slowdown analysis results for HERE data. All 16 significant slowdowns observed during the data collection time period were captured, with 13 fully captured and the remaining three partially captured.

Table 11 – HERE Slowdown Analysis Summary

Significant Slowdowns	Fully Captured	Partially Captured	Not Captured
16	13	3	0

Figures 2 and 3 provide representative examples of each slowdown categorization for HERE data.

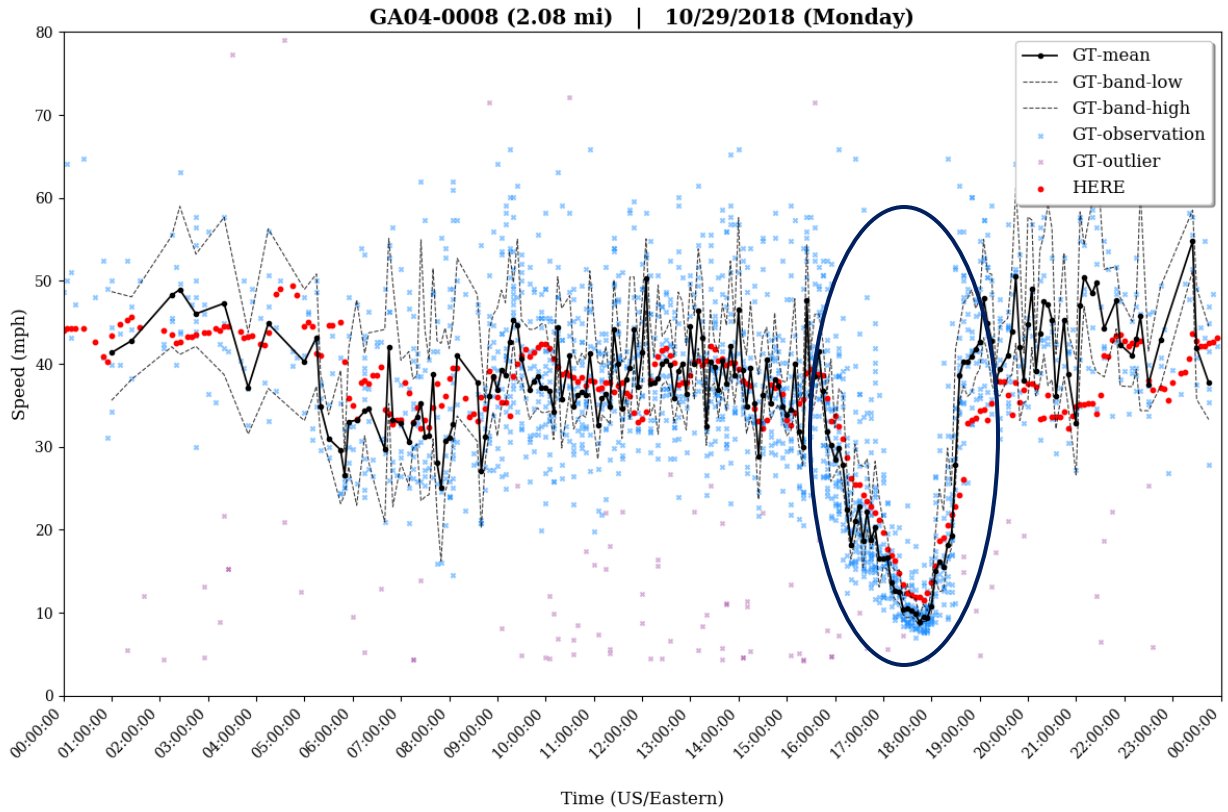

Figure 2 – HERE representative example of a fully captured slowdown.

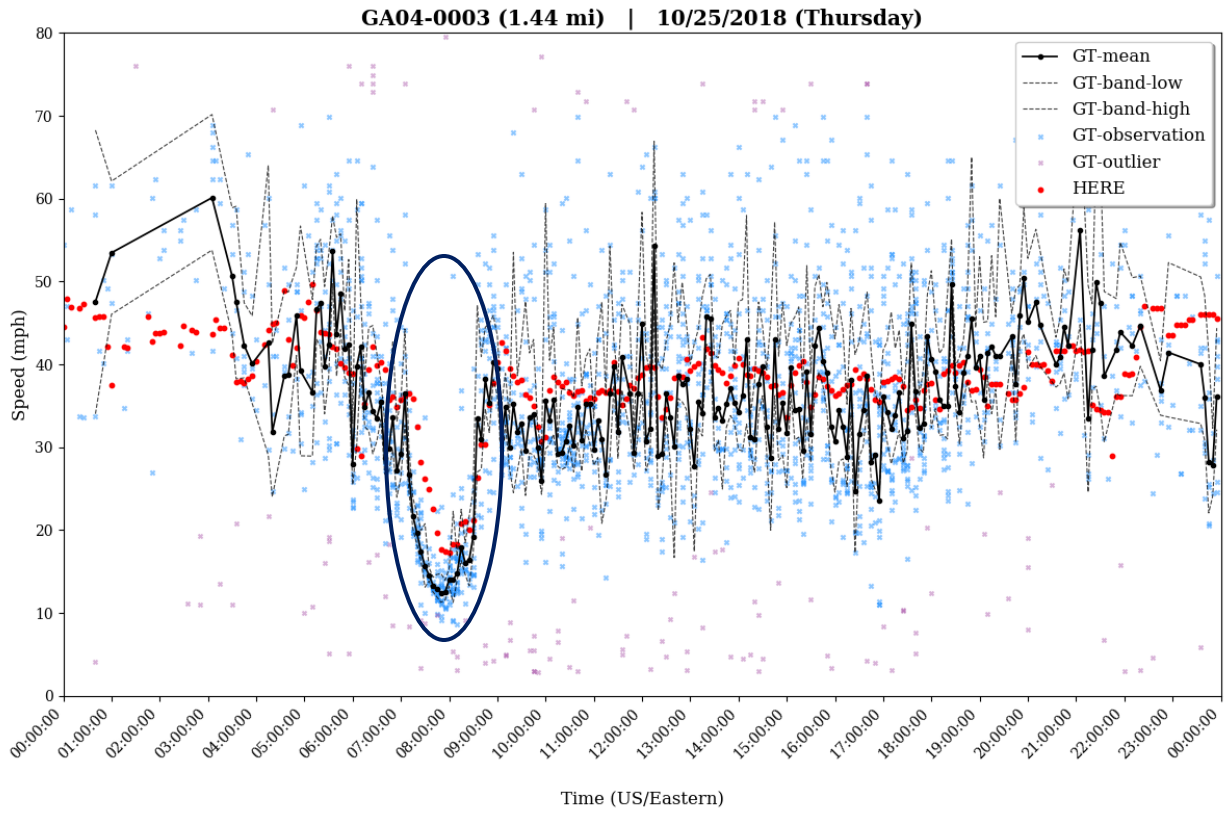

Figure 3 – HERE representative example of a partially captured slowdown.

INRIX

Table 12 summarizes the slowdown analysis results for INRIX data. 15 of the 16 significant slowdowns observed during the data collection time period were captured, with 12 fully captured, three partially captured, and one not captured.

Table 12 – INRIX Slowdown Analysis Summary

Significant Slowdowns	Fully Captured	Partially Captured	Not Captured
16	12	3	1

Figures 4-6 provide representative examples of each categorization for INRIX data.

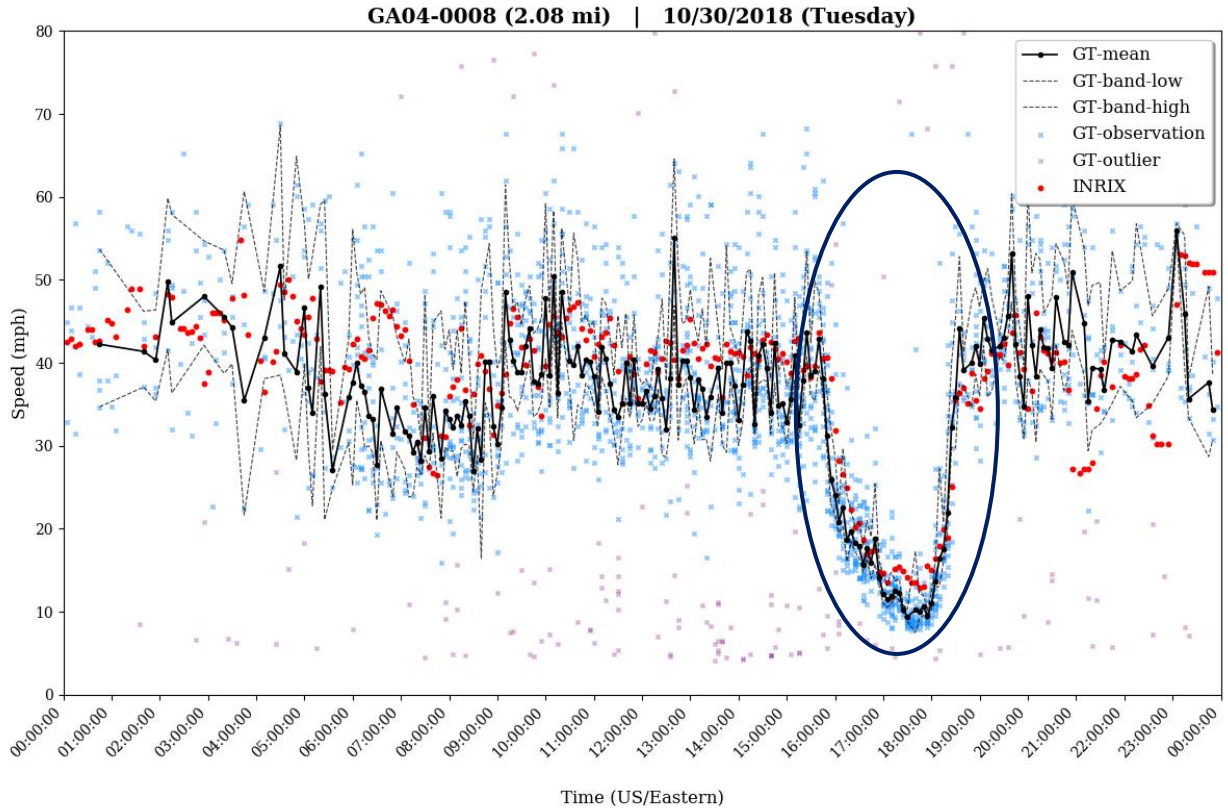

Figure 4 – INRIX representative example of a fully captured slowdown.

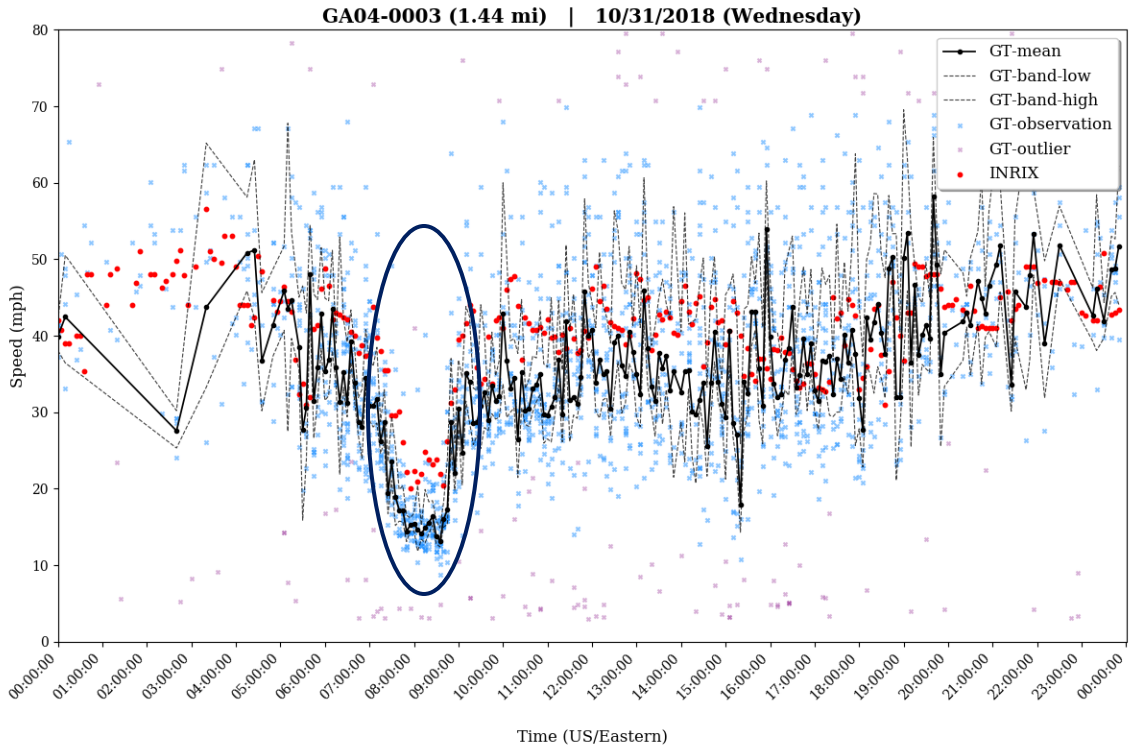

Figure 5 – INRIX representative example of a partially captured slowdown.

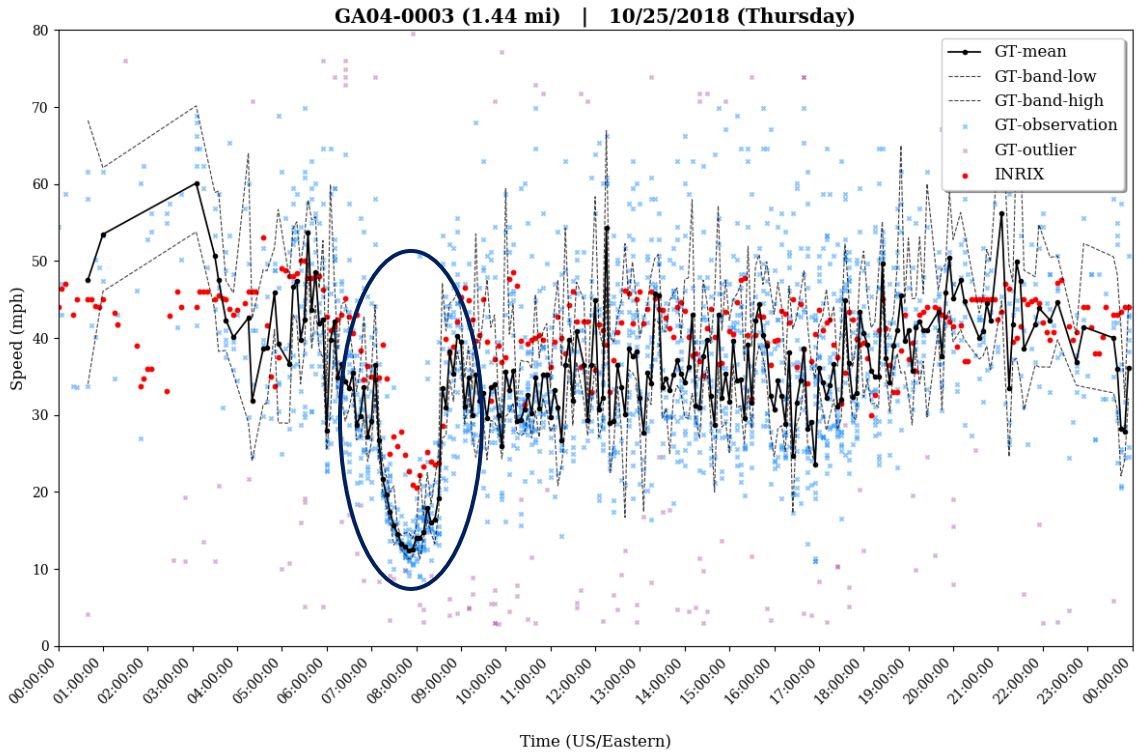

Figure 6 – INRIX representative example of failure to capture a slowdown

TOMTOM

Table 13 summarizes the slowdown analysis results for TOMTOM data. All 16 significant slowdowns observed during the data collection time period were captured, with 15 fully captured and one partially captured.

Table 13 – TOMTOM Slowdown Analysis Summary

Significant Slowdowns	Fully Captured	Partially Captured	Not Captured
16	15	0	1

Figures 7 and 8 provide representative examples of each slowdown categorization for TOMTOM data.

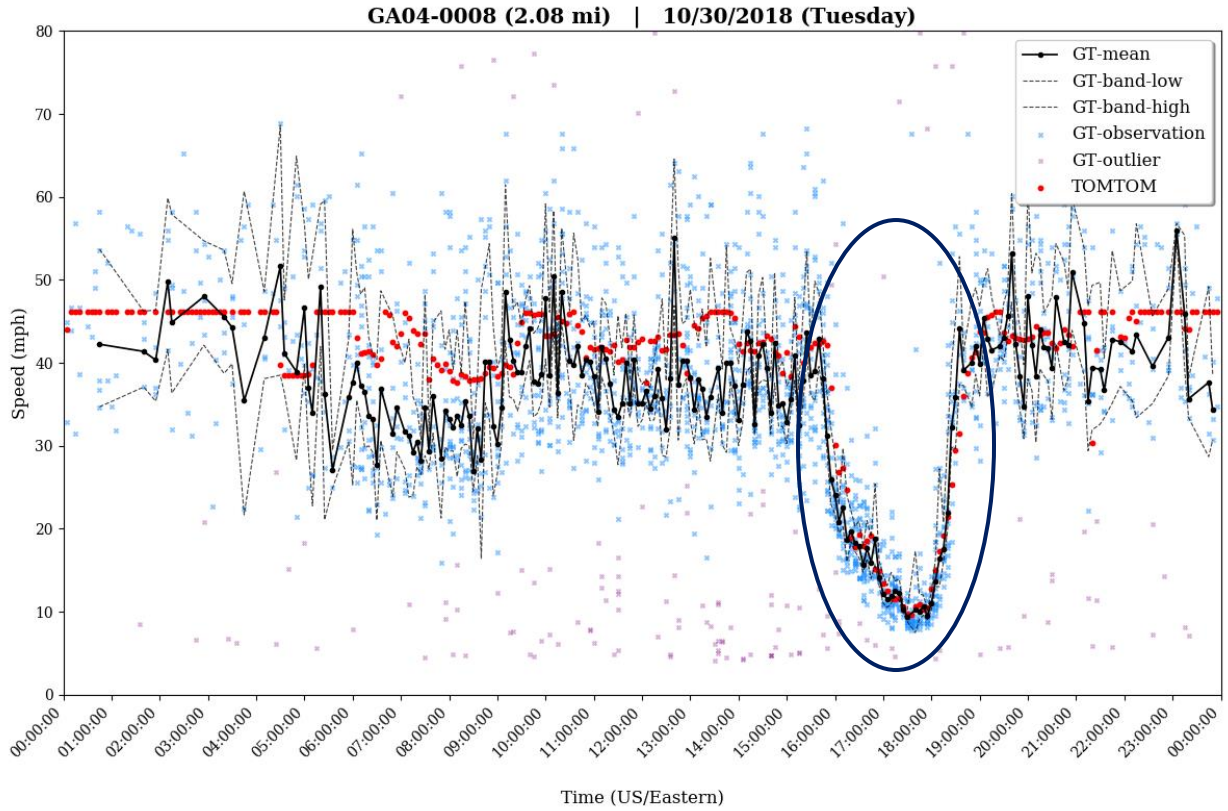

Figure 7 – TOMTOM representative example of a fully captured slowdown.

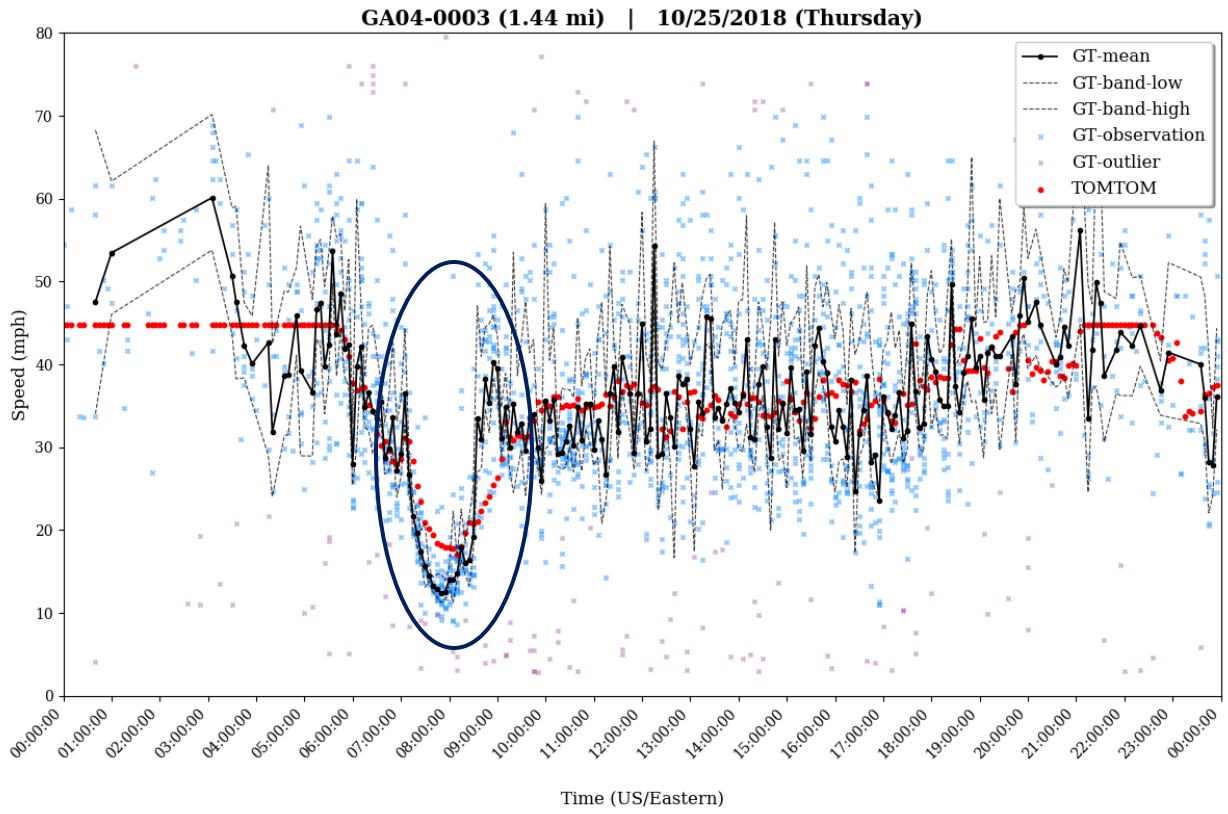

Figure 8 – TOMTOM representative example of failure to capture a slowdown.