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

Report for New Jersey (#15)
Arterial Validation: US-1

Data Collection: June 2019
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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

- Lawrence Township, NJ (see Figure 1)
- Arterial segments along US-1
- Number of traffic signals: 24
- Number of validation segments: 34
- Directional miles: 24
- 4 segments with hard-shoulder running M-F, 6-9AM, 4-7PM

WRTM sensors

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

Data collection:

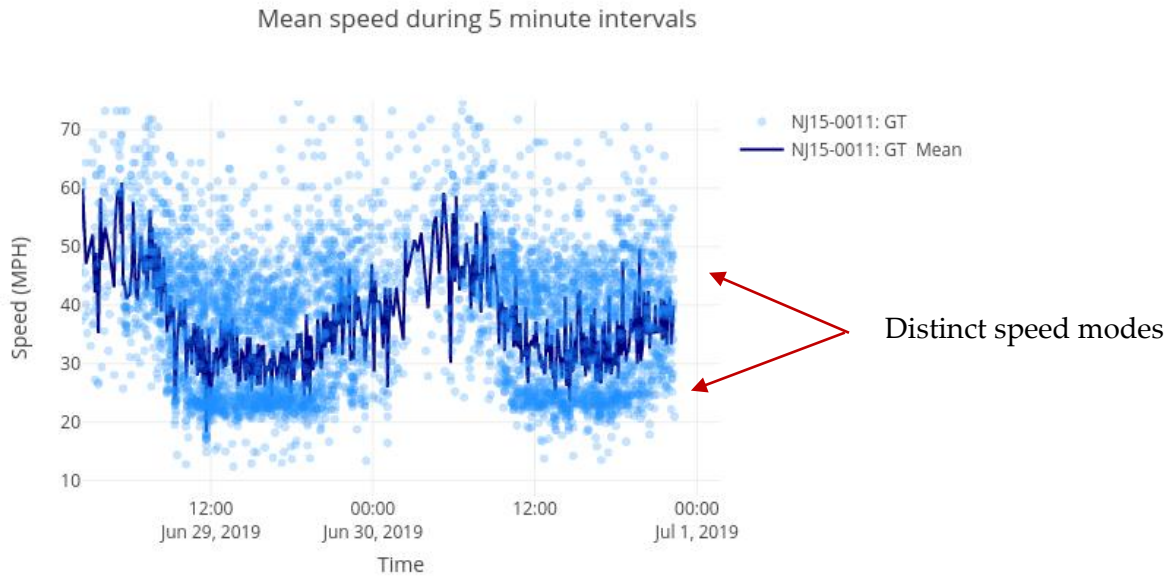
- Dates: June 19-28, 2019
- Effective five-minute travel time samples observed: 92,135

ES Table 1 -- Arterial Corridor Description

Corridor Name	Number of Lanes	AADT	Speed Limit
US-1	2 to 5 directional lanes	82,000	50 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)

Two types of analyses are used to quantify probe data accuracy in this report: the "traditional analysis", and the "slowdown analysis". Although the traditional analysis has historically been the primary analysis technique used for evaluating probe data, it describes ground truth traffic conditions in terms of the reference WRTM mean speed (or confidence band around the WRTM mean) - a perspective that is useful for summarizing "average" or "typical" speeds but cannot capture the complexity of multi-modal traffic flow commonly observed on signalized arterials (as is the case for the US-1 study corridor in New Jersey). For example, Figure ES1 shows bi-modal speed data along the US-1 corridor, where blue dots are individual ground truth WRTM speed observations and the solid blue line represents the space mean speed. Note that the the mean WRTM speed lies in between two distinct speed modes, and thus the "ground truth" typical speed may be a speed at which no actual vehicles travel. **Accordingly, the resulting traditional analysis metrics should be interpreted with caution, recognizing that this approach CAN describe how well vendor data captures average behavior for each time period, but CANNOT specify whether errors are caused by (a) vendor data not tracking observed reference data, or (b) vendor data tracking a legitimate speed mode that differs from the mean. For a more complete view of performance, the slowdown analysis results should also be considered.**



ES Figure 1: Example of bimodal traffic speeds

Results of both the traditional and slowdown analyses are summarized below in ES Tables 2-7. In the case of the traditional analysis, 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 (AASE <= 10 mph, SEB <= 5 mph).

ES Tables 2 and 3 summarize **HERE**'s traditional and slowdown analysis results, respectively.

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	
0-15 MPH	5.47	6.48	5.39	6.27	697
15-25 MPH	6.62	9.39	6.58	9.26	4164
25-35 MPH	4.66	8.76	4.61	8.54	18209
>35 MPH	1.34	4.77	0.18	0.85	69039
All Speeds	2.27	5.78	1.38	2.79	92109

- **AASE**: Within specification (< 10 mph) in all speed bins
- **SEB**: Within specification (< 5 mph) in upper two speed bins when compared to the SEM band, but not within specification for lowest two speed bins

ES Table 3 -- HERE Slowdown Analysis Summary			
Significant Slowdowns	Fully Captured	Partially Captured	Not Captured
66	28	30	8

ES Tables 4 and 5 summarize **INRIX**'s traditional and slowdown analysis results, respectively.

ES Table 4 – 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	
0-15 MPH	4.28	5.32	4.24	5.18	697
15-25 MPH	6.94	9.71	6.9	9.59	4164
25-35 MPH	5.02	9.23	4.98	9.05	18208
>35 MPH	1.46	4.92	0.09	0.55	69064
All Speeds	2.43	5.99	1.4	2.67	92133

- **AASE**: Within specification (< 10 mph) in all speed bins
- **SEB**: Within specification (< 5 mph) in all but the 15-25 mph speed bin when compared to the SEM band.

ES Table 5 -- INRIX Slowdown Analysis Summary			
Significant Slowdowns	Fully Captured	Partially Captured	Not Captured
66	43	21	2

ES Tables 6 and 7 summarize **TomTom**'s traditional and slowdown analysis results, respectively.

ES Table 6 – 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	
0-15 MPH	0.69	1.53	0.57	1.1	697
15-25 MPH	1.59	3.82	1.54	3.53	4164
25-35 MPH	1.69	4.99	1.62	4.33	18209
>35 MPH	1.12	4.34	0.11	0.61	69065
All Speeds	1.25	4.42	0.48	1.48	92135

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

ES Table 7-- TomTom Slowdown Analysis Summary			
Significant Slowdowns	Fully Captured	Partially Captured	Not Captured
66	66	0	0

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[2] .

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.

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

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) mean speeds against vendor mean 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[3] 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

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

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 (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 the ground truth mean speed.

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.

Slowdown analysis

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 34 directional validation road segments in Lawrence Township, NJ between June 19 and June 28, 2019. These validation segments are located along US-1, 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.

A small section of the US-1 study area uses hard-shoulder running (HSR) during peak periods on weekdays (6-9 AM, 4-7 PM Monday – Friday). The orange sensor locations in Figure 1 indicate this area, which corresponds to validation segments NJ15-0006, NJ15-0007, NJ15-0028, NJ15-0029.

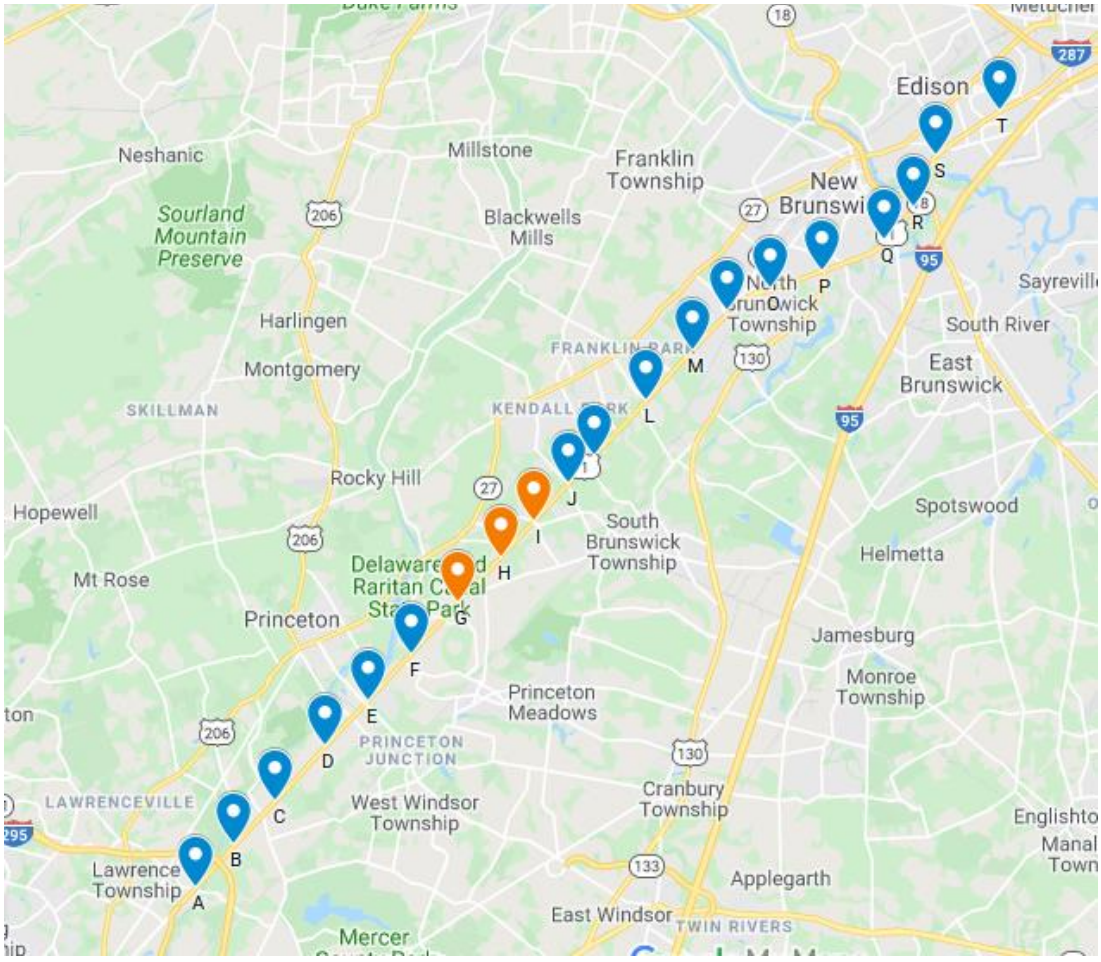


Figure 1 – WRTM Sensor locations

Table 1 - Validation Segment Attributes

Segment (Map Link)	DESCRIPTION						Deployment	
	Highway Direction	Starting at Ending at	Lane (Min) Lane (Max)	Signals Signal/mile	AADT	Access Points Speed Limit	Begin Lat/Lon End Lat/Lon	Length (mile)
	Arterial							
A1	US-1	Bakers Basin Rd	2	0	74978	4	"40.2752 -74.7060"	1.132
NJ15-0001	Northbound	Grovers Mill Rd	2	0		55	"40.2873 -74.6914"	
A2	US-1	Grovers Mill Rd	2	0	128151	10	"40.2873 -74.6914"	1.317
NJ15-0002	Northbound	Quakerbridge Rd	4	0		55	"40.3013 -74.6744"	
A3	US-1	Quakerbridge Rd	3	3	97552	18	"40.3013 -74.6744"	2.948
NJ15-0003	Northbound	Fisher PI	4	1.02		55	"40.3326 -74.6365"	
A4	US-1	Fisher PI	3	1	85621	8	"40.3326 -74.6365"	1.323
NJ15-0004	Northbound	Forrestal Rd	3	0.76		55	"40.3467 -74.6195"	
A5	US-1	Forrestal Rd	3	1	67806	7	"40.3467 -74.6195"	1.408
NJ15-0005	Northbound	Independence Way	4	0.75		55	"40.3616 -74.6014"	
A6	US-1	Independence Way	2	1	61134	8	"40.3616 -74.6014"	1.34
NJ15-0006	Northbound	Deerpark Dr	3	0.99		55	"40.3758 -74.5840"	
A7	US-1	Deerpark Dr	2	1	58446	5	"40.3758 -74.5840"	1.008
NJ15-0007	Northbound	CR 522	4	2.83		55	"40.3865 -74.5710"	
A8	US-1	CR 522	2	3	61023	6	"40.3865 -74.5710"	1.061
NJ15-0008	Northbound	New Rd	3	1.64		55	"40.3978 -74.5573"	
A9	US-1	New Rd	2	4	59784	11	"40.3978 -74.5573"	2.438
NJ15-0009	Northbound	Hendorson Rd	2	2.11		55	"40.4236 -74.5258"	
A10	US-1	Hendorson Rd	2	3	64371	10	"40.4236 -74.5258"	1.423
NJ15-0010	Northbound	Main St	3	0.96		55	"40.4387 -74.5074"	
A11	US-1	Main St	3	1	70231	10	"40.4387 -74.5074"	1.037
NJ15-0011	Northbound	Adams Ln	4	2.18		55	"40.4497 -74.4940"	
A12	US-1	Adams Ln	3	1	76340	4	"40.4497 -74.4940"	1
NJ15-0012	Northbound	Bishop Blvd	4	1		55	"40.2752 -74.7060"	

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	US-1	Bishop Blvd	3	2	76101	7	"40.4565 -74.4778"	1.095
NJ15-0013	Northbound	Carolier Ln	3	1.82		55	"40.4618 -74.4583"	
A14	US-1	Carolier Ln	3	0	102904	5	"40.4618 -74.4583"	0.879
NJ15-0014	Northbound	Technology Way	5	0		55	"40.4661 -74.4426"	
A15	US-1	Technology Way	3	0	110192	7	"40.4661 -74.4426"	1.699
NJ15-0015	Northbound	Burnet St	4	0		50	"40.4823 -74.4191"	
A16	US-1	Burnet St	3	0	97291	6	"40.4823 -74.4191"	1.12
NJ15-0016	Northbound	Leo St	3	0		50	"40.4971 -74.4114"	
A17	US-1	Leo St	3	3	90012	10	"40.4971 -74.4114"	1.661
NJ15-0017	Northbound	old Post Rd	3	1.81		50	"40.5107 -74.3855"	
A18	US-1	old Post Rd	3	3	89912	1	"40.5107 -74.3859"	1.648
NJ15-0018	Southbound	Leo St	3	1.82		50	"40.4971 -74.4116"	
A19	US-1	Leo St	2	0	97506	4	"40.4971 -74.4116"	1.115
NC08-0019	Southbound	Burnet St	3	0		50	"40.4824 -74.4192"	
A20	US-1	Burnet St	3	0	109749	9	"40.4824 -74.4192"	1.697
NJ15-0020	Southbound	Technology Way	3	0		50	"40.4663 -74.4426"	
A21	US-1	Technology Way	3	0	101377	6	"40.4663 -74.4426"	0.878
NJ15-0021	Southbound	Carolier Ln	4	0		55	"40.4620 -74.4583"	
A22	US-1	Carolier Ln	3	2	77145	9	"40.4620 -74.4583"	1.096
NJ15-0022	Southbound	Bishop Blvd	3	1.82		55	"40.4566 -74.4779"	
A23	US-1	Bishop Blvd	3	1	76485	4	"40.4566 -74.4779"	1.004
NJ15-0023	Southbound	Adams Ln	4	1.00		55	"40.4498 -74.4941"	
A24	US-1	Adams Ln	3	1	70313	9	"40.4498 -74.4941"	1.039
NJ15-0024	Southbound	Main St	4	0.96		55	"40.4387 -74.5075"	

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								
A25	US-1	Main St	2	3	64147	7	"40.4387	-74.5075"	1.445
NJ15-0025	Northbound	Hendorson Rd	3	2.08		55	"40.4234	-74.5262"	
A26	US-1	Hendorson Rd	3	4	59813	7	"40.4234	-74.5262"	2.412
NJ15-0026	Southbound	New Rd	3	1.66		55	"40.3979	-74.5574"	
A27	US-1	New Rd	2	3	61012	5	"40.3979	-74.5574"	1.073
NJ15-0027	Southbound	CR 522	3	2.80		55	"40.3865	-74.5713"	
A28	US-1	CR 522	2	1	58418	5	"40.3865	-74.5713"	1.002
NJ15-0028	Southbound	Deerpark Dr	3	1.00		55	"40.3759	-74.5842"	
A29	US-1	Deerpark Dr	2	1	62092	4	"40.3759	-74.5842"	1.335
NJ15-0029	Southbound	Independence Way	3	0.75		55	"40.3617	-74.6015"	
A30	US-1	Independence Way	2	1	69309	8	"40.3617	-74.6015"	1.405
NJ15-0030	Southbound	Forrestal Rd	3	0.71		55	"40.3468	-74.6196"	
A31	US-1	Forrestal Rd	3	1	83087	6	"40.3468	-74.6196"	1.325
NJ15-0031	Southbound	Fisher PI	4	0.75		55	"40.3327	-74.6366"	
A32	US-1	Fisher PI	3	3	97205	12	"40.3327	-74.6366"	2.947
NJ15-0032	Northbound	Quakerbridge Rd	4	1.02		55	"40.3013	-74.6745"	
A33	US-1	Quakerbridge Rd	3	0	127044	6	"40.3013	-74.6745"	1.312
NJ15-0033	Southbound	Grovers Mill Rd	4	0		55	"40.2874	-74.6914"	
A34	US-1	Grovers Mill Rd	2	0	77079	5	"40.2874	-74.6914"	1.152
NJ15-0034	Southbound	Bakers Basin Rd	2	0		55	"40.2751	-74.7062"	

Validation Results

Traditional Validation Results

HERE

Table 2 summarizes the standard error metrics computed between ground truth (i.e., WRTM) and HERE speeds. Average Absolute Speed Error (AASE) is within specifications for all speed bins, while Speed Error Bias (SEB) is within specifications for the upper two bins when compared with the SEM band, but not for the lower two 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	5.47	6.48	5.39	6.27	697
15-25	6.62	9.39	6.58	9.26	4164
25-35	4.66	8.76	4.61	8.54	18209
>35	1.34	4.77	0.18	0.85	69039
All Speeds	2.27	5.78	1.38	2.79	92109

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	10.76	54.66	-	46.05	697
15-25	7.73	41.98	-	22.17	4164
25-35	23.25	58.43	-	26.43	18209
35+	60.2	90.87	-	60.6	69039

Tables 4 and 5 summarize the error metrics specifically for the four segments where hard shoulder running takes place. Since HSR is only active on weekdays during AM and PM peak

periods (i.e., M-F 6-9 AM and 4-7 PM), the metrics are reported separately during times when HSR is and is not active.

Data quality on HSR segments, which represents only about 12% of 5-minute intervals used in the overall evaluation, was similar during periods when HSR was active (Table 4) and inactive (Table 5). Data was generally only observed in the upper three speed bins, and in both cases AASE and SEB values were well within target values in the highest speed bin (35+ mph), but exhibited much higher error levels in the middle two (15-25 and 25-35 mph). Overall, the HSR segments only played a minor role in the overall error metrics with higher SEB values (i.e., the lowest three speed bins); the HSR segments only contributed one of 697 samples (0.1%) in the 0-15 mph band, 61 of 4164 (0.6%) in the 15-25 mph bin, and 1627 of 18,209 (8.9%) in the 25-35 mph bin.

Table 4– HERE data quality measures on HSR segments when HSR is active

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	-	-	-	-	-
15-25	11.05	13.67	10.9	13.33	31
25-35	7.9	14.72	7.88	14.68	513
>35	1.37	5.55	0.74	3.2	2292
All Speeds	2.66	7.29	2.15	5.39	2836

Table 5 – HERE data quality measures on HSR segments when HSR is inactive

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	6.83	7.78	6.83	7.78	1
15-25	15.93	21.43	15.93	21.43	30
25-35	7.96	14.8	7.96	14.77	1114
>35	1.62	5.89	1.21	4.03	6788
All Speeds	2.56	7.2	2.22	5.6	7933

Table 6 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 6 – 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	
NJ15-0001	1.132	0-15	-	-	-	-	-
		15-25	2.86	5.19	2.26	3.71	6
		25-35	2.55	4.54	2.55	4.53	9
		35+	1.29	4.81	-1.07	-3.53	2348
NJ15-0002	1.317	0-15	1.7	2.56	0.7	0.75	10
		15-25	1.67	3.62	-0.65	-0.19	15
		25-35	3.02	8.42	1.51	5.02	7
		35+	0.92	3.51	-0.38	-0.54	2727
NJ15-0003	2.948	0-15	2.65	3.45	2.53	3.02	65
		15-25	5.13	6.08	5.13	6.06	116
		25-35	8.83	10.5	8.82	10.33	103
		35+	2.09	5.26	1.91	4.31	2465
NJ15-0004	1.323	0-15	-	-	-	-	-
		15-25	0.69	1.91	0.66	1.1	22
		25-35	3.12	6.12	2.99	5.51	232
		35+	1.45	4.8	0.02	0.61	2510
NJ15-0005	1.408	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	10.19	14	10.19	14	6
		35+	2.04	5.74	-1.37	-2.89	2832
NJ15-0006	1.340	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	8.38	14.14	8.38	14.14	40
		35+	1.48	5.16	0.83	2.76	2657
NJ15-0007	1.008	0-15	-	-	-	-	-
		15-25	17.32	22.55	17.32	22.55	42
		25-35	8.24	15.79	8.24	15.79	1083
		35+	1.61	7.64	1.35	6.36	1549
NJ15-0008	1.061	0-15	3.34	4.5	3.33	4.42	102
		15-25	7.29	10.13	7.28	10.05	441
		25-35	4.42	8.4	4.36	8.18	1262
		35+	1.48	5.51	1.09	3.61	830
NJ15-0009	2.438	0-15	-	-	-	-	-
		15-25	3.52	5.32	3.52	5.29	145
		25-35	3.33	5.84	3.29	5.59	1129
		35+	1.23	4.51	0.7	2.25	1422
NJ15-0010	1.423	0-15	4.87	7.04	4.87	7.04	3
		15-25	4.58	7.34	4.56	7.28	553
		25-35	2.56	6.46	2.48	5.89	1215
		35+	1.19	5.12	0.03	0.64	944

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	
NJ15-0011	1.037	0-15	21.48	24.31	21.48	24.31	1
		15-25	6.08	10.06	6.08	10.06	235
		25-35	2.48	6.91	2.47	6.8	1286
		35+	0.84	4.76	0.32	2.07	1370
NJ15-0012	1.000	0-15	22.38	25.75	22.38	25.75	3
		15-25	14.55	21.42	14.55	21.42	8
		25-35	7.06	14.48	7.06	14.48	9
		35+	1.05	4.07	-0.84	-2.49	2876
NJ15-0013	1.095	0-15	14.49	15.74	14.49	15.52	9
		15-25	13.93	16.04	13.93	16.04	59
		25-35	9.41	13.59	9.36	13.49	832
		35+	2.56	7.64	2.35	6.6	1870
NJ15-0014	0.879	0-15	6.83	8.09	6.83	7.79	7
		15-25	12.9	18.56	12.9	18.56	1
		25-35	7.73	15.38	6.7	11.62	5
		35+	1.54	4.93	-1.46	-4.18	2482
NJ15-0015	1.699	0-15	7.6	8.51	7.13	7.3	7
		15-25	21.53	26.14	16.9	19.95	4
		25-35	11.76	14.72	11.76	14.72	9
		35+	0.92	3.45	0.73	2.31	2652
NJ15-0016	1.120	0-15	21.67	23.61	21.67	23.61	7
		15-25	6.29	9.16	4.61	5.78	12
		25-35	5.99	8.84	2.71	3.34	10
		35+	1.59	4.75	-1.46	-3.71	2737
NJ15-0017	1.661	0-15	4.61	5.62	4.61	5.62	111
		15-25	5.53	7.79	5.51	7.73	495
		25-35	4.57	7.97	4.53	7.78	1197
		35+	1.46	5.23	0.79	2.88	739
NJ15-0018	1.648	0-15	2.35	3.14	1.48	1.55	33
		15-25	5.65	8.77	5.43	8.45	73
		25-35	2.78	6.57	2.75	6.37	880
		35+	0.79	3.7	0.12	1.01	1614
NJ15-0019	1.115	0-15	7.13	8.04	7.13	8.01	6
		15-25	11.87	13.42	11.07	11.83	9
		25-35	5.16	12.78	5.16	11.82	4
		35+	0.92	3.7	-0.7	-2.13	2699
NJ15-0020	1.697	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	5.75	7.8	5.75	7.8	6
		35+	0.54	2.6	0.19	0.53	2744
NJ15-0021	0.878	0-15	-	-	-	-	-
		15-25	8.62	10.64	8.62	10.64	2
		25-35	12.2	14.96	12.2	14.96	11
		35+	0.81	3.68	-0.5	-1.58	2470
NJ15-0022	1.096	0-15	-	-	-	-	-
		15-25	12.98	15.6	12.98	15.6	115
		25-35	8.6	12.88	8.6	12.88	1330
		35+	2.31	7.43	2.06	6.42	1227

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	
NJ15-0023	1.004	0-15	-	-	-	-	-
		15-25	11.1	12.47	11.1	12.47	1
		25-35	5.69	11.33	5.69	11.33	227
		35+	1.02	5.36	0.63	3.15	2614
NJ15-0024	1.039	0-15	3.88	5.54	3.88	5.54	31
		15-25	5.94	9.57	5.93	9.53	228
		25-35	1.74	5.53	1.73	5.27	1558
		35+	1.08	5.18	-0.66	-0.88	1195
NJ15-0025	1.445	0-15	-	-	-	-	-
		15-25	6.31	8.65	6.31	8.62	535
		25-35	3.45	6.49	3.44	6.38	1557
		35+	1.25	4.5	0.77	2.41	800
NJ15-0026	2.412	0-15	0.61	1.13	0.61	1.13	2
		15-25	3.7	4.68	3.68	4.58	40
		25-35	4.96	7.93	4.92	7.84	942
		35+	1.61	4.75	1.42	3.74	1793
NJ15-0027	1.073	0-15	17.44	23.08	17.44	23.08	2
		15-25	8.41	13.07	8.41	13.07	451
		25-35	3.92	9.32	3.9	9.17	1290
		35+	1.12	5.76	0.46	2.42	852
NJ15-0028	1.002	0-15	-	-	-	-	-
		15-25	2.19	4.06	1.24	1.96	5
		25-35	5.82	12.53	5.82	12.42	233
		35+	1.14	5.16	0.62	2.74	2414
NJ15-0029	1.335	0-15	6.83	7.78	6.83	7.78	1
		15-25	5.85	7.07	5.85	7.07	14
		25-35	8.51	12.7	8.47	12.63	271
		35+	2.02	5.96	1.68	4.42	2460
NJ15-0030	1.405	0-15	0.06	1.28	0.06	1.17	9
		15-25	3.44	6.87	3.38	5.34	25
		25-35	1.54	5.19	-0.97	-2.61	37
		35+	1.75	4.42	-0.74	-1.45	2894
NJ15-0031	1.325	0-15	7.49	8.3	7.49	8.3	197
		15-25	8.2	9.65	8.16	9.53	233
		25-35	5.08	8.15	4.98	7.84	787
		35+	1.69	5.64	1.28	3.55	1577
NJ15-0032	2.947	0-15	0.58	1.17	0.41	0.45	26
		15-25	3.11	4.76	2.81	3.31	36
		25-35	1.72	3.42	0.38	0.69	48
		35+	0.97	3.1	-0.3	-0.5	2612
NJ15-0033	1.312	0-15	10.93	12.07	10.86	11.91	34
		15-25	8.21	9.8	8.02	9.4	118
		25-35	9.06	11.95	8.96	11.75	70
		35+	0.73	3.31	0.03	-0.39	2529
NJ15-0034	1.152	0-15	4.4	5.42	4.4	5.42	31
		15-25	6.1	8.7	6.07	8.37	125
		25-35	5.69	11.6	5.61	10.97	524
		35+	1.76	7.3	1.39	5.6	1535

INRIX

Table 7 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 7– 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	4.28	5.32	4.24	5.18	697
15-25	6.94	9.71	6.9	9.59	4164
25-35	5.02	9.23	4.98	9.05	18208
>35	1.46	4.92	0.09	0.55	69064
All Speeds	2.43	5.99	1.4	2.67	92133

Table 8 shows the percentage of time the INRIX data falls within 5 mph of the mean and SEM band for each speed bin.

Table 8– 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	8.61	63.99	-	51.65	697
15-25	7.16	37.3	-	21.23	4164
25-35	18.55	54.27	-	19.83	18208
35+	59.28	89.8	-	59.79	69064

Tables 9 and 10 summarize the error metrics specifically for the four segments where hard shoulder running takes place. Since HSR is only active on weekdays during AM and PM peak periods (i.e., M-F 6-9 AM and 4-7 PM), the metrics are reported separately during times when HSR is and is not active.

Data quality on HSR segments, which represents only about 12% of 5-minute intervals used in the overall evaluation, was similar during periods when HSR was active (Table 9) and inactive (Table 10). Data was generally only observed in the upper three speed bins, and in both cases AASE and SEB values were well within target values in the highest speed bin (35+ mph), but exhibited much higher error levels in the middle two (15-25 and 25-35 mph). Overall, the HSR segments only played a minor role in the overall error metrics with higher SEB values (i.e., the lowest three speed bins); the HSR segments only contributed one of 697 samples (0.1%) in the 0-15 mph band, 61 of 4164 (0.6%) in the 15-25 mph bin, and 1627 of 18,208 (8.9%) in the 25-35 mph bin.

Table 9 – INRIX data quality measures on HSR segments when HSR is active

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	-	-	-	-	-
15-25	11.17	13.72	11.03	13.33	31
25-35	9.42	16.23	9.41	16.17	513
>35	2.27	6.88	1.78	5.24	2292
All Speeds	3.66	8.64	3.26	7.31	2836

Table 10 – INRIX data quality measures on HSR segments when HSR is inactive

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	13.31	14.26	13.31	14.26	1
15-25	17.2	22.72	17.2	22.72	30
25-35	9.06	15.83	9.06	15.8	1114
>35	1.82	6.13	1.12	3.58	6792
All Speeds	2.89	7.56	2.3	5.37	7937

Table 11 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 11 – 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	
NJ15-0001	1.132	0-15	-	-	-	-	-
		15-25	2.5	4.16	2.28	2.98	6
		25-35	4.36	7.38	4.36	7.38	9
		35+	1.48	5.09	-1.21	-3.72	2348
NJ15-0002	1.317	0-15	1.25	2.09	0.62	0.7	10
		15-25	0.81	2.85	0.44	1.33	15
		25-35	1.94	6.42	1.05	3.52	7
		35+	1.26	4.03	-0.84	-1.69	2727
NJ15-0003	2.948	0-15	2.24	3.1	2.21	2.69	65
		15-25	4.24	5.22	4.24	5.22	116
		25-35	6.41	8.02	6.41	7.92	103
		35+	1.98	5.03	1.4	2.98	2465
NJ15-0004	1.323	0-15	-	-	-	-	-
		15-25	1.44	3.01	1.44	2.89	22
		25-35	3.08	6.1	3.07	5.81	232
		35+	1.85	5.34	-0.71	-0.72	2510
NJ15-0005	1.408	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	5.64	9.45	5.64	9.45	6
		35+	2.62	6.48	-1.61	-3.09	2832
NJ15-0006	1.340	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	9.14	14.92	9.14	14.92	40
		35+	1.77	5.59	0.8	2.55	2657
NJ15-0007	1.008	0-15	-	-	-	-	-
		15-25	17.81	23.04	17.81	23.04	42
		25-35	9.19	16.71	9.19	16.71	1083
		35+	1.99	8.13	1.55	6.34	1549
NJ15-0008	1.061	0-15	2.74	3.98	2.72	3.93	102
		15-25	7.17	9.95	7.15	9.85	441
		25-35	5.34	9.49	5.28	9.24	1262
		35+	1.84	6.22	1.02	3.35	830
NJ15-0009	2.438	0-15	-	-	-	-	-
		15-25	4.51	6.36	4.49	6.32	145
		25-35	4.16	6.85	4.09	6.63	1129
		35+	1.6	5.05	0.49	1.74	1422
NJ15-0010	1.423	0-15	5.14	7.31	5.14	7.31	3
		15-25	5.79	8.62	5.77	8.52	553
		25-35	3.47	7.72	3.37	7.32	1215
		35+	1.48	5.63	0.09	0.86	944

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	
NJ15-0011	1.037	0-15	29.18	32.01	29.18	32.01	1
		15-25	8.27	12.2	8.26	12.16	235
		25-35	3.4	8.24	3.38	8.06	1286
		35+	1.14	5.14	0.42	2.07	1370
NJ15-0012	1.000	0-15	33.19	36.55	33.19	36.55	3
		15-25	12.08	19.28	12.08	19.28	8
		25-35	7.38	14.26	5.82	11.85	9
		35+	0.92	3.8	-0.55	-1.6	2876
NJ15-0013	1.095	0-15	4.72	6.07	4.72	6.07	9
		15-25	7.81	9.94	7.77	9.79	59
		25-35	6.21	10.13	6.16	9.98	832
		35+	2	6.42	1.06	3.1	1870
NJ15-0014	0.879	0-15	2.97	4.38	0.88	1.25	7
		15-25	11.92	17.58	11.92	17.58	1
		25-35	8.37	16.02	6.5	11.42	5
		35+	0.74	3.54	0.46	1.49	2482
NJ15-0015	1.699	0-15	0.95	1.72	0.89	1.12	7
		15-25	6.18	9.19	1.84	3.29	4
		25-35	11.06	13.64	11.06	13.64	9
		35+	0.98	3.45	0.5	1.26	2652
NJ15-0016	1.120	0-15	12.95	14.9	12.95	14.9	7
		15-25	3.54	5.93	3.54	5.2	12
		25-35	5.27	8.23	5.07	5.6	10
		35+	1.05	4	-0.82	-2.54	2737
NJ15-0017	1.661	0-15	6.18	7.2	6.18	7.2	111
		15-25	7.01	9.32	7.01	9.32	495
		25-35	4.58	7.92	4.55	7.79	1196
		35+	1.4	4.94	0.23	1.23	739
NJ15-0018	1.648	0-15	3.57	4.43	3.54	4.35	33
		15-25	7.46	10.55	7.46	10.55	73
		25-35	3.52	7.4	3.5	7.31	880
		35+	0.91	3.93	0.04	0.82	1615
NJ15-0019	1.115	0-15	0.93	1.85	0.91	1.52	6
		15-25	6.89	8.39	6.24	6.92	9
		25-35	3.16	9.5	3.16	9.5	4
		35+	0.78	3.46	-0.43	-1.22	2699
NJ15-0020	1.697	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	4.84	6.56	4.84	6.56	6
		35+	0.82	3.08	-0.13	-0.49	2746
NJ15-0021	0.878	0-15	-	-	-	-	-
		15-25	8.91	10.94	8.91	10.94	2
		25-35	5.91	8.48	5.91	8.48	11
		35+	1.95	5.53	-1.87	-4.96	2470
NJ15-0022	1.096	0-15	-	-	-	-	-
		15-25	8.92	11.53	8.9	11.5	115
		25-35	5.77	9.7	5.76	9.6	1330
		35+	1.69	5.92	0.97	3.4	1230

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	
NJ15-0023	1.004	0-15	-	-	-	-	-
		15-25	8.13	9.5	8.13	9.5	1
		25-35	5.5	10.87	5.5	10.83	227
		35+	1.26	5.74	0.66	2.89	2619
NJ15-0024	1.039	0-15	3.43	5.1	3.43	5.1	31
		15-25	6.81	10.46	6.81	10.46	228
		25-35	3.21	7.76	3.2	7.59	1558
		35+	1.37	5.88	-0.51	0.02	1196
NJ15-0025	1.445	0-15	-	-	-	-	-
		15-25	7.71	10.02	7.71	10.02	535
		25-35	4.57	7.71	4.5	7.47	1557
		35+	1.46	4.8	0.1	0.75	801
NJ15-0026	2.412	0-15	2.14	2.66	2.14	2.66	2
		15-25	4.65	5.75	4.65	5.75	40
		25-35	6.02	9.04	6.02	9.02	942
		35+	1.86	5.05	1.44	3.34	1795
NJ15-0027	1.073	0-15	17.95	23.6	17.95	23.6	2
		15-25	8.89	13.5	8.89	13.44	451
		25-35	4.66	10.13	4.65	9.94	1290
		35+	1.3	6.15	0.07	1.03	854
NJ15-0028	1.002	0-15	-	-	-	-	-
		15-25	0.68	1.86	-0.18	-0.56	5
		25-35	7.83	14.39	7.83	14.18	233
		35+	1.65	5.96	1.05	3.6	2416
NJ15-0029	1.335	0-15	13.31	14.26	13.31	14.26	1
		15-25	7.91	9.29	7.91	9.29	14
		25-35	10.23	14.43	10.21	14.39	271
		35+	2.35	6.32	1.88	4.48	2462
NJ15-0030	1.405	0-15	3.21	5.67	3.21	5.67	9
		15-25	7.98	12.32	7.98	12.32	25
		25-35	6.1	11.14	6.1	11.14	37
		35+	1.39	4.13	-0.42	-1.05	2896
NJ15-0031	1.325	0-15	5.33	6.14	5.33	6.14	197
		15-25	6.94	8.4	6.91	8.33	233
		25-35	5.77	8.85	5.71	8.64	787
		35+	1.56	5.45	0.65	2	1579
NJ15-0032	2.947	0-15	1.03	1.61	0.96	1.45	26
		15-25	3.35	5.26	3.14	4.94	36
		25-35	4.21	6.29	4.21	6.22	48
		35+	1.26	3.62	-0.29	-0.68	2612
NJ15-0033	1.312	0-15	2.42	3.4	2.4	2.98	34
		15-25	2.04	3.36	1.55	2	118
		25-35	4.9	7.58	4.2	6.12	70
		35+	0.88	3.59	-0.01	-0.47	2529
NJ15-0034	1.152	0-15	2.77	3.76	2.77	3.54	31
		15-25	5.6	8.28	5.57	7.8	125
		25-35	5.31	11.1	5.26	10.63	524
		35+	1.83	7.14	1.09	4.21	1535

TomTom

Table 12 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 12 – 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	0.69	1.53	0.57	1.1	697
15-25	1.59	3.82	1.54	3.53	4164
25-35	1.69	4.99	1.62	4.33	18209
>35	1.12	4.34	0.11	0.61	69065
All Speeds	1.25	4.42	0.48	1.48	92135

Table 13 shows the percentage of time the TomTom data falls within 5 mph of the mean and SEM band for each speed bin.

Table 13 – 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	44.91	98.71	-	96.27	697
15-25	42.27	90.83	-	73.82	4164
25-35	51.05	87.95	-	59.05	18209
35+	63.15	92.9	-	64.77	69065

Tables 14 and 15 summarize the error metrics specifically for the four segments where hard shoulder running takes place. Since HSR is only active on weekdays during AM and PM peak periods (i.e., M-F 6-9 AM and 4-7 PM), the metrics are reported separately during times when HSR is active versus inactive.

Speed data was well within the error target values for AASE and SEB in all speed bins when HSR was active (Table 14) and all speed bins except the 15-25 mph bin when HSR was inactive (Table 15). In both cases the data was particularly accurate in the highest speed bin. Overall, the HSR segments only played a minor role in the overall error metrics in the lowest three speed bins; the HSR segments only contributed one of 697 samples (0.1%) in the 0-15 mph band, 61 of 4164 (0.6%) in the 15-25 mph bin, and 1627 of 18,208 (8.9%) in the 25-35 mph bin.

Table 14 – TomTom data quality measures on HSR segments when HSR is active

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	-	-	-	-	-
15-25	2.63	4.86	2.51	4.12	31
25-35	2.66	7.92	2.66	7.82	513
>35	1.19	5.07	0.57	2.58	2292
All Speeds	1.47	5.58	0.97	3.55	2836

Table 15 – TomTom data quality measures on HSR segments when HSR is inactive

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	2.92	3.87	2.92	3.87	1
15-25	8.26	13.47	8.26	13.47	30
25-35	3.32	9.15	3.32	9.09	1114
>35	1.11	4.88	0.49	2.17	6792
All Speeds	1.45	5.51	0.92	3.18	7937

Table 16 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 16 – 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	
NJ15-0001	1.132	0-15	-	-	-	-	-
		15-25	2.52	4.42	2.52	4.42	6
		25-35	2.46	5.41	2.46	5.01	9
		35+	0.77	3.75	0.3	0.86	2348
NJ15-0002	1.317	0-15	0.78	1.43	0.7	1.14	10
		15-25	0.66	2.64	0.33	1.57	15
		25-35	4.22	8.71	4.22	8.71	7
		35+	0.85	3.52	0.55	1.78	2727
NJ15-0003	2.948	0-15	1.04	1.88	0.65	0.72	65
		15-25	1.2	2.04	1.18	1.87	116
		25-35	1.95	3.5	1.93	3.3	103
		35+	1.04	3.85	0.86	2.48	2465
NJ15-0004	1.323	0-15	-	-	-	-	-
		15-25	0.76	2.18	-0.71	-1.69	22
		25-35	0.68	2.82	0.39	1.46	232
		35+	1.66	4.88	-1.43	-3.13	2510
NJ15-0005	1.408	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	2.12	5.29	2.12	5.29	2832
		35+	1.4	4.88	-0.18	-0.19	40
NJ15-0006	1.340	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	3.53	8.82	3.53	8.75	2657
		35+	0.93	4.23	0.09	0.98	42
NJ15-0007	1.008	0-15	-	-	-	-	-
		15-25	7.2	11.98	7.2	11.98	1083
		25-35	2.5	8.5	2.5	8.41	1549
		35+	0.82	5.18	-0.24	0.88	102
NJ15-0008	1.061	0-15	0.59	1.63	0.54	1.43	441
		15-25	2.12	4.63	2.11	4.49	1262
		25-35	2.44	6.08	2.41	5.72	830
		35+	0.61	4.02	0.18	1.64	145
NJ15-0009	2.438	0-15	-	-	-	-	-
		15-25	1.64	3.3	1.58	3.06	1129
		25-35	1.71	4.1	1.69	3.88	1422
		35+	0.82	3.81	0.24	1.23	3
NJ15-0010	1.423	0-15	2.65	4.82	2.65	4.82	553
		15-25	0.71	2.64	0.67	2.3	1215
		25-35	0.38	2.92	0.17	0.69	944
		35+	1.02	4.75	-0.75	-2.37	1

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	
NJ15-0011	1.037	0-15	10.55	13.38	10.55	13.38	235
		15-25	2.06	5.57	2.06	5.57	1286
		25-35	1.1	4.65	1.09	4.21	1370
		35+	0.56	4.05	-0.26	-0.28	3
NJ15-0012	1.000	0-15	3.1	6.46	3.1	6.46	8
		15-25	0.78	3.04	0.78	2.07	9
		25-35	1.09	5.45	1.09	1.76	2876
		35+	2	5.47	-1.94	-4.8	9
NJ15-0013	1.095	0-15	0.66	1.92	0.58	0.69	59
		15-25	1.69	3.44	1.65	3.13	832
		25-35	1.83	4.98	1.79	4.73	1870
		35+	0.77	4.33	0.11	0.88	7
NJ15-0014	0.879	0-15	0.75	1.57	0.36	0.31	1
		15-25	0	3.36	0	3.36	5
		25-35	1.09	5.15	1.09	5.12	2482
		35+	1.37	4.59	1.26	3.71	7
NJ15-0015	1.699	0-15	0.46	1.16	-0.46	-0.83	4
		15-25	5.87	10.48	5.24	9.46	9
		25-35	3.98	6.75	3.98	6.75	2652
		35+	1.93	4.73	1.83	4.09	7
NJ15-0016	1.120	0-15	0.86	2.39	0.52	1.81	12
		15-25	0.4	2.37	0.4	1.21	10
		25-35	2.87	5.25	2.87	4.58	2737
		35+	0.68	3.34	-0.49	-1.73	111
NJ15-0017	1.661	0-15	1.22	2.17	1.22	2.15	495
		15-25	1.44	3.42	1.4	3.2	1197
		25-35	1.03	3.65	0.96	3.08	739
		35+	0.96	3.94	-0.82	-2.09	33
NJ15-0018	1.648	0-15	0.47	1.19	0.19	0.21	73
		15-25	1.73	4.46	1.69	4.3	880
		25-35	0.52	3.04	0.4	2.21	1615
		35+	0.98	3.73	-0.93	-2.68	6
NJ15-0019	1.115	0-15	0.31	0.88	-0.31	-0.81	9
		15-25	1.43	2.43	0.92	1.63	4
		25-35	2.38	10.16	2.38	10.16	2699
		35+	0.55	3.03	0.04	0.27	6
NJ15-0020	1.697	0-15	-	-	-	-	-
		15-25	-	-	-	-	-
		25-35	0.51	2.34	0.09	1.57	2746
		35+	0.82	3.01	0.66	1.79	2
NJ15-0021	0.878	0-15	-	-	-	-	-
		15-25	1.14	2.32	1.14	2.32	11
		25-35	0.63	2.65	0.63	2.65	2470
		35+	1.9	5.37	-1.85	-4.81	115
NJ15-0022	1.096	0-15	-	-	-	-	-
		15-25	3.79	6.23	3.79	6.13	1330
		25-35	2.88	6.49	2.88	6.45	1230
		35+	0.9	4.73	0.46	2.55	1

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	
NJ15-0023	1.004	0-15	-	-	-	-	-
		15-25	3.34	4.71	3.34	4.71	227
		25-35	7.6	13.3	7.6	13.29	2619
		35+	1.92	7.21	1.81	6.31	31
NJ15-0024	1.039	0-15	0.6	1.81	0.6	1.81	228
		15-25	3.26	6.73	3.26	6.72	1558
		25-35	1.29	4.94	1.29	4.65	1196
		35+	1.16	5	-1.09	-2.43	535
NJ15-0025	1.445	0-15	-	-	-	-	-
		15-25	0.89	2.64	0.87	2.39	1557
		25-35	0.65	2.8	0.32	0.8	801
		35+	1.01	3.93	-0.89	-2.3	2
NJ15-0026	2.412	0-15	0.45	0.67	0.45	0.44	40
		15-25	0.85	1.63	0.72	1.17	942
		25-35	2.4	5.11	2.39	5.02	1796
		35+	0.89	3.65	0.62	2.22	2
NJ15-0027	1.073	0-15	7.25	12.9	7.25	12.9	451
		15-25	1.54	4.73	1.54	4.55	1290
		25-35	0.77	4.12	0.7	2.99	854
		35+	1.05	5.11	-0.94	-3.03	5
NJ15-0028	1.002	0-15	-	-	-	-	-
		15-25	0.4	2.22	-0.4	-2.17	233
		25-35	4.93	11.12	4.93	11.07	2416
		35+	1.33	5.47	1.03	3.82	1
NJ15-0029	1.335	0-15	2.92	3.87	2.92	3.87	14
		15-25	1.79	2.87	1.79	2.81	271
		25-35	3.94	7.78	3.94	7.77	2462
		35+	1.35	4.97	0.94	3.02	9
NJ15-0030	1.405	0-15	1.73	3.59	1.73	3.59	25
		15-25	6.18	10.64	6.18	10.64	37
		25-35	6.06	11.48	6.06	11.48	2896
		35+	1.04	3.52	0.54	0.92	197
NJ15-0031	1.325	0-15	0.23	0.74	0.17	0.37	233
		15-25	0.72	1.76	0.67	1.47	787
		25-35	1.18	3.44	1.14	2.91	1579
		35+	0.66	3.91	-0.14	-0.62	26
NJ15-0032	2.947	0-15	0.94	1.53	0.48	0.84	36
		15-25	1.16	2.67	1.09	2.31	48
		25-35	1.25	3.15	1.25	3.01	2612
		35+	0.7	2.88	-0.18	-0.53	34
NJ15-0033	1.312	0-15	0.04	0.57	-0.01	-0.12	118
		15-25	0.4	1.5	-0.13	-0.56	70
		25-35	0.73	2.79	0.24	0.84	2529
		35+	0.82	3.57	0.45	1.05	31
NJ15-0034	1.152	0-15	0.71	1.78	0.71	1.52	125
		15-25	2.17	4.41	2.17	4.23	524
		25-35	3.75	9.37	3.72	8.99	1535
		35+	1.04	5.82	0.72	4.06	----------

Slowdown Analysis Results

HERE

Significant Slowdowns	Fully Captured	Partially Captured	Not Captured
66	28	30	8

HERE data captured 58 of the 66 significant slowdowns observed during the data collection time period. 28 of the 66 captured slowdowns were fully captured, while the remaining 30 were partially captured.

Figures 2-4 provide representative examples of significant slowdowns that were fully captured, partially captured, or not captured by HERE speed data. Each figure shows 24-hour speed data for both ground truth and HERE on a selected validation segment.

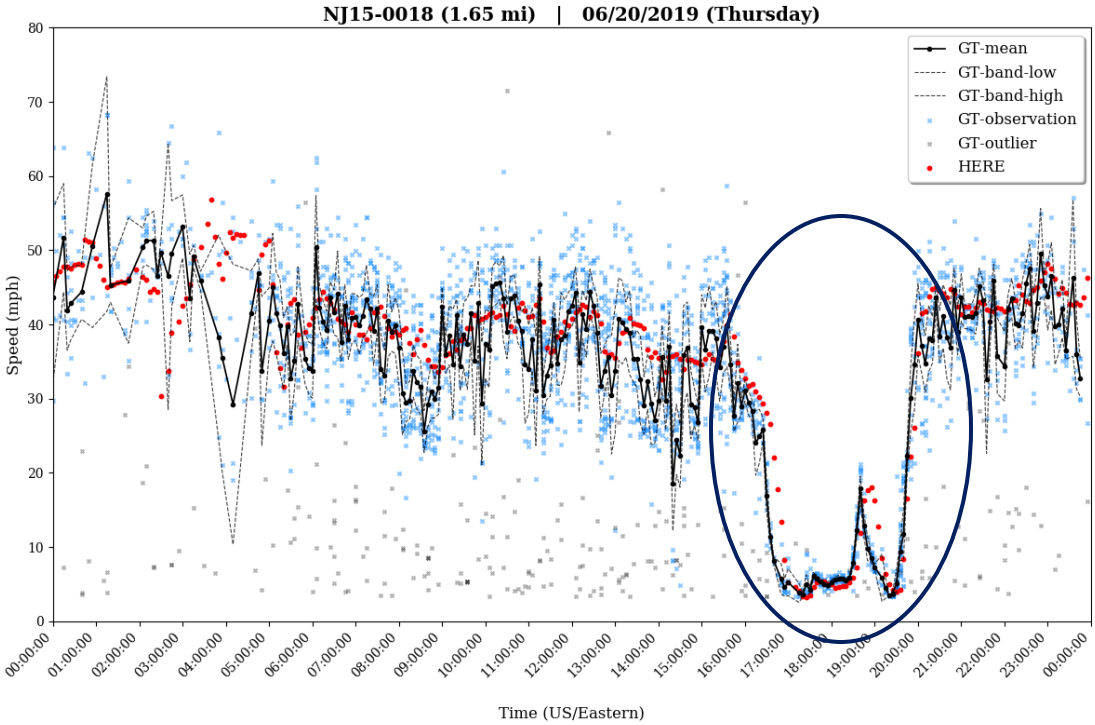


Figure 2 - Representative example of a fully captured slowdown: HERE

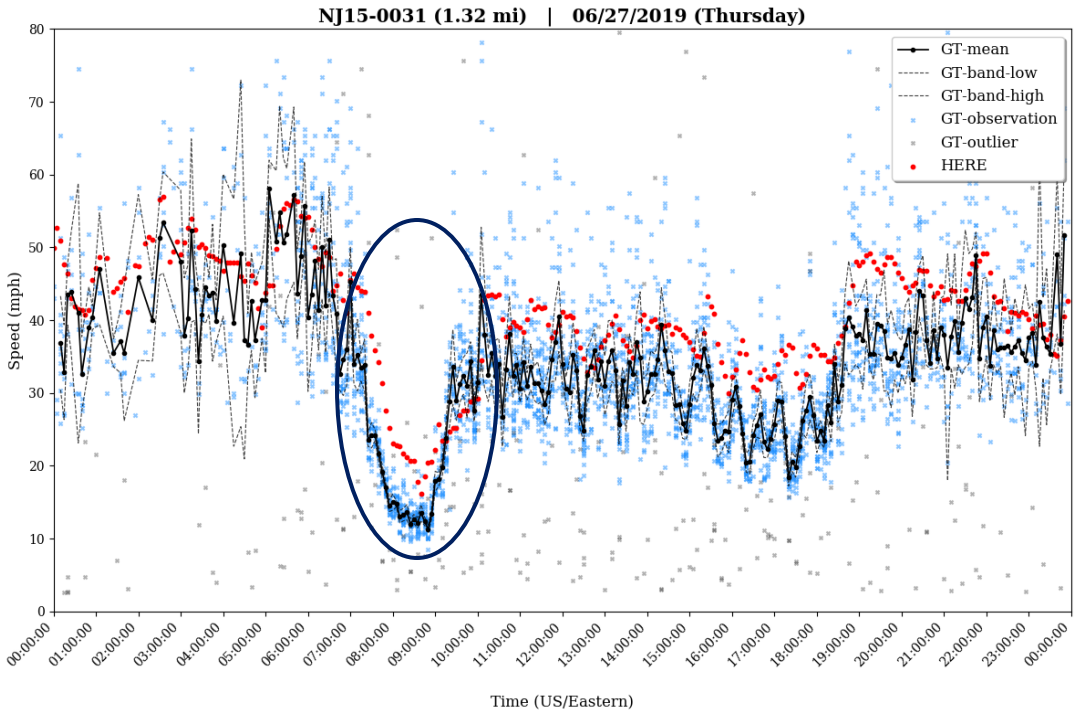


Figure 3 - Representative example of a partially captured slowdown: HERE

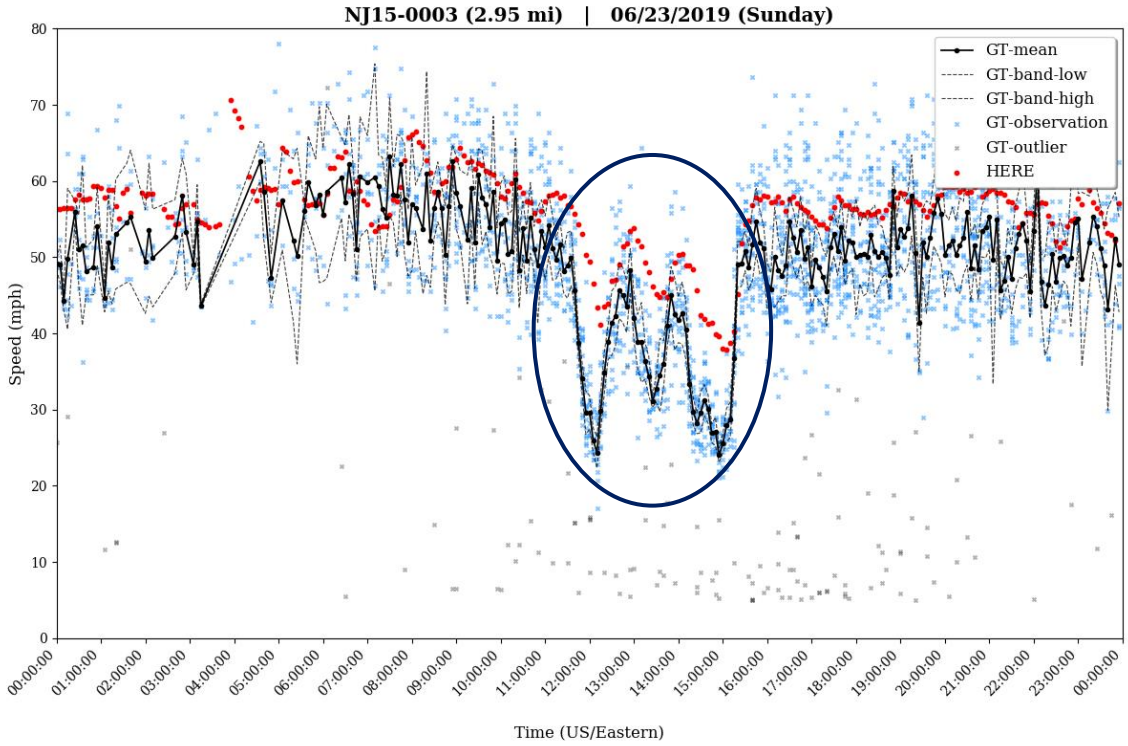


Figure 4 - Representative example of failure to capture a slowdown: HERE

INRIX

Significant Slowdowns	Fully Captured	Partially Captured	Not Captured
66	43	21	2

INRIX data captured 64 of the 66 significant slowdowns observed during the data collection time period. 43 of the 66 captured slowdowns were fully captured, while the remaining 21 were partially captured.

Figures 5-7 provide representative examples of significant slowdowns that were fully captured, partially captured, or not captured by INRIX speed data. Each figure shows 24-hour speed data for both ground truth and INRIX on a selected validation segment.

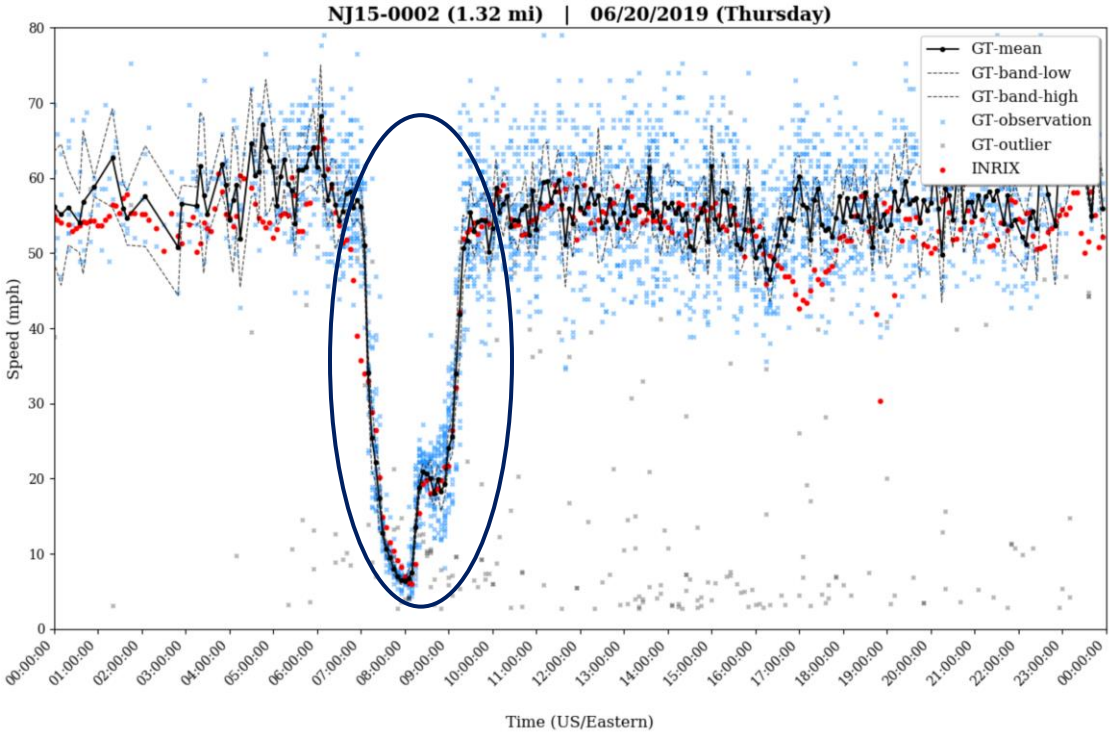


Figure 5 - Representative example of a fully captured slowdown: INRIX

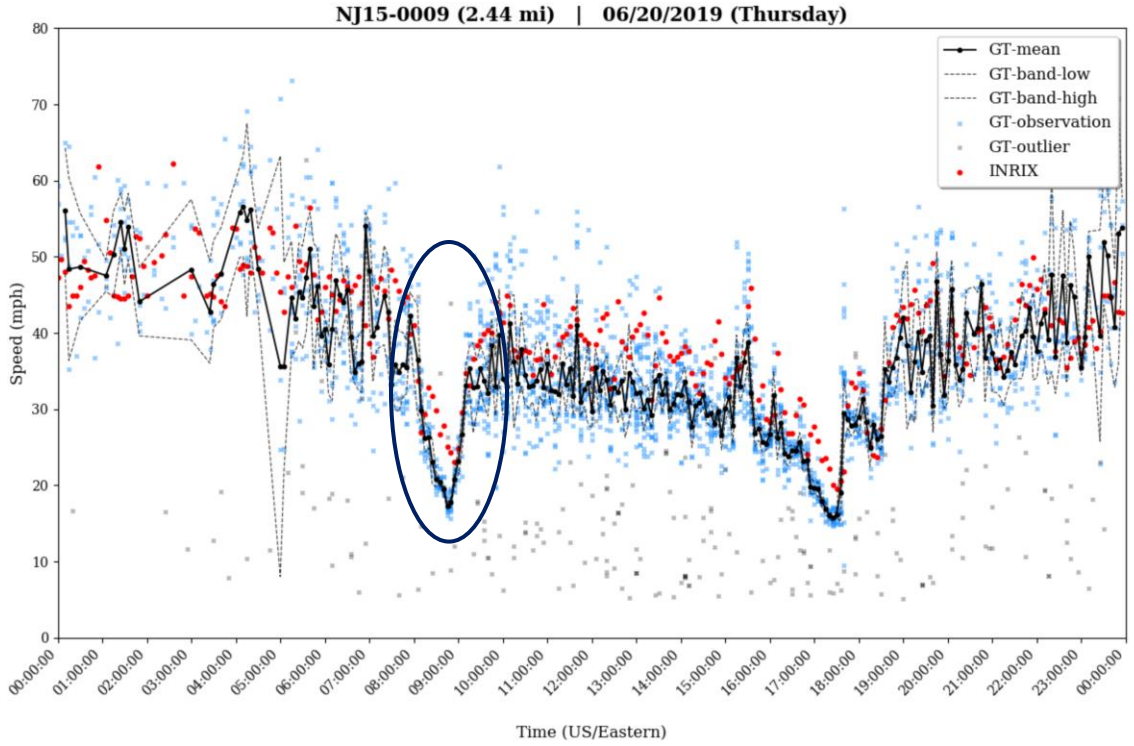


Figure 6 - Representative example of a partially captured slowdown: INRIX

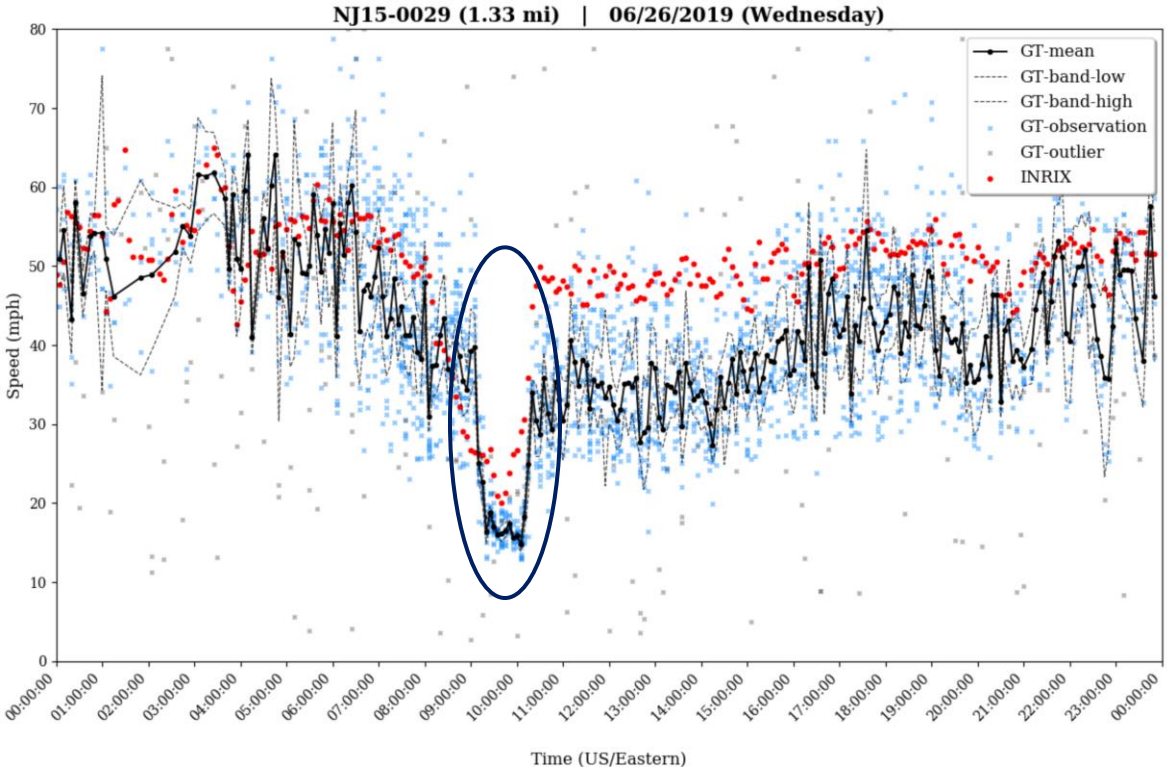


Figure 7 - Representative example of failure to capture a slowdown: INRIX

TomTom

Significant Slowdowns	Fully Captured	Partially Captured	Not Captured
66	66	0	0

TomTom data captured 66 of the 66 significant slowdowns observed during the data collection time period. All the 66 captured slowdowns were fully captured.

Figure 8 provides a representative example of a significant slowdown that was fully captured by TomTom speed data. The figure shows 24-hour speed data for both ground truth and TomTom on a selected validation segment.

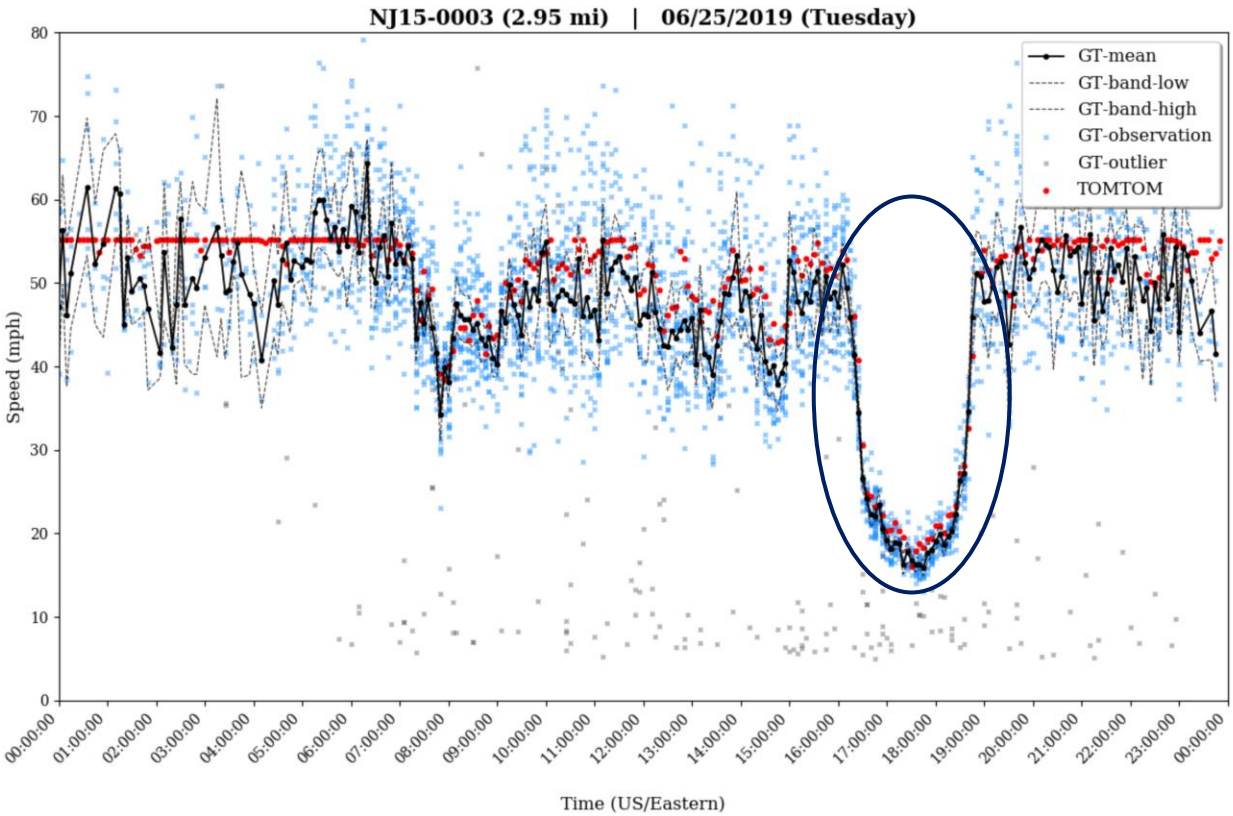


Figure 8 - Representative example of a fully captured slowdown: TomTom