TxDOT Houston District Radar Data Evaluation -- Phase 2

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TEXAS A&M TRANSPORTATION INSTITUTE
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TXDOT HOUSTON DISTRICT RADAR DATA EVALUATION -- PHASE 2

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TXDOT HOUSTON DISTRICT RADAR DATA EVALUATION -- PHASE 2

INTRODUCTION

The Houston District of the Texas Department of Transportation (TxDOT) requested the Texas A&M Transportation Institute (TTI) to perform a limited side-by-side comparison of data received from two vendors' side fire radar products and a ground truth comparison to that data using archived video from a roadside camera. This comparison is a follow-up to the one performed in November 2018 which resulted in several recommendations to further compare and ground truth the data collected by the radar.

The two radar products used in this comparison were: 1) the Wavetronix SmartSensor™ HD-126 (firmware 4, lv) and 2) the SpeedLane® Pro from Houston Radar. This comparison documents the data received from each of the products for a limited time period under specific, demanding conditions and is not an examination of the product specifications or long-term reliability of the products. Prior to the start of the test, each vendor independently inspected the field site for set-up, sensor configuration/alignment, and operation. Testing did not commence until each vendor indicated that the equipment was operating correctly such that the testing could begin.

RECOMMENDATIONS FROM INITIAL COMPARISON

The initial radar data comparison completed in November 2018 resulted in several findings.

1) Both the average speed and total vehicle volume data compared very favorably between the two sensors, with a less than 1% difference in both data elements overall in all measured lanes over a full week. However, it was observed that during periods of lower speeds (40 mph or less), the total volume differences were greater, reaching a 50% difference during one 15 minute interval.
2) Vehicle classification counts (small, medium, and large) varied significantly between the two vendor datasets. The SpeedLane® classified 5-15% more small vehicles than the Wavetronix. Overall, the Wavetronix sensors consistently classified 75-160% more vehicles as medium. Additionally, Wavetronix classified 5-15% more large vehicles than SpeedLane®.

To further address the findings above, TxDOT recommended a follow-up data comparison with the following requirements:

1) Perform another data comparison in a location with significant recurring congestion along an 8 lane roadway to better understand the volume differences during slow speeds and measure the accuracy of the data being collected in the lanes furthest from the sensors.
2) Perform manual counts from traffic video at the location to ground-truth the data collected by the sensors for a two hour window during the data comparison period.

COMPARISON LOCATION

The comparison was done at a location along the Interstate 610 North Loop near Airline Drive in Houston. This location meets the requirements of the location recommended based on the results of the first radar comparison. Both radar were located on the same pole and were configured to monitor the same lanes. The roadway section is located in a highly congested, urban freeway corridor with 4 freeway mainlanes and adjacent one-way frontage road lanes in each direction. Individual freeway mainlane volumes average 1,500 vehicles per hour during the week. For the purpose of this comparison, the radar were only configured to detect the mainlane traffic. The geographic layout of the radar configuration is shown in Figure 1 and the roadside view of the sensor locations is shown in Figure 2. Figure 3 presents a view of the sensor installation on the roadside pole. The sensors are separated by 5.5 feet.

Figure 1. Geographic Layout of Radar.

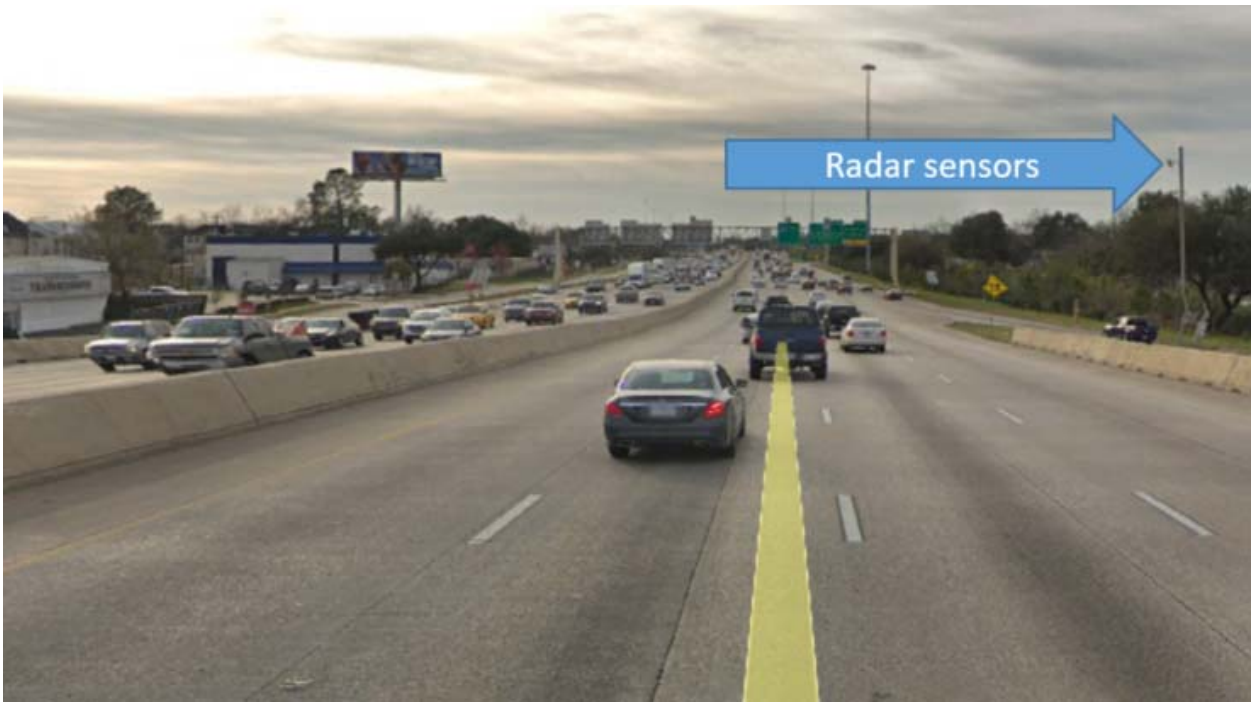

Figure 2. Roadside View of Sensor Installation Looking West.

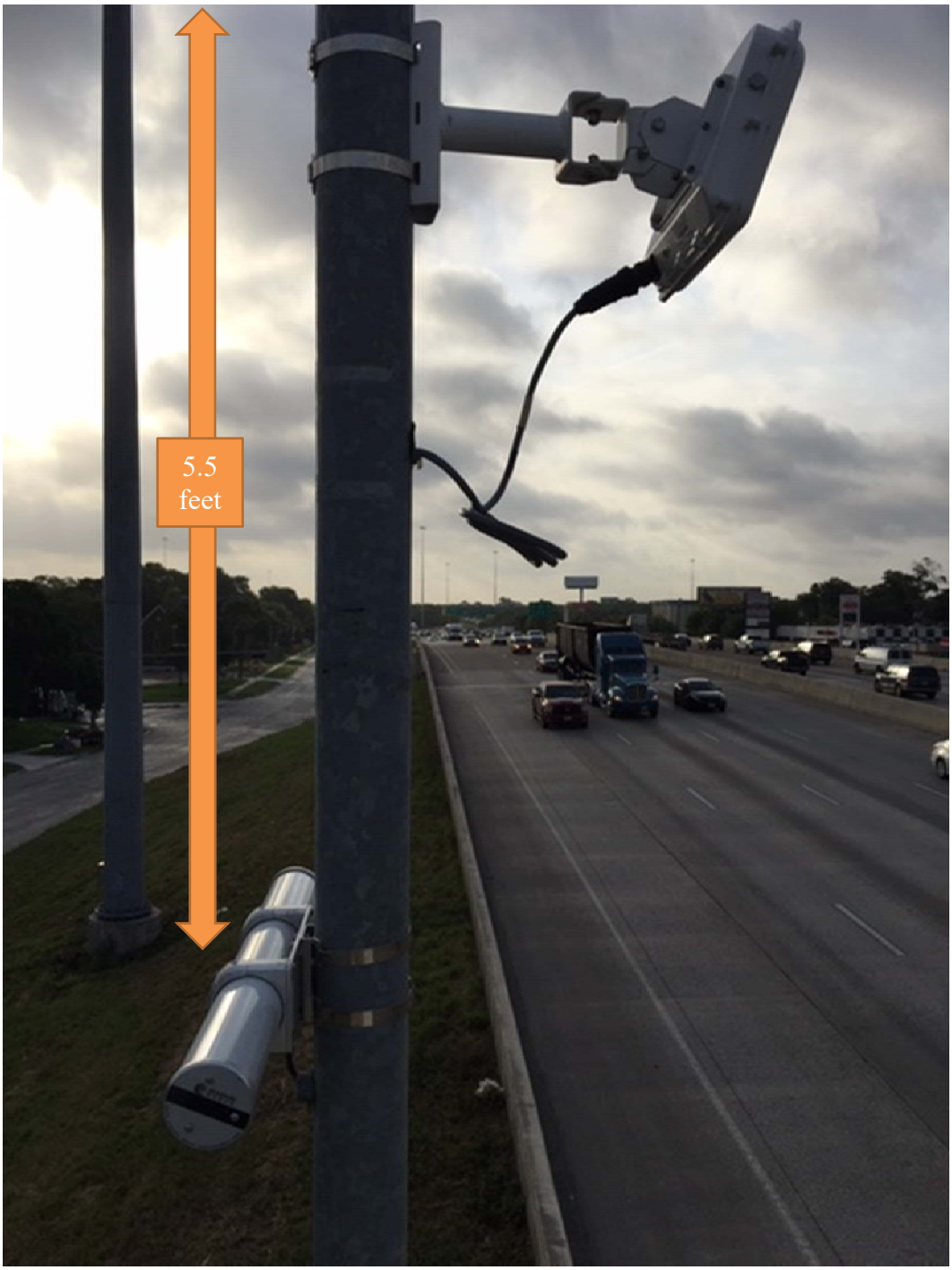

Figure 3. Sensor Installation on Roadside Pole

DATA PARAMETERS

Data collected from both radar was compared for the period from noon on Monday April 1, 2019 to noon on Monday April 8, 2019. The data was received in 30 second summaries, separated by lane, directly from the radar. For the purpose of the comparison, the information was aggregated into 5 minute, 15 minute, and hourly summaries. Speed, total volume, and vehicle classification

were utilized for the comparison. Other elements such as occupancy and 85th percentile speed were also available from each radar but were not used in this comparison.

To perform an accurate comparison, the clocks on each of the radar were synchronized and the vehicle classification lengths were set to the following parameters:

- Small (passenger vehicle/pickup truck) – less than 25 feet.
- Medium – greater than 25 feet and less than 40 feet.
- Large (tractor trailers) - greater than 40 feet.

A portable camera with recording capabilities was placed at the location for constant archival of the traffic flow during the data collection period. Additionally, video from a TxDOT CCTV camera located in close proximity was also recorded. After analyzing video recordings from both cameras, it was determined that the TxDOT camera had a better vantage point for viewing the traffic on all 8 lanes and thus, video from the TxDOT camera was utilized for the ground truth counts in this analysis. The TxDOT camera was only able to be used because it was not moved by traffic operations staff during the time of the ground truth recording. The view from the TxDOT camera is shown in Figure 4.

Figure 4. TxDOT Camera Used for Ground Truth Volume Counts.

For the ground truth video counts, a two hour window during the data collection period was chosen. After analyzing the data collected by the sensors, it was determined that the time period used for the ground truth video counts should occur on Thursday April 4, 2019 from 6:30 AM-

8:30 AM. This period was chosen because of significant congestion and significant differences between the volume and classification data received from the sensors during this time. From the video, vehicles were manually classified by time period into small, medium, and large categories based on the length thresholds defined on the sensors.

COMPARISON RESULTS

This section summarizes the overall themes seen in the data comparison. For a detailed comparison of all the data, including a lane by lane analysis, visit the website at http://ttihouston.tamu.edu/radarcomparison/.

A comparison of the radar data can be done on both a lane by lane basis and by combining the data from all lanes into a single direction. In its final form, TxDOT more commonly uses the combined data but the lane by lane analysis is necessary to identify differences between the sensor data sets. Both comparisons will be made although, generally the differences in the individual lane data match closely with those in the directional data.

Sensor Data Element Comparison

The same overall trends from the previous comparison were observed in this data analysis. Overall, the average speeds collected by both radar were within 3% or 1-3 miles per hour of each other for all lanes and for both directions. The Wavetronix sensor consistently counted approximately 4-5% fewer vehicles on a daily basis with larger discrepancies in the peak periods when speeds are slower than 40 mph. This is slightly larger than the 1% difference in total volume observed in the first comparison. Figure 5 shows the westbound 15 minute total volume comparisons for Tuesday, April 2. The blue and red lines represent the Wavetronix and SpeedLane® volume respectively and the green line represents the difference in volume between the two.

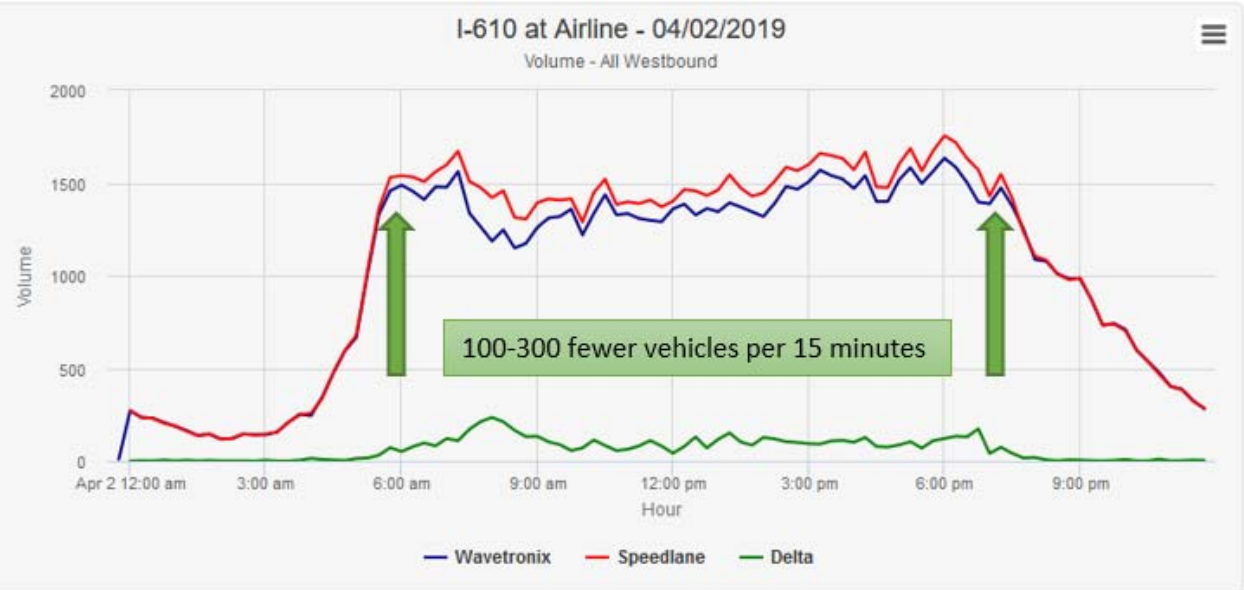

Figure 5. 15 Minute Volume Comparison – 4/2/2019.

Beginning just before 6:00 AM and lasting until 7:00 PM, the Wavetronix sensor counted 100-300 fewer vehicles every 15 minute period. Eastbound results are similar and are representative of the entire week of data.

Also similar to the previous comparison, the largest differences observed between the sensor datasets were found in the vehicle classification counts. The differences in classification can be summarized as follows:

1) Wavetronix classifies 25-30% fewer small vehicles than the SpeedLane® does. The differences are larger when overall volumes are higher. The differences are consistent across all lanes.
2) SpeedLane® classifies 75% fewer medium vehicles that Wavetronix does. The differences are consistent across all lanes.
3) SpeedLane® classifies 50-60% fewer large vehicles that Wavetronix does. The differences are consistent across all lanes. This is represented in Figure 6 below.

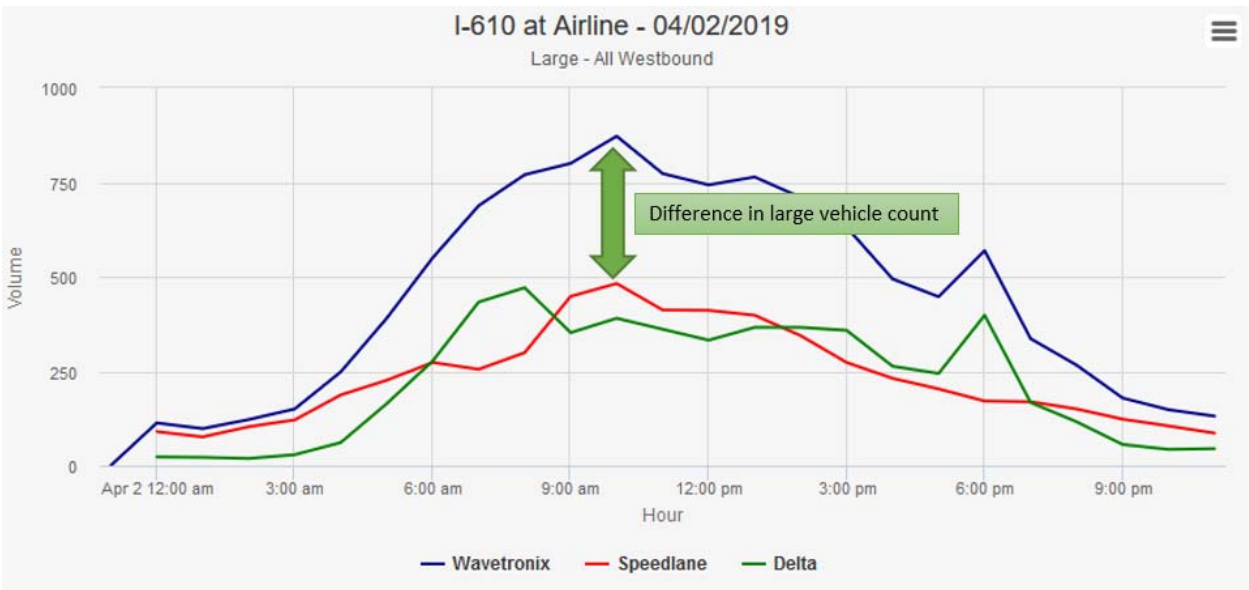

Figure 6. 15 Minute Large Vehicle Comparison – 4/2/2019.

Ground Truth Comparisons

The primary goal of this analysis is to utilize the ground truth counts obtained from video to reconcile the differences in volumes observed from each sensor dataset which were described in the previous section. For this portion of the analysis, a 2 hour window of video was selected to obtain volume and classification counts which were used as ground truth to compare to the sensor data. The time period utilized for the ground truth was 6:30 AM to 8:30 AM on Thursday, April 4. During this period, the speeds in the westbound direction dropped below 20 mph and were consistently recorded by both radar. This time was specifically selected because the volume and classifications were observed to have larger differences when speeds are lower. Figure 7 and Figure 8 show 5 minute summaries of the speeds from the radar datasets during the ground truth data collection period.

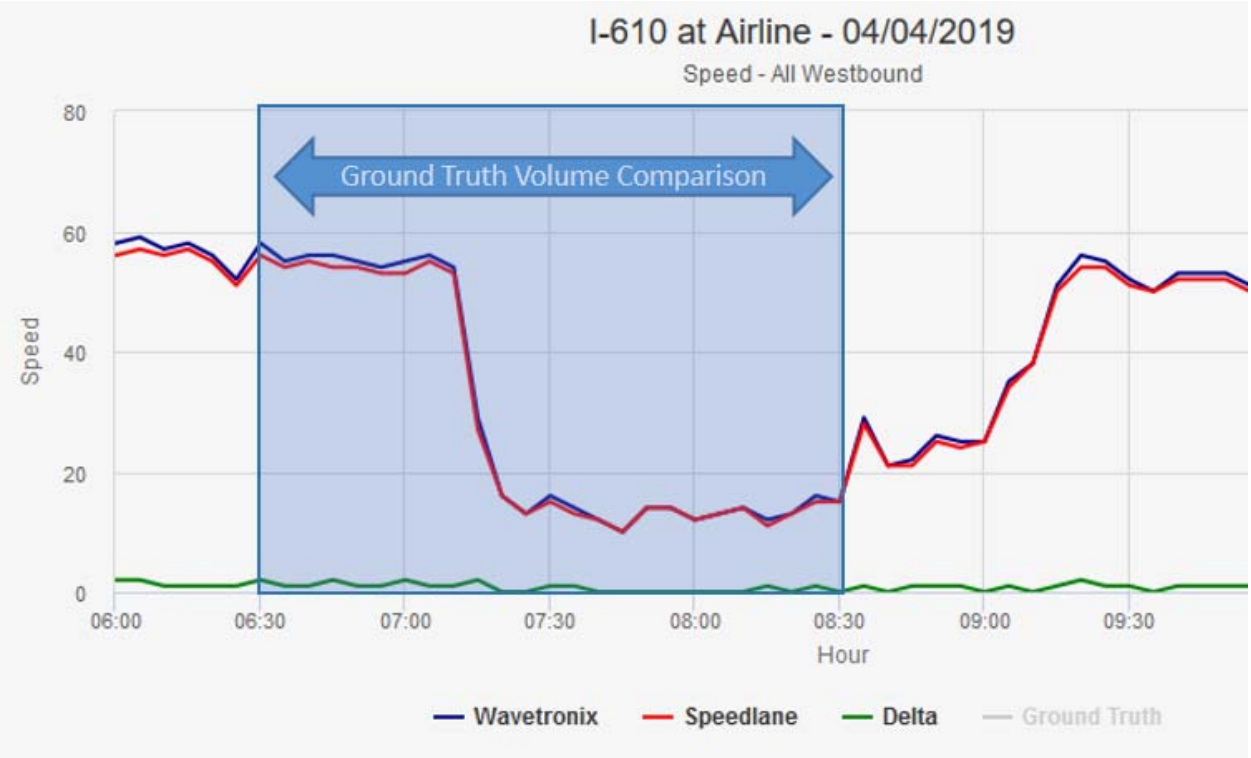

Figure 7. Westbound Speeds During Ground Truth Comparison.

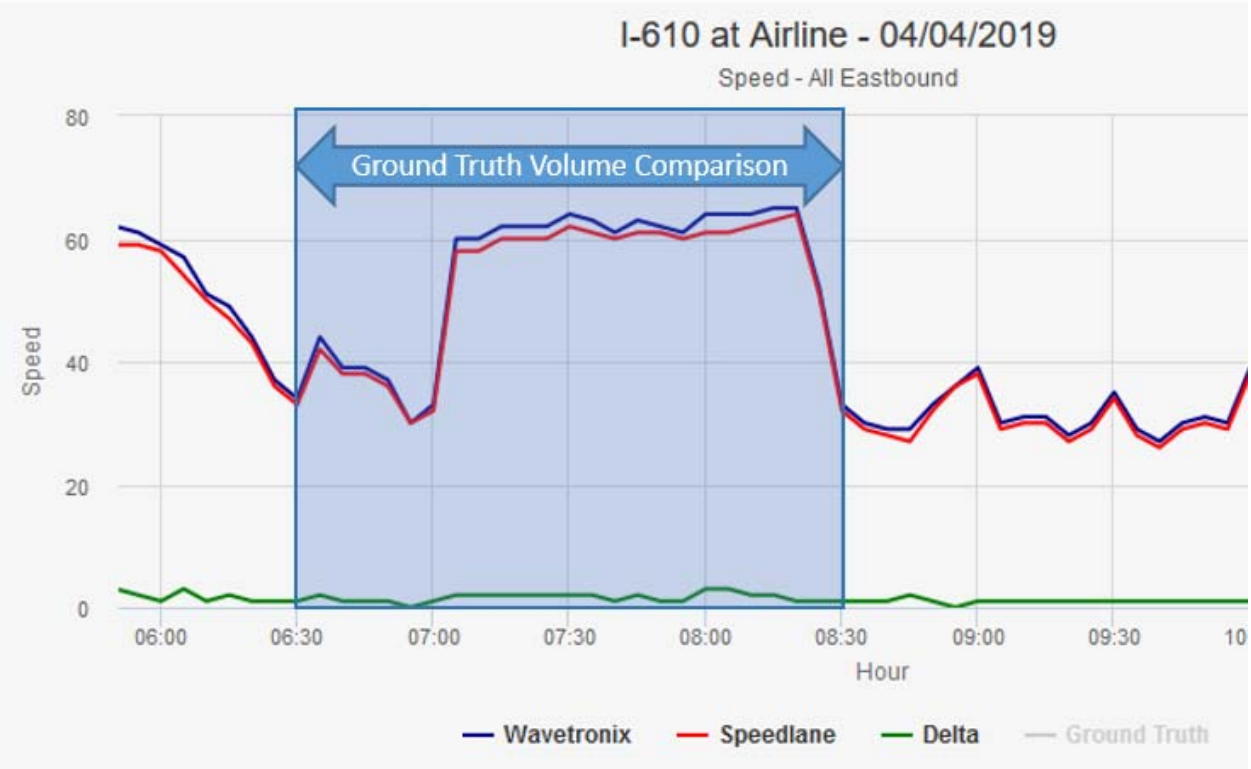

Figure 8. Eastbound Speeds During Ground Truth Comparison.

In the lanes closest to the sensor (westbound direction- Figure 7), the speed drops below 20 mph at 7:20 AM and remains that way through the ground truth period. In the lanes furthest from the sensor (eastbound direction-- Figure 8), measured speeds are below 40 mph from 6:30 AM until 7:05 AM where they then return to 60 mph for the remainder of the ground truth period.

Ground Truth Results

Overall Volume

In all observed bins, ground truth counts were higher than counts from both sensor datasets. For the entire two hour period, total volume for the SpeedLane® was 2% less than ground truth in the lane direction closest to the sensor and 3% less than ground truth the direction furthest from the sensor. Total volume for the Wavetronix was 11% less than ground truth in the lane direction closest to the sensor and 29% less than ground truth the direction furthest from the sensor. These results are summarized in Figure 9 and Figure 10.

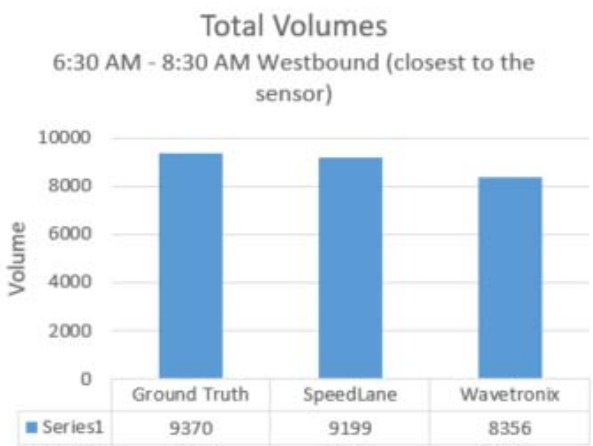

Figure 9. Westbound Total Volumes During Ground Truth Comparison.

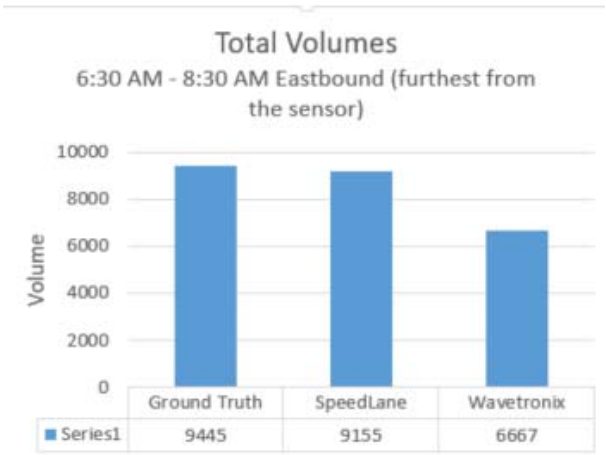

Figure 10. Eastbound Total Volumes During Ground Truth Comparison.

Figure 11 shows the volume comparison between the ground truth counts and each sensor in the eastbound direction.

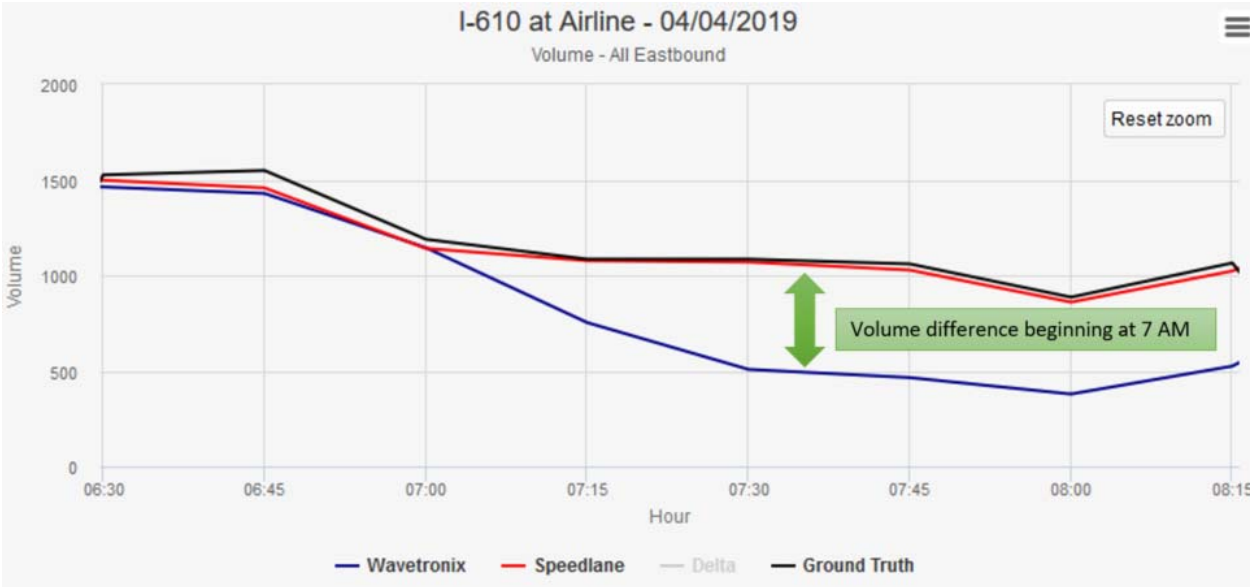

Figure 11. Eastbound Sensor Volume vs Ground Truth.

Beginning at 7:00 AM, the volume recorded by the Wavetronix began to steadily decline when compared to ground truth for each 15 minute period. The largest deviation from ground truth occurred from 8:15 AM to 8:30 AM, when the Wavetronix counted 57% fewer vehicles than were observed by ground truth. The SpeedLane® counted an average of 3% fewer vehicles than ground truth with the maximum difference occurring from 6:45 AM to 7:00 AM when it counted 8% fewer vehicles than were observed.

The discrepancy in volume between ground truth and Wavetronix corresponds to the time when speeds on the westbound lanes (closest to the sensor) started to fall rapidly.

Lane by Lane Volume

Generally, the differences in total volume from both sensors compared to ground truth increased in the lanes furthest from the sensor. This is especially true with the Wavetronix sensor with lane 1 counting 13% fewer vehicles than ground truth and lane 8 counting 30% fewer vehicles than ground truth. With Wavetronix, lane 5 and lane 7 had the biggest differences from ground truth (32% fewer) while lane 2 was closest to ground truth (9% fewer). With the SpeedLane®, lane 8 was actually the closest to ground truth (1% fewer) and lane 7 was the furthest from ground truth (6% fewer).

The lane by lane volume comparisons are shown in Figure 12.

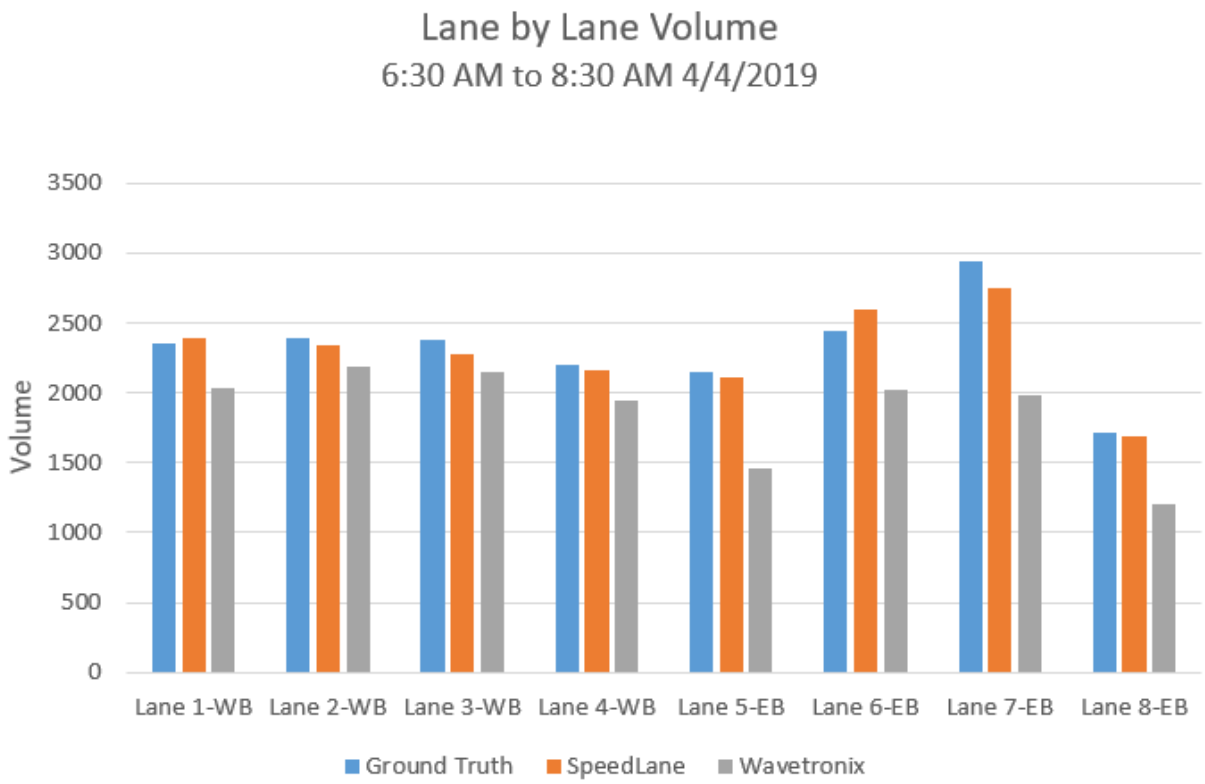

Figure 12. Lane by Lane Volume Comparison.

Classification Volume

While performing the ground truth counts from video, vehicles were classified into small, medium, and large bins based on vehicle type. The counts obtained from the ground truth were compared to the data from each sensor.

Overall, the Wavetronix sensor classified 29% fewer vehicles as small in the westbound direction (closest to the sensor) and 54% percent fewer vehicles as small in the eastbound direction (furthest from the sensor) when compared to ground truth. The SpeedLane® classified 2% fewer vehicles as small in the westbound direction (closest to the sensor) and 6% percent fewer vehicles as small in the eastbound direction (furthest from the sensor) when compared to ground truth. Figure 13 and Figure 14 show the small vehicle classification comparisons per direction.

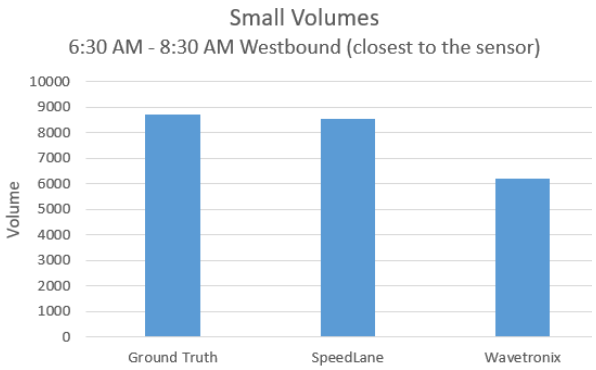

Figure 13. Westbound Small Vehicle Volume Versus Ground Truth.

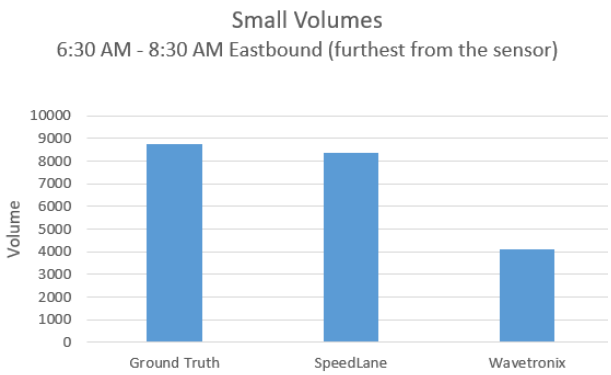

Figure 14. Eastbound Small Vehicle Volume Versus Ground Truth.

The Wavetronix sensor classified 275% more vehicles as medium in the westbound direction (closest to the sensor) and 360% percent more vehicles as medium in the eastbound direction (furthest from the sensor) when compared to ground truth. The SpeedLane® classified 5% more vehicles as medium in the westbound direction (closest to the sensor) and 50% percent more vehicles as medium in the eastbound direction (furthest from the sensor) when compared to ground truth. Figure 15 and Figure 16 show the medium vehicle classification comparisons per direction.

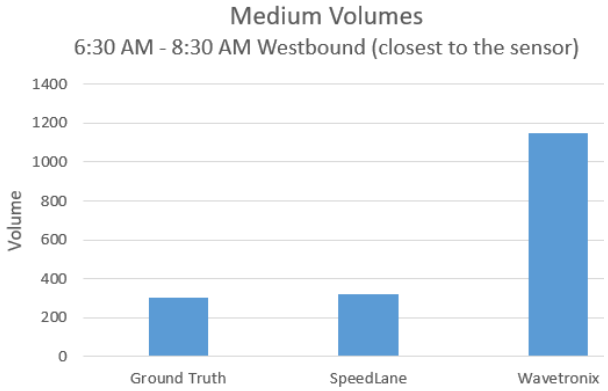

Figure 15. Westbound Medium Vehicle Volume Versus Ground Truth.

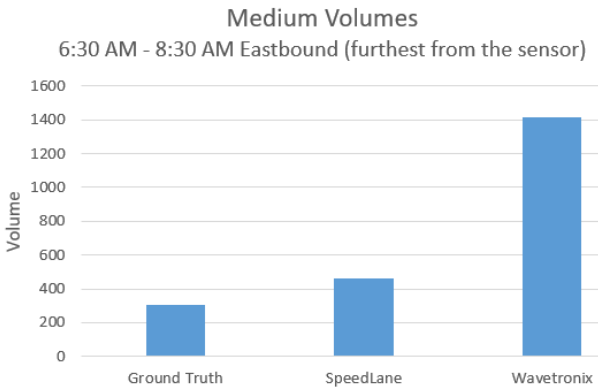

Figure 16. Eastbound Medium Vehicle Volume Versus Ground Truth.

The Wavetronix sensor classified 195% more vehicles as large in the westbound direction (closest to the sensor) and 360% percent more vehicles as large in the eastbound direction (furthest from the sensor) when compared to ground truth. The SpeedLane® classified 4% more vehicles as large in the westbound direction (closest to the sensor) and 30% percent more vehicles as large in the eastbound direction (furthest from the sensor) when compared to ground truth. Figure 17 and Figure 18 show the large vehicle classification comparisons per direction.

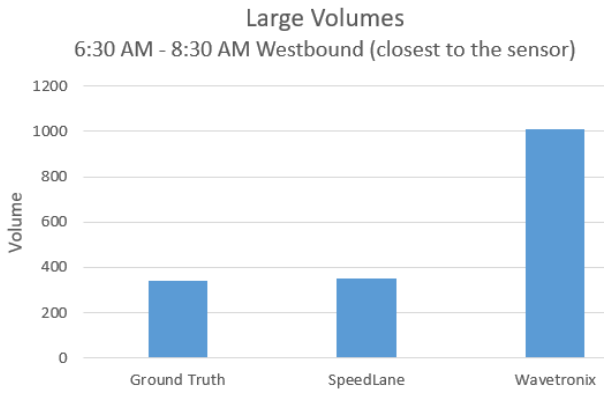

Figure 17. Westbound Large Vehicle Volume Versus Ground Truth.

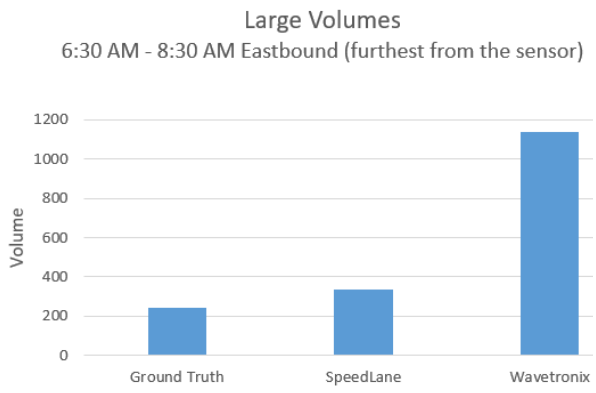

Figure 18. Eastbound Large Vehicle Volume Versus Ground Truth.

Similar to total volume counts, in general, the further away the lanes are from the sensor, the greater difference in ground truth vehicle classification for both sensors. The Wavetronix sensor was within 73% of ground truth for the small bin and differed by ground truth by 125% for the medium and large bins in the eastbound direction (furthest from the sensor).

Classification Ratio

The classification bins allow for the determination of small, medium, and large ratios as they relate to vehicle volume. From the ground truth data in all lanes, 93% of vehicles are classified as small, 3% as medium, and 4% as large. The ratios for the ground data and the sensor data are shown in Figure 19.

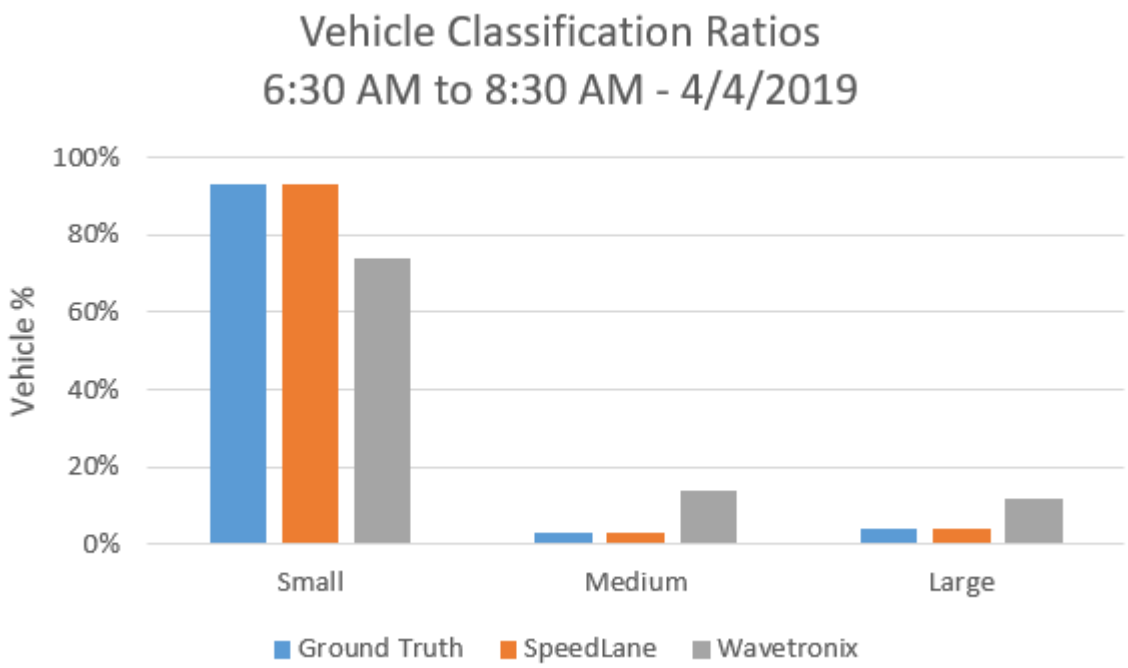

Figure 19. Vehicle Classification Ratios.

Overall, taken as a ratio of all classified vehicles, the Wavetronix classifies 20% fewer vehicles as small, 300% more as medium, and 270% more as large than the ground truth indicates. The SpeedLane® classifies 4% fewer vehicles as small, 28% more as medium, and 19% more as large than the ground truth indicates.

TXDOT RADAR DATA REQUIREMENT COMPLIANCE

TxDOT specifies its radar sensor data accuracy requirements in the document, "Special Specification 6304 Intelligent Transportation System (ITS) Radar Vehicle Sensing Device" (see Appendix/Document Section 2.5). The specification states that radar data must meet or exceed 5 required measures of accuracy during nominal conditions. Although the term "nominal conditions" is not explicitly defined in the specification, based on the data collected for this study, sensor data accuracy compliance for each vendor is shown in Table 1.

Table 1. TxDOT Radar Data Requirement Compliance.

	Met Accuracy Requirement?	
Requirement	**SpeedLane®**	**Wavetronix**
Sensor volume data accuracy is within 5 percent of actual per direction of travel.	*Yes*	[1]*Yes*
Sensor average speed data is accurate within 5 mph per direction of travel.	*Yes*	*Yes*
Individual lane speed accuracy is within 10 mph of actual.	*Yes*	*Yes*
Individual vehicle speed accuracy is within 5 mph for 90% of measurements.	*Not Measured*	*Not Measured*
Vehicle classification data is accurate for 90% of detected vehicles.	*Yes*	*No*

SUMMARY

From the comparison, several trends can be observed, some of which should prompt further investigation and discussion with each radar vendor.

1) Consistent with the first comparison completed at I-45 North at Shenandoah, the speed profiles from both sensors compare favorably with only a 1-3% difference in measured speed for any given period. Additionally, the Wavetronix sensor consistently counts approximately 5% fewer vehicles on a daily basis than the SpeedLane®, with larger discrepancies in the peak periods when speeds are lower than 40 mph.
2) In all observed comparison periods, ground truth counts were higher than sensor data counts for both sensors. Total volume for the SpeedLane® is within 2-3% of ground truth in both directions. Total volume of Wavetronix differs by 11% for the closest direction

[1] The Wavetronix met the requirement for the full ground truth comparison period but did not meet it for all specific individual periods. The TxDOT specification does not indicate the length of time over which the requirements are measured.

and 29% for the furthest direction. The differences are more extreme during congested conditions regardless of the direction.

3) Generally, the differences in total volume from both sensors compared to ground truth increased in the lanes furthest from the sensor.
4) The small class bin for the SpeedLane® is 2% and 6% less than ground truth for both for the closest and furthest directions respectively. Wavetronix classified 29% and 53% fewer small vehicles than ground truth on the closest and furthest lanes respectively.
5) The medium class bin for the SpeedLane® is 5% more than ground truth on the direction closest to the sensor and 50% more in the direction furthest from the sensor. Wavetronix classified 275% and 360% more medium vehicles than ground truth on the closest and furthest lanes respectively.
6) The large class bin for the SpeedLane® is 4% more than ground truth on the direction closest to the sensor and 34% more in the direction furthest from the sensor. Wavetronix classified 195% and 360% more large vehicles than ground truth on the closest and furthest lanes respectively.
7) Classification for both sensors was less accurate on the lanes furthest from the sensor.
8) Overall, the Wavetronix sensor under counts vehicles as traffic speeds decline. This is especially evident in the lanes furthest from the sensor.
9) Overall, taken as a ratio of all classified vehicles, the Wavetronix classifies 20% fewer vehicles as small, 300% more as medium, and 270% more as large than the ground truth indicates. The SpeedLane® classifies 4% fewer vehicles as small, 28% more as medium, and 19% more as large than the ground truth indicates.

RECOMMENDATIONS

- Conduct additional ground truth comparisons using existing data and archived video to measure sensor performance during higher speed conditions.
- Contact sensor vendors, particularly Wavetronix, to discuss sensor performance and discrepancies with ground truth counts and vehicle classification.

APPENDIX

TxDOT Radar Specification Requirements (pages 1 and 2)

Special Specification 6304

Intelligent Transportation System (ITS) Radar Vehicle Sensing Device

1. DESCRIPTION

Furnish, install, relocate, or remove Intelligent Transportation System (ITS) radar vehicle sensing device (RVSD) system at locations shown on the plans, or as directed.

2. MATERIALS

2.1. **General.** Except as allowed for relocation of RVSD equipment, ensure all equipment and component parts are new and in an operable condition at time of delivery and installation. Ensure all RVSD within the project are from the same manufacturer. RVSD are further classified by the type of functions they can perform. The primary classifications are RVSD (Data Collection Only) and RVSD (Data Collection and Wrong-way alarm).

Provide RVSD field equipment that is compatible with existing infrastructure and software located in the Department's Traffic Management Centers (TMCs) across the state or as directed.

RVSD system equipment must include the following:

- Radar vehicle sensing devices
- Mounting assembly and hardware
- All cabling and connector assemblies
- Associated devices required to integrate into communication system

RVSD must be a roadside sensor, or group of sensors, that accurately provides volume, speed, occupancy, and classification data for the roadway segment where they are installed.

Ensure sensor is designed and constructed with subassemblies, circuits, cards, and modules to maximize standardization and commonality. Ensure all external parts and surfaces are designed to protect against corrosion, fungus and moisture deterioration.

Design the equipment for ease of maintenance. Provide component parts that are readily accessible for inspection and maintenance. Provide test points for checking essential voltages and waveforms.

RVSD must self-recover from power failure once power is restored.

Sensor must be provided with a mounting bracket designed to mount directly to a pole, mast-arm, or other structure. Ensure bracket is designed such that the sensor can be tilted both vertically and horizontally for alignment and then locked into place after proper alignment is achieved. All hardware must be designed to support the load of the RVSD sensor and mounting bracket.

2.2. **Configuration.** Each RVSD system consists of roadside sensors as shown on the plans. Ensure the RVSD system detects a minimum of eight lanes. Ensure lane width, medians, and geometry are configurable. Traffic barriers must not interfere with detection.

Ensure RVSD does not require tuning or recalibration to maintain performance once initial calibration and configuration is complete. RVSD must not require cleaning or adjustment to maintain performance.

Ensure RVSD can detect vehicles within a range of 10 to 200 feet from the sensor and can simultaneously detect vehicles in all lanes within the detection range of the radar.

2.3. **Automatic Detection.** Once installed and aligned, ensure the sensor automatically detects vehicle volume, speed, and occupancy. Ensure only minor operator input is required for setup, such as verification of lane configuration and distance from sensor. Ensure the sensor tunes out stationary objects to omit false readings.

2.4. **Data Collection.** The RVSD must automatically calibrate vehicle speed, detection level, and sensitivity. Ensure RVSD provides accurate, real-time volume, average speed, and occupancy for each lane detected.

RVSD must provide user configurable settings for collection and polling intervals. Interval configurations must include options ranging from twenty seconds to 15 minutes or more.

RVSD must be able to correctly categorize detected vehicles into a minimum of three user definable length-based classification bins.

Ensure RVSD sensor performance is not affected by environmental conditions such as shadows, glare, wind, rain, heat, or snow. Ensure speed detection is accurate without requiring vehicle length for calculations.

Ensure RVSD system includes remote connection capabilities allowing an operator to update configuration and firmware as well as download interval data. In the event of communication loss, ensure RVSD stores and transfers data upon communication restoration and subsequent request for data.

Ensure RVSD sensor provides non-volatile memory for configuration settings and for local storage. The sensor must store a minimum of 3 hours of data for all data collected over eight travel lanes at twenty-second intervals. Ensure local storage data is overwritten in a first-in first-out manner.

Ensure RVSD supports the Department's Transportation Sensor System Protocol Document (TSS-Protocol) as detailed in the *TSS Tools* link on the Department's website (http://www.bplot.gov/business/resources/engineering-software.html).

2.5. **Accuracy.** Ensure RVSD accuracy meets or exceeds the following requirements during nominal conditions:

- Sensor volume data accuracy is within 5 percent of actual per direction of travel.
- Sensor average speed data is accurate within 5 mph per direction of travel.
- Individual lane speed accuracy is within 10 mph of actual.
- Individual vehicle speed accuracy is within 5 mph for 90% of measurements.
- Vehicle classification data is accurate for 90% of detected vehicles.

2.6. **Functional Requirements for RVSD with Wrong-way Alarms.** RVSD with wrong-way alarms must be capable of detecting and reporting direction of travel for each vehicle detected as well as include all features and functions required for Data Collection RVSD.

The RVSD sensor must automatically determine if a vehicle is traveling in the opposite direction for which the lane is configured.

Ensure the RVSD can detect real-time vehicle direction of travel.

2.7. **Cabling.** Supply the RVSD with all cabling of the appropriate length for each installation site.

2.8. **Communication.** RVSD must be remote accessible and provide communication options including RS-232, RS-485 and TCP/IP.

RVSD communication through RS-232 or RS-485 must include an internal RS-232, RS-485 communication port. Each serial communication port must support the following baud rates: 9600, 19200, 38400, 57600 and