TDOT RDS Data Quality Assurance and High-Resolution Content Enhancement

Research Final Report from Vanderbilt University | William Barbour, Hiba Baroud, Abhishek Dubey, Jonathan Sprinkle, and Daniel Work | January 31, 2024

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16. Abstract

TDOT's ITS radar detection system, spanning Tennessee's urban interstates and highways, faced challenges with data quality and reliability, limiting its potential for advanced traffic management and analytics. This research aimed to enhance the system by standardizing configurations, recalibrating sensors, replacing outdated equipment, and implementing data storage and visualization tools. Collaboration with ITS contractors, TDOT IT, and TMCs resulted in significant improvements in data quality and downstream data applications. High-resolution RDS data provided actionable intelligence for variable speed limit control, detailed volume data for crash rate performance evaluation, and traffic wave analysis. Future applications lie in traffic management, incident detection alerts, more detailed traffic volume reporting and congestion impacts, and others that have not been identified. Recommendations for maintaining the quality and integrity of the system include increasing awareness of RDS data applications within TDOT, centralizing configuration processes to ensure statewide consistency, transitioning to event-level data reporting for modern detectors, and implementing continuous outage monitoring with automated tools. These efforts lay the foundation for expanding the RDS system's capabilities, improving traffic safety, efficiency, and planning outcomes across Tennessee.

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Executive Summary

TDOT's ITS radar detection system spans the four major cities of Tennessee and their urban interstates and major highways. The system's primary challenge was identified as impaired data quality and reliability. Addressing these issues is critical for unlocking the potential in the TDOT's RDS network and enhancing both short- and long-term transportation analytics.

This research aims to improve the quality, accessibility, and usability of the RDS data for TDOT's operational needs. Hands-on work was performed throughout the project with ITS maintenance contractors, TDOT IT, TMC's, and others to standardize hundreds of detectors statewide. The project team, with assistance from other stakeholders, implemented new data pathways, implemented large-scale optimized data storage, and build new data monitoring and visualization tools.

Key Findings

- **Improved Data Quality and Accessibility.** Significant improvements to RDS data were achieved through recalibration, sensor replacement, and configuration standardization. The deployment of real-time dashboards and monitoring tools enhanced data accessibility, enabling stakeholders to make informed decisions.
- **Enhanced Traffic Management.** The updated RDS system supported critical traffic management functions, including variable speed limit (VSL) control on the I-24 SMART Corridor. These advancements directly contributed to safer and more efficient roadways.
- **Actionable Insights for Planning and Incident Management.** High-resolution RDS data allowed for detailed traffic analyses, including volume trends, speed stratification, and congestion patterns. Early results with automated incident detection using RDS data show 5-10 minute faster event identification and accurately discern recurrent congestion (not a notable event) from non-recurrent congestion (actionable even tfor the TMC).
- **Foundations for Future Development.** The groundwork laid by this project positions TDOT to expand the capabilities of the RDS system. Recommendations for centralized device management, automated anomaly detection, and integration of emerging data formats provide a clear path for future improvements.

Key Recommendations

- **Increase awareness of RDS data within TDOT.** Throughout the stakeholder engagement process, the project team heard enthusiasm for improving the quality, usability, and applications of RDS data. The more time went on, the more new applications were found for which RDS data was the perfect tool for analytics – the barrier was awareness.
- **Centralize RDS configuration and create more clear roles and responsibilities.** Managing a statewide system with decentralized configuration and maintenance processes introduced challenges. Clearer role definitions, centralized oversight, and automation tools are critical to maintaining system integrity into the future. Moving some of the software configuration within TDOT may help reconcile the RDS system across the regions and keep all detectors in sync.

- **Change data reporting to SwCS into event-level data.** Modern radar detectors can report individual vehicle measurements and should have their device drivers that live within SwCS changed to record this stream. Older detectors that do not report this fidelity of data should be replaced. The high quality of 30-second averaged data speaks
- **Implement improved outage monitoring.** A range of automated tools – some of them free to use – are available for continually monitoring the hundreds of ITS devices on TDOT's network and providing detailed statistics and reports on outages. The current method of checking device alive status one per month is not sufficient for high quality sensor data.

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Chapter 1 Introduction

As traffic volumes increase on Tennessee's major roadways, understanding real-time traffic conditions and their dynamics has become crucial. Rising passenger and freight demand are driving concerns related to congestion and safety, prompting the Tennessee Department of Transportation (TDOT) to invest in capital projects, active traffic management strategies, and real-time incident response systems. Central to these efforts is the availability and effective use of high-quality data, which is increasingly abundant yet underutilized. Maintaining high data quality is a challenge especially in a distributed statewide ITS network with thousands of devices.

A key data source in Tennessee is the Radar Detection System (RDS), which encompasses over 800 detectors statewide, shown in Figure 1. These sensors provide detailed, non-invasive measurements on vehicle counts, classifications, and speeds — data not readily obtainable at the same scale from other sources like cloud traffic data, cameras, and inductive loop detectors.

Despite its potential, the RDS data system faces challenges in data quality and reliability, such as outages, noise in measurements, sensor misconfiguration, and sensor calibration drift. Addressing these issues is critical for optimizing TDOT's traffic management capabilities and enhancing both short- and long-term transportation planning.

This research aims to improve the quality, accessibility, and usability of the RDS data for TDOT's operational needs. Key research questions include: how to effectively collect and aggregate RDS data to capture traffic patterns; best practices for configuring detectors and backend systems that ingest data; strategies for automating the detection of malfunctioning sensors; and methods to enhance data accessibility through robust data repositories and user interfaces. By resolving these challenges, the project seeks to deliver actionable insights, improve system uptime, and support TDOT's mission to enhance roadway safety and efficiency across Tennessee.

1.1 Project methodology

The project focuses on enhancing the accuracy and usability of TDOT's Roadway Detection System (RDS) data. Key tasks include evaluating current RDS applications, identifying and replacing malfunctioning sensors, and improving data quality through recalibration and configuration standardization. The plan also involves validating RDS data using I-24 MOTION and CCTV cameras and developing a real-time databases and dashboards for monitoring system status and data. The project spans from late 2022 to early 2025, with phased activities targeting data integrity, sensor upgrades, and deployment of monitoring tools to improve traffic management and operational efficiency.

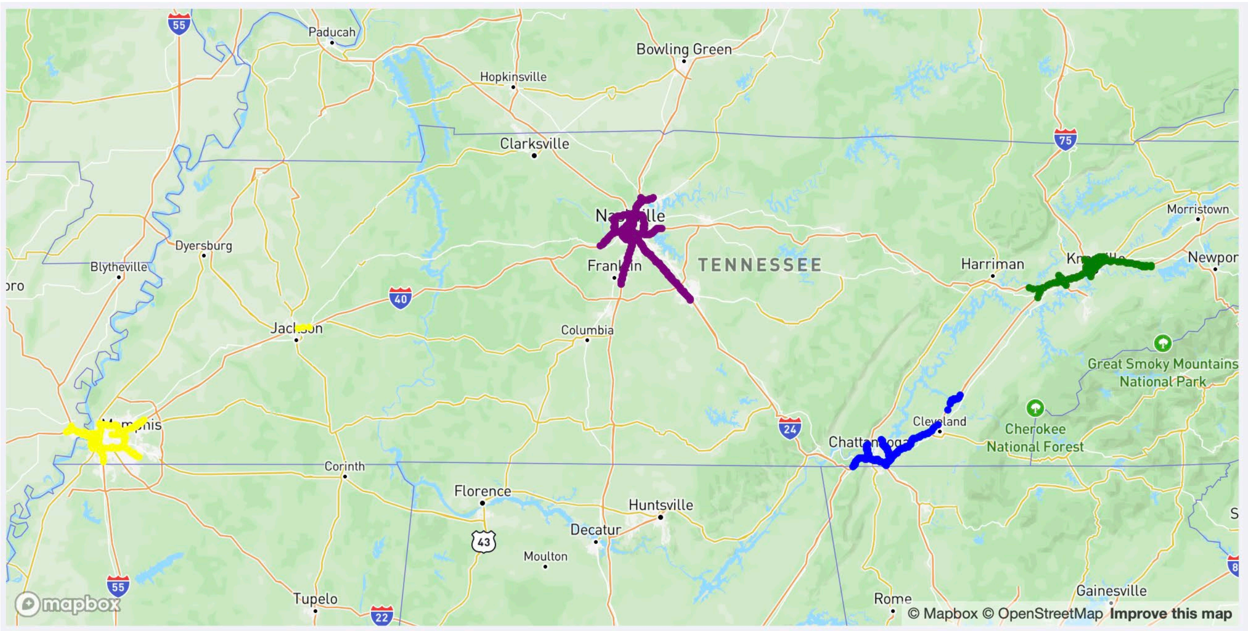


Figure 1 Locations of RDS units: Over 800 detectors are spread across the four TDOT regions (Region 1: green; Region 2: blue; Region 3: purple; Region 4: yellow).

Chapter 2 Literature Review

2.1 Radar detection overview

Highway radar systems have become integral to modern traffic management and analysis, offering real-time data on vehicle speeds, counts, and classifications. Their non-intrusive nature and resilience to various weather conditions make them advantageous over other data collection methods.

Applications of Highway Radar Data

Radar sensors are extensively used for monitoring traffic flow, detecting congestion, and optimizing traffic signal timings on surface streets (including highway ramps). They provide critical data for traffic control systems, enabling real-time adjustments to traffic lights, ramp metering, and variable speed limits, thereby reducing congestion and enhancing roadway safety. (FHWA, 2007)

Accuracy and Reliability

Radar detection offers several benefits, including the ability to detect vehicles under poor visibility conditions, making them more reliable in some circumstances than vision-based systems. Additionally, radar sensors are non-intrusive, allowing for installation and maintenance without disrupting traffic flow. However, data quality can be affected by noise, false positives, and inaccuracies due to sensor misalignment or hardware degradation over time. To address these challenges, integrating radar data with other data sources, such as cameras or probe data, has been suggested to enhance accuracy. (Antoniou, 2011)

Integration with Other Traffic Data Sources

To overcome the limitations of standalone radar systems, integrating radar data with other traffic data sources, such as GPS probes, Bluetooth detectors, and video analytics, is beneficial. The fusion of heterogeneous data streams provides more comprehensive insights into traffic flow and enhances the accuracy of congestion detection, incident management, and traffic forecasting. For instance, the “Review of Traffic Management Systems - Current Practice” examines the basic functions of Traffic Management Systems (TMS) and supported operational strategies, highlighting the importance of integrating various data sources for effective traffic management. (FHWA, 2023)

2.2 Radar detection best practices

Resources for data best practices from the Federal Highway Administration identify key findings for multi-user operational systems such as TDOT’s RDS: standard formats for data fields, periodic data validation (Megler, 2016), sensor calibration, and documentation of metadata and sensor locations (FHWA, 2016a; FHWA, 2016b). The PeMS inductive loop sensor system in California has dealt with an inherently unreliable sensor technology, and system findings include the need for quality enhancement, data sharing, and live visualization (Chen, 2002). The NEXTRANS center emphasizes common data platforms within agencies (Adams, 2017).

2.3 Data anomaly detection

Prior research by PI Work has developed methods for detection of anomalous traffic events on roadway networks (Hu, 2020(a)) and for imputing missing data alongside anomaly detection (Hu, 2020(b)), even with large amounts of missing data (Hu, 2021). Long short-term memory networks are a form of deep learning model that can learn the dynamics of the traffic network and have shown prior success in congestion prediction (Basak, 2019). Other approaches may include Pythagorean mean-based invariant (Talusan, 2022). Machine learning and deep learning approaches, specifically support vector machines and artificial neural networks, have shown to accurately estimate missing values across all types of missing values (Richman, 2009).

Chapter 3 Methodology

This section describes the methodology for investigating RDS configurations, altering and standardizing these configurations, and propagating the new configurations across the state. This work covers tasks 1-4 in the project plan, with further tasks covered primarily in Chapter 4.

3.1 Reviewing the current state of RDS data and stakeholder needs [Task 1]

Engagement with stakeholders was a key focus in refining the project's scope and addressing the data needs for the statewide RDS system. Discussions with the Tennessee Department of Transportation (TDOT) Traffic Operations Division and other stakeholders provided valuable insights into current and historical uses of RDS data and its applications. These engagements included:

Stakeholder Discussions:

- 05/09/2023: Meeting with TDOT Region 1 and maintenance contractors to discuss historical RDS data usage and the "Mist" monitoring system.
- 05/16/2023: Meeting with TDOT Region 3 TMC IT manager to explore current and historical uses of RDS data and associated tools.
- 05/02/2023: Brief meeting with TDOT IT and ITS maintenance contractor (Stansell Electric) to identify data consumers and use cases.
- 05/01/2023: A spring 2023 update meeting with TDOT and Vanderbilt project teams summarized progress since the project kickoff, incorporating feedback from earlier discussions.
- 12/05/2023: Meeting with TDOT Freight and Logistics and TDOT Long Range Planning personnel to discuss potential synergies or data supplementation with RDS data within their existing systems and workflow. Length classifications were coordinated with TDOT LRP in order to enable reporting of vehicle classification data from RDS with USDOT. This is discussed further in Section 3.4.

The conclusion of stakeholder engagement was that the RDS system is underutilized but could be the highest-fidelity and most complete source of data on urban interstates in the major Tennessee cities if properly curated and distributed.

I-24 Smart Corridor project engagement

Following these stakeholder engagements, the project team conducted a detailed evaluation of RDS data quality on Interstate 24 in coordination with the I-24 SMART Corridor project team. Speed estimates, critical for the variable speed limit (VSL) system, were found to be unreliable on older or improperly calibrated sensors. This assessment revealed that the current state of RDS data was insufficient, necessitating the replacement of key sensors along the corridor.

Additionally, a change was needed to the Traffic Management Center's (TMC) process for managing links within Smartway Central Software (SwCS). This adjustment separated data feeds between mainline traffic and interchange ramps, separating low-speed and high-speed traffic for better consistency between sensors. This change is discussed further in Section 3.4.

These efforts underline the importance of addressing stakeholder needs and upgrading RDS infrastructure to support the operational goals of statewide traffic data collection, traffic management, and the I-24 SMART Corridor.

3.2 Evaluating RDS sensors for data integrity and accuracy [Task 2]

An early prototype dashboard focused on time-space visualization of radar data was developed to view radar data in both the time and spatial dimensions. The spatial visualization across sensors helps identify inconsistencies between adjacent sensors on the roadway. There should normally be a strong correlation between traffic speeds at nearby sensors and the deviation from this pattern should only be due to a geometric change or traffic bottleneck. The time visualization lets the viewer see the consistency, or lack thereof, for successive measurements by the same sensor. During peak traffic periods, a speed response should be observed for relevant sensors; a completely consistent speed across an entire day or longer indicates a miscalibration or misalignment of the sensor to the lanes. Additionally, we should see alignment of traffic patterns during traffic-inducing events across affected sensors. These two dimensions of data inspection were the primary methods for identifying potential data issues and verifying they have been fixed. An example of these spatial and temporal data errors is shown in Figure 2.

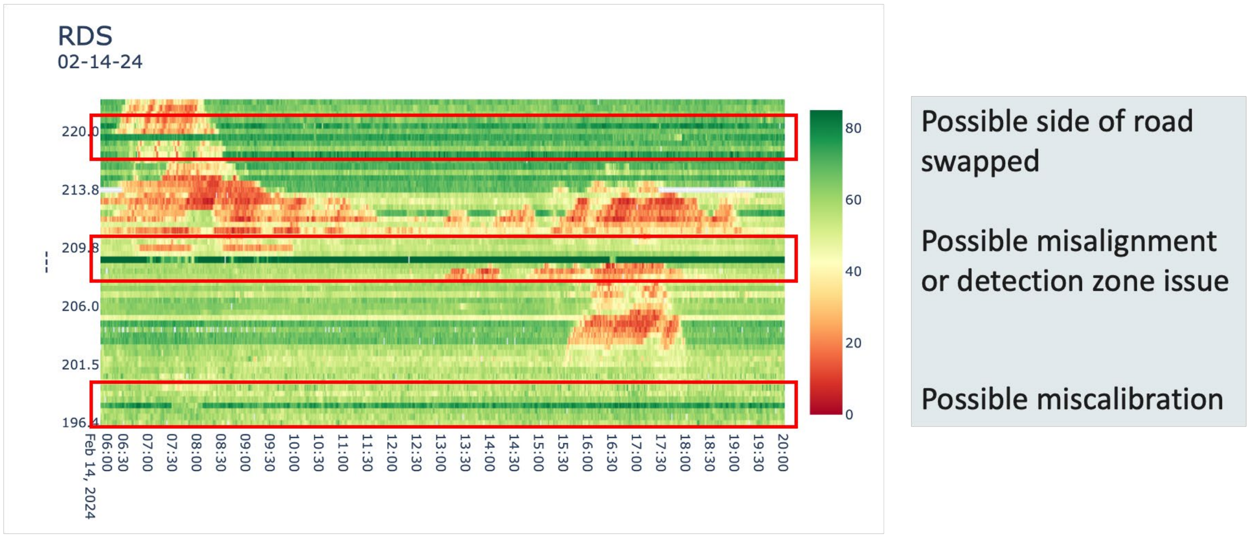


Figure 2 Sample RDS data issues: Common issues encountered with RDS data, illustrated on a time-space diagram.

The prototype dashboard was first used to identify problematic sensor configurations within the I-24 SMART Corridor project. Issues that were uncovered included direction of roadway reversal, lane and interchange ramp inclusion, name/location overlap, and sensor/signage ordering. High-quality radar data within the SMART Corridor project was extremely important, since it drove the algorithms for automated variable speed limit control.

The reason that automated variable speed limit control needs the highest quality speed estimates available is that each speed limit display gantry is reflecting the speed of traffic up ahead. Since gantries are spread only 0.5mi apart on average, only one or two detectors are situated in the traffic stream following the gantry. Poor data quality from even a single detector could be enough to produce erroneous speed limits for the corridor and reduce driver confidence in the system. Figure 3 shows a before (left) and after (right) time-space diagram for the I-24 SMART Corridor. Inconsistencies in the original data are rampant but are gone after the data enhancement effort. More information on the exact remediation steps is given in Sections 3.3 and 3.4.

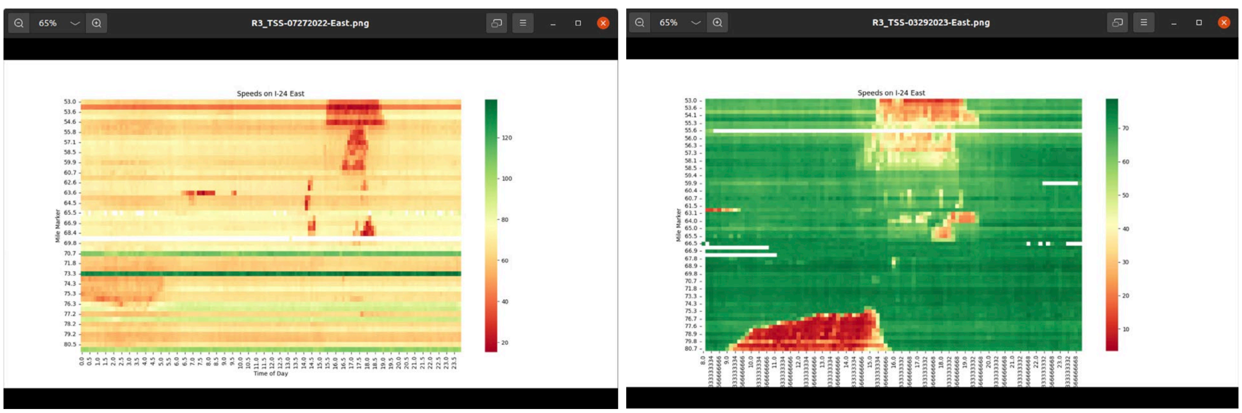


Figure 3 Data improvement comparison: Improvement of RDS data on Interstate 24 resulting from standardization and recalibration, shown in before (left) and after (right) time-space diagrams.

3.3 Replacement of invalid sensors [Task 3]

As part of the I-24 SMART Corridor targeted effort, approximately 30 sensors were upgraded with new models to ensure consistent data with the new detectors installed by the project contractor.

Results from this I-24 effort were brought by the project team to the preconstruction meeting for the Region 3 maintenance contract. Insight from and coordination with the maintenance contractor (and their CEI) was critical for elements of this project dealing with hardware and configuration. The RDS project team continually worked with TDOT Region 3 and Stansell Electric to replace problematic sensors as they were discovered during the course of this project.

Following the evaluation process for sensor data, we curated a list of sensors that were inconsistently reporting data or could not have their speed measurements fixed with recalibration. Figure 4 shows data outage rates for the top-offending sensors in each TDOT region as of late 2023. A small outage rate around 3-5% is expected because sensors will not report data if no vehicles are detected within their aggregation time window. Sensors with outage rates above this threshold were marked for investigation and possible replacement by each region's maintenance contractor.

link_name text	outage_percent numeric
R1G-00I40-384.9W-2	34.2
R1G-00I40-379.2E-1	10.5
R1G-00I40-379.2W-2	10.5
R1G-00I40-364.9E-4	3.7
R1G-00I40-364.9W-4	3.7

link_name text	outage_percent numeric
R2G-0SR29-001.2N	82.8
R2G-0SR29-000.4N	70.1
R2G-SR153-003.1S	49.6
R2G-00I24-178.4E	37.0
R2G-00I24-178.9W	35.7

link_name text	outage_percent numeric
R3G-00I40-213.8W (319)	78.4
R3G-00I40-213.8E (319)	78.4
R3G-00I40-207.6E (95)	36.9
R3G-SR155-8.6N (432)	28.5
R3G-SR155-8.6S (432)	28.5

link_name text	outage_percent numeric
R4G-0I240-017.9E (295)	30.5
R4G-0I240-017.9W (295)	30.5
R4G-0I240-014.68W (309)	16.5
R4G-0I240-014.68E (309)	16.5
R4G-00I40-083E(999)	14.9

Figure 4 Sensor outage rate sample: Sample data on highest outage-rate radar sensors from each of four TDOT regions. Problematic sensors have outage rates over 5%.

3.4 Standardization of sensor configuration and calibration [Task 4]

Due to the large number of radar sensors across the State of Tennessee, the task of standardizing sensor configuration must be distributed to the regions and their maintenance contractors. The RDS project team developed a sensor configuration standard in coordination with TDOT Traffic Operations Division. The standardization plan is provided in full in Appendix 1. The standard defines the proper configuration of RDS units and their implementation into Smartway Central Software. We met with the maintenance contractors multiple times to explain the plan, its importance, and how we would implement the changes.

Sensor standardization breaks down into two coordinated efforts:

- <u>Sensor internal configuration:</u> proper settings, communication protocol choice, zone to lane calibration, speed calibration, and length bin classifications.
    - Performed by regional ITS maintenance contractor; oversight by ITS maintenance CEI for ongoing work.
- Smartway CS receiving configuration: matching communication protocol choice, detection zone to lane mapping, lane to link mapping, and link to detector mapping.

- Performed by TDOT regional TMC staff and/or TDOT IT staff; oversight and coordination by CEI for ongoing work.

Key points that standardization sought to address include:

- Consistency of lane count by roadway direction, matching the number of detection zones in the sensor to the correct lane layout.
- Separation of lower-speed traffic on auxiliary portions of the roadway, including on-ramps and off-ramps, from main-line traffic. This is accomplished at SwCS level following proper configuration of detection zones on the sensor. An example is shown in Figure 5.
- Lane numbering with each direction starting from lane 1 on the left-most side in the direction of travel. An example is shown in Figure 6.
- Length bin classifications based on the number of bins supported for each sensor. The scheme is shown in Figure 7.
- Communication protocol matching between the sensor and SwCS.

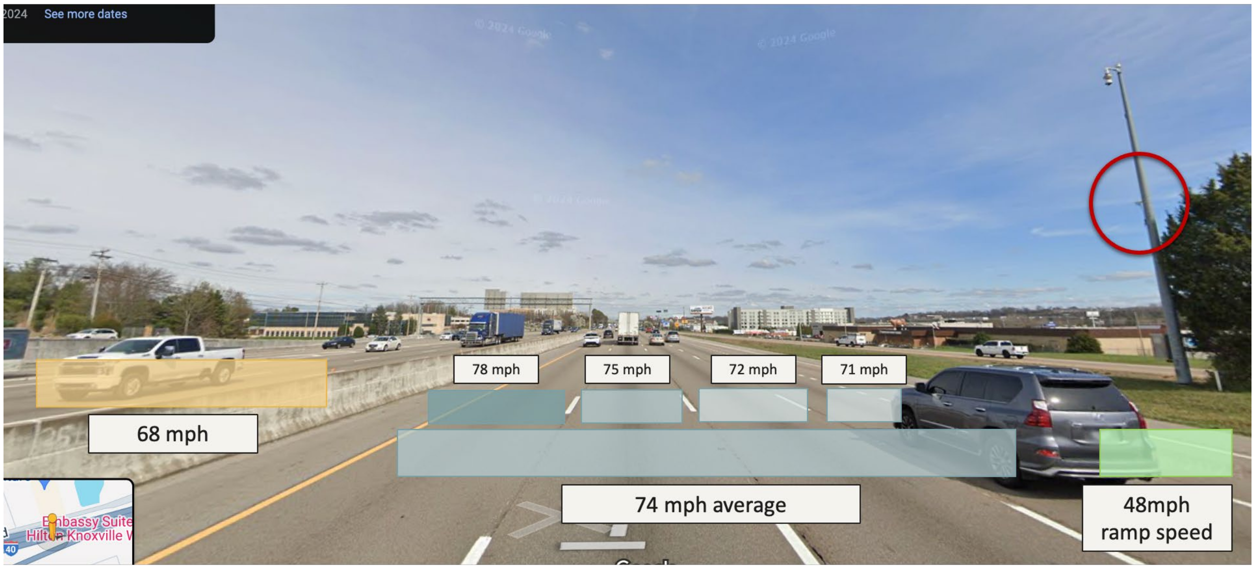


Figure 5 Roadway link separation: Demonstration of Smartway CS link separation between roadway directions and between main line and auxiliary/ramp lanes.

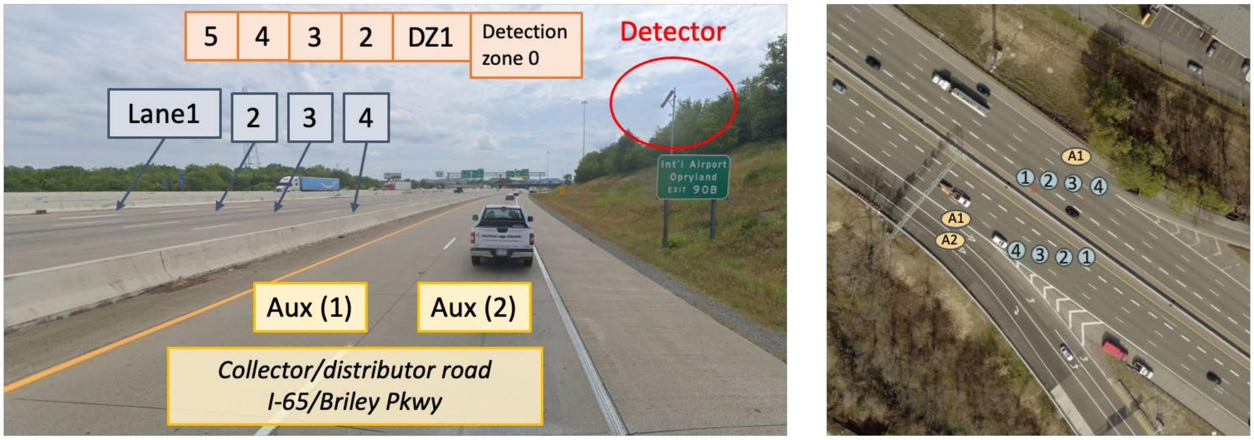


Figure 6 Lane numbering scheme: Lane numbering from inside (left-most) to outside, including separation of auxiliary lanes. Detection zones for each radar sensor begin at 0 nearest the sensor and increment outwards, which must be corresponded with lane numbers.

**4-bin scheme	**6-bin scheme	8-bin scheme	13-bin scheme	Description	Length Range (feet)
1**	1	1	1	Motorcycles	00.0 - 08.3 [08.0]
	2	2	2	Passenger cars	[08.1] 08.4 - 18.1 [18.0]
2**	3	3	3	Light trucks	[18.1] 18.2 - 23.0
	4	4	4	Buses	23.1 - 25.0
3**	5**	5*	5	2-Axle, single-unit	25.1 - 30.0
			6	3-Axle, single-unit	30.1 - 35.0
			7	>3 Axle, single-unit	35.1 - 40.0
4**	6**	6*	8	<5 Axle, single trailer	40.1 - 45.0
			9	5-Axle, semitrailer	45.1 - 50.0
		7*	10	>5 Axle, single trailer	50.1 - 65.0
			11	<6 Axle, multi trailer	65.1 - 70.0
		8*	12	6-Axle, multi trailer	70.1 - 75.0
			13	>6 Axle, multi trailer	75.1+

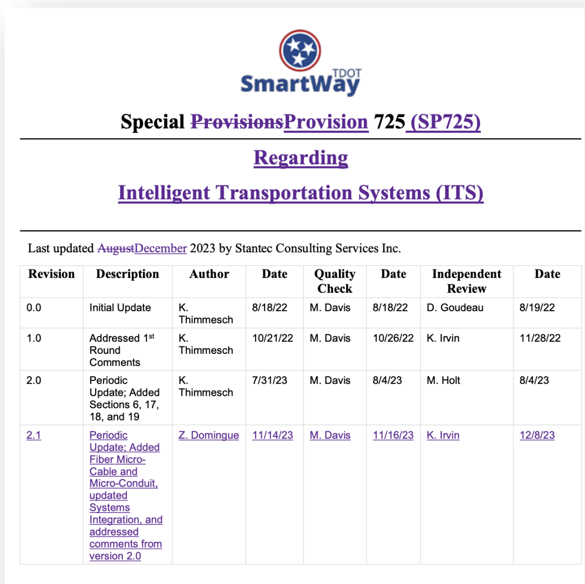
Figure 7 Length classification ranges: Length bin ranges for vehicle classifications. RDS units of various vintages must be configured with 4-, 6-, or 8-bin scheme.

The project team made RDS standardization spreadsheets for each TDOT region, which were disseminated to the respective maintenance contractors. A sample spreadsheet is provided in Appendix 2. These documents, upon their completion, were used for configuration updates of RDS detectors within Smartway CS. Approximately twelve meetings were held at various times with regional maintenance contractors, construction engineering inspectors, TDOT IT, and TDOT TMC staff to complete the standardization process across the state.

Following the first round of standardization in Q1 2024, we began looking at individual sensor quality and calibration to determine issues that need special attention. A sensor configuration issue in Region 4 was solved in order to allow standardization to continue. The model of sensor that is deployed across the region only allows configuration of four length classification bins to comply with the message protocol implemented in SWCS. The standardization guidelines were updated accordingly with the new classification scheme for this edge case.

To make these changes endure past the life of this project, we communicated the RDS standardization plan to the Stantec team working on revisions to the ITS Special Provision document. Special Provision 725, shown in Figure 8, was updated to reflect the new RDS standardization guidelines and practices. The relevant section of SP725 is provided in full in Appendix 3. The primary notable changes are:

- Changed configuration of detector links in SWCS to break out main line and auxiliary/on-/off-ramp links.
- Updated lane numbering standard to coincide with TMC event reporting convention.
- Length bin classifications for all detector vintages (6- and 8-bin schemes).



SmartWay TDOT

Special ~~Provisions~~Provision 725 (SP725)

Regarding

Intelligent Transportation Systems (ITS)

Last updated ~~August~~December 2023 by Stantec Consulting Services Inc.

Revision	Description	Author	Date	Quality Check	Date	Independent Review	Date
0.0	Initial Update	K. Thimmesch	8/18/22	M. Davis	8/18/22	D. Goudeau	8/19/22
1.0	Addressed 1st Round Comments	K. Thimmesch	10/21/22	M. Davis	10/26/22	K. Irvin	11/28/22
2.0	Periodic Update; Added Sections 6, 17, 18, and 19	K. Thimmesch	7/31/23	M. Davis	8/4/23	M. Holt	8/4/23
2.1	Periodic Update; Added Fiber Micro-Cable and Micro-Conduit, updated Systems Integration, and addressed comments from version 2.0	Z. Domingue	11/14/23	M. Davis	11/16/23	K. Irvin	12/8/23

Figure 8 SP-725: Cover page from Special Provision 725, "Regarding Intelligent Transportation Systems (ITS)", into which new standardization guidelines were incorporated for reference by future installations and maintenance.

Additionally, a detector configuration worksheet was developed for contractors to document new or replaced RDS units and ensure they meet the same standards as existing units and necessary SwCS changes are communicated to the TMC. This worksheet is available in Appendix 4.

Chapter 4 Results and Discussion

This chapter summarizes the results of the project tasks following the RDS standardization process. The subsequent sections focus in more detail on project deliverables and implementation, as well as a discussion of recommended remaining implementation and future work.

4.1 Comparison of re-calibrated RDS data to other sources [Task 5]

This section discusses multiple comparisons between the RDS data and other TDOT and commercially available data sources with similar aims. Overall, the comparisons demonstrate the high quality of TDOT's RDS system and the potential it has to be a powerful data source for the organization.

With I-24 MOTION

Data improvement efforts that were conducted on Interstate 24 provided a unique opportunity to check data against "ground truth" data from TDOT's I-24 MOTION system. The I-24 MOTION camera network and testbed collects individual vehicle measurements that can be aggregated into time-space data like RDS provides. The MOTION system revealed a repeated traffic wave pattern in morning commute traffic on the westbound direction, along with a traffic congestion horizon around milemarker 56. Newly improved RDS data from this area was able to capture the same traffic pattern, albeit at a lower data resolution. Figure 9 shows a time-space diagram created from I-24 RDS data. Direction of travel in this diagram is from upper left to lower right; traffic waves can be seen moving upstream from lower left to upper right across a 10 mile stretch of I-24 from milemarker 56 to 66. Traffic waves are not normally apparent in radar data due to severe data aggregation. This quality speaks to the ability of the TDOT RDS system to supply high-quality data in its raw form, without the need for further aggregation that may obscure traffic phenomena or detail.

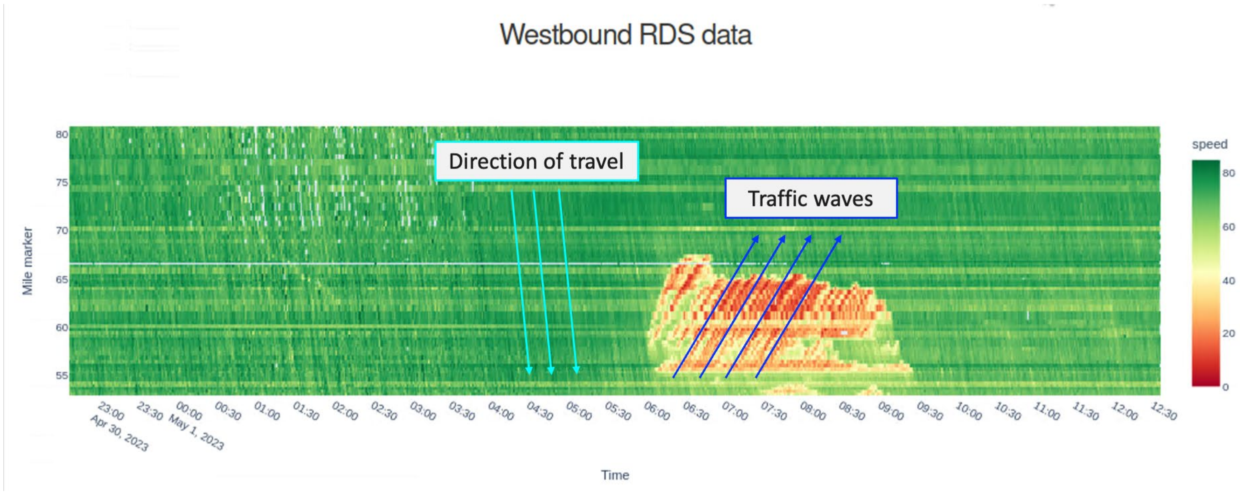


Figure 9 RDS data quality: Traffic phenomena demonstrated from raw RDS 30-second data on Interstate 24. Traffic waves are apparent in the morning peak period congestion.

With other traffic metrics

In addition to traffic speed, volume and occupancy measures from RDS detectors were both checked to confirm correctness. Figure 10 shows an example of speed, volume, and occupancy measures in a period with a crash on I-24 eastbound around milemarker 60. Figure 11 shows lane-by-lane speed measurements from a single sensor at milemarker 56 and this sensor's position within the eastbound time-space diagram for this time period. The sensor is positioned within the traffic waves of the PM peak hours. Stratification in speed across the four lanes of the road is evident during free-flow traffic, with a spread of approximately 20mph; lane 1 (left most) is shown in purple and lane 4 (right most) is shown in blue.

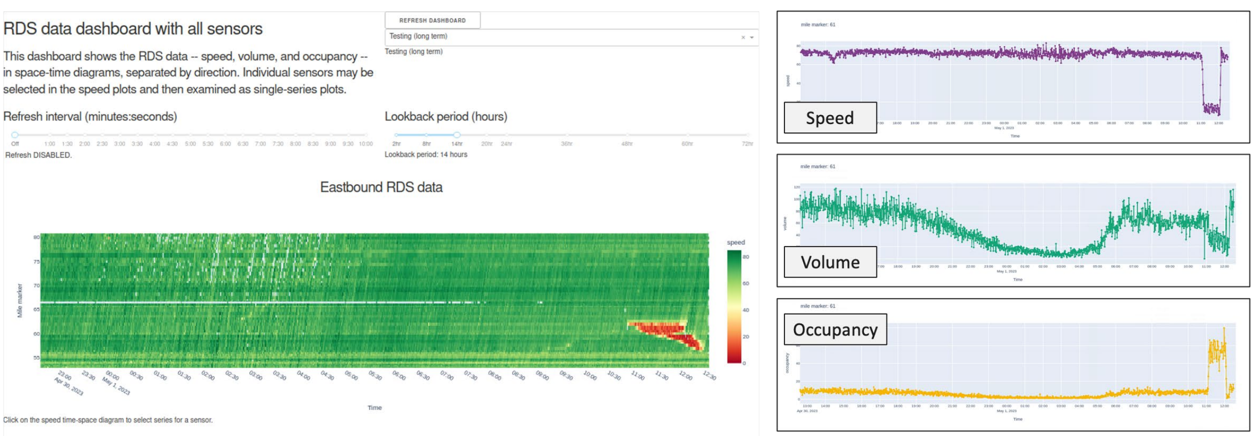


Figure 10 RDS traffic metrics: Traffic speed, volume, and occupancy during a 24-hour period with a small traffic jam.

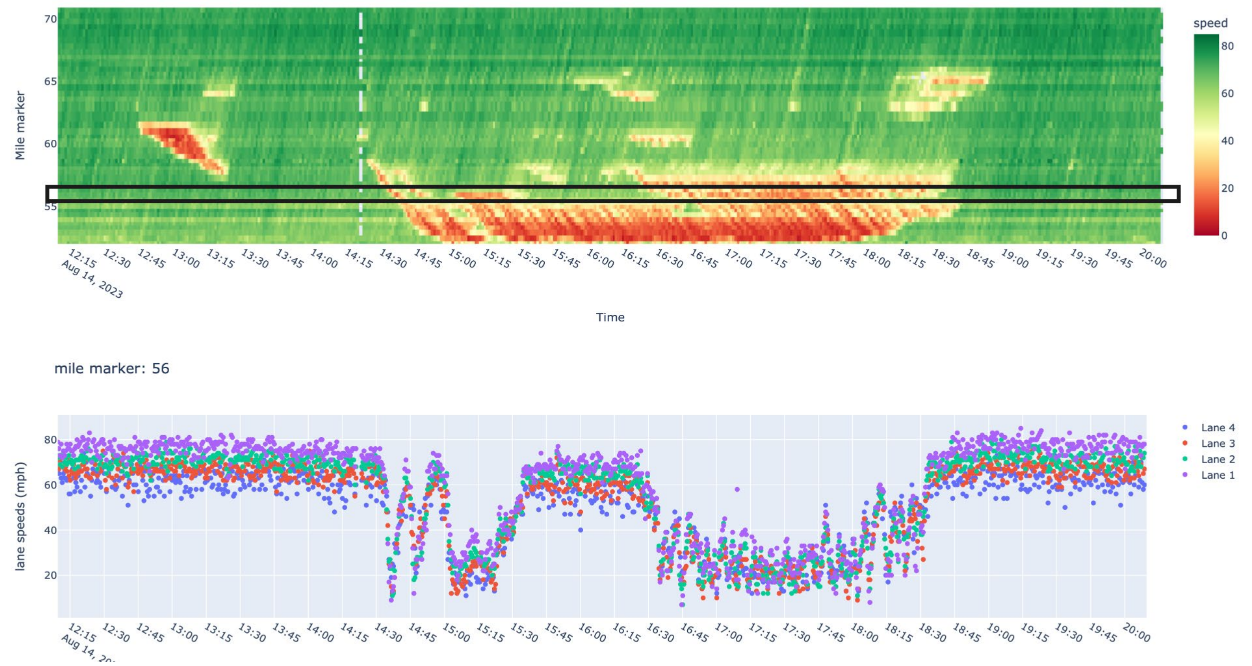


Figure 11 RDS lane speed stratification: Individual sensor inspection reveals an expected 20mph speed range from lane 1 (left most) to lane 4 (right most).

With Cloud Traffic Data

Newly improved RDS data was also compared with a commercially available cloud data source. The objectives of cloud-based traffic data are different (e.g., universal roadway coverage) than RDS and it never claims to provide the same resolution. Figure 12 demonstrates the difference in the two data sources across the same time and spatial dimensions; the cloud data is on the top and the RDS data is on the bottom. The cloud data has a response latency that can exceed 5 minutes during unexpected congestion, since probe vehicle measurements are fused with historically averaged data. Reporting resolution for this particular cloud data source is 2 minutes temporally and approximately 0.5 miles spatially. The reduced temporal resolution obscures the traffic wave phenomena present in actuality, which is readily apparent in the RDS data. In fact, the radar data is even able to reveal the approximate number or frequency of traffic waves. Temporal smoothing also obscures the severity of slowdowns on roadways, or speed heterogeneity. This is an important metric for roadway safety, particularly for rear-end collisions resulting from sudden congestion or lane shear.

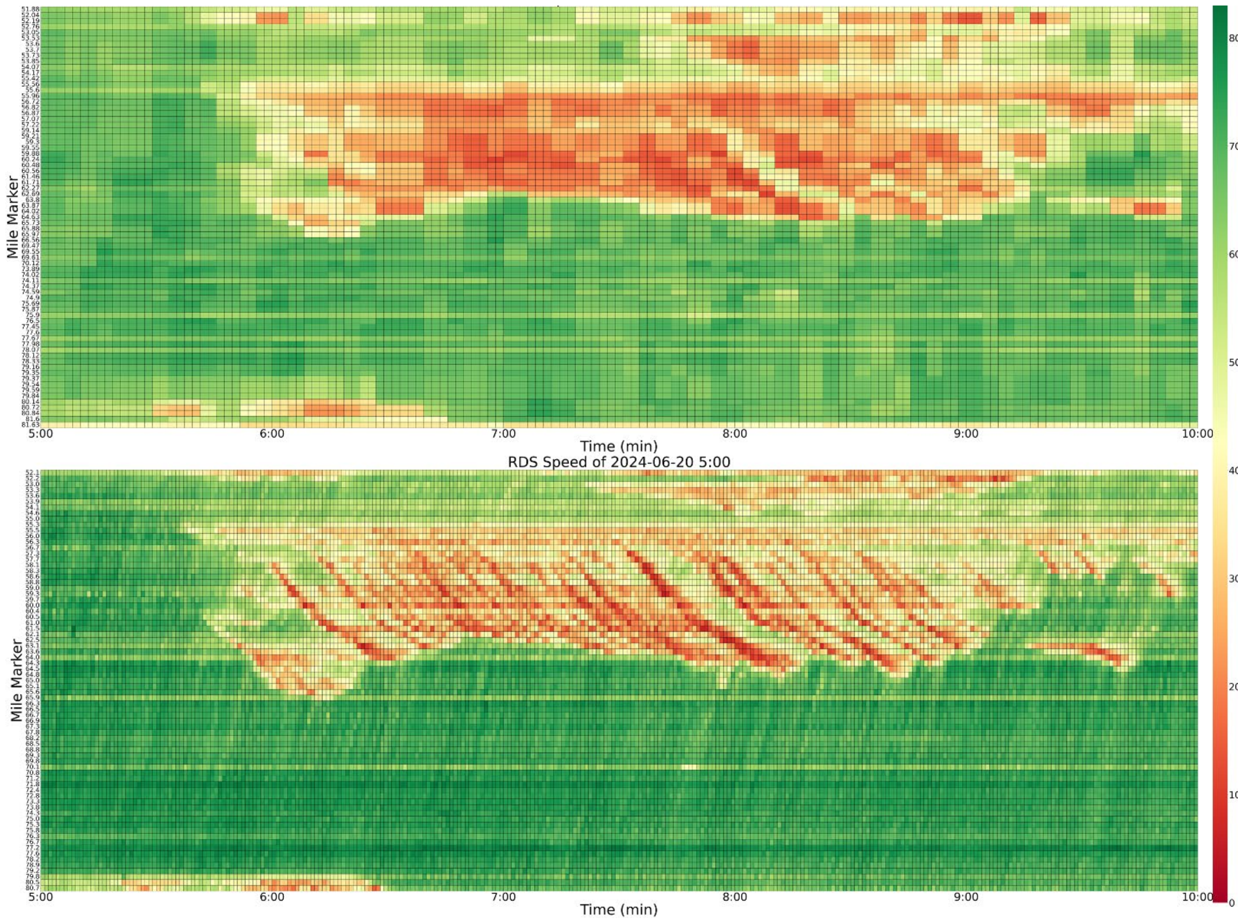
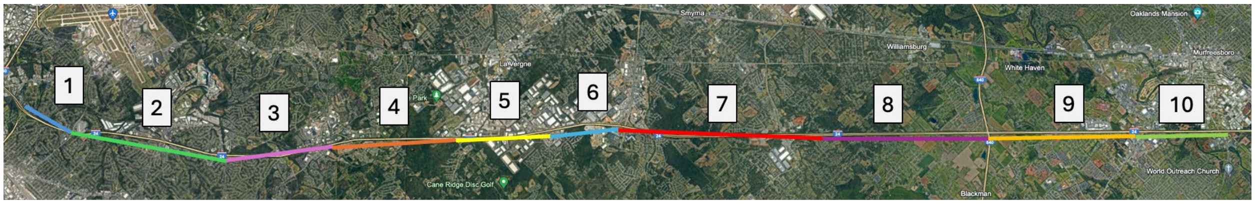


Figure 12 Comparison of RDS and cloud traffic data: Raw 30-second RDS data shows higher temporal fidelity and clear traffic wave phenomena instead of vague slow speeds.

With Existing Traffic Volume Sources

The RDS project team was asked in August 2024 to help with the performance evaluation of the I-24 SMART Corridor Phase II project. In order to analyze crash rates, an accurate and detailed assessment of year-over-year traffic volume on the corridor was needed. The analysis also needed to include a geographic breakdown of volume trends across the areas of interest on the corridor. Figure 13 shows a map of the ten segments that were analyzed and the traffic volume change on each. Importantly, the RDS data can be delineated exactly between before and after the VSL go-live day, since it is not aggregated on a weekly or monthly basis. Nearly 100 radar detectors, some of which were no longer in service, were used to compute the traffic volume change. Since the data quality had improved over time as part of this project, some outlier detection and removal was needed. In total, 3.6 billion RDS data records were processed for this analysis. The effort was only possible because of the performant database and analysis tools that were set up as part of the RDS quality improvement project.



Zone	Bounds
1	I-440 to Briley Parkway
2	Briley Parkway to Harding Pl
3	Harding Pl to Bell Rd
4	Bell Rd to Old Hickory Blvd
5	Old Hickory Blvd to Waldron Rd
6	Waldron Rd to Sam Ridley Pkwy
7	Sam Ridley to Mile marker 71
8	Mile marker 71 to I-840
9	I-840 to Med Center Pkwy
10	Med Center to Old Fort Pkwy
11	Old Fort Pkwy to S. Church St

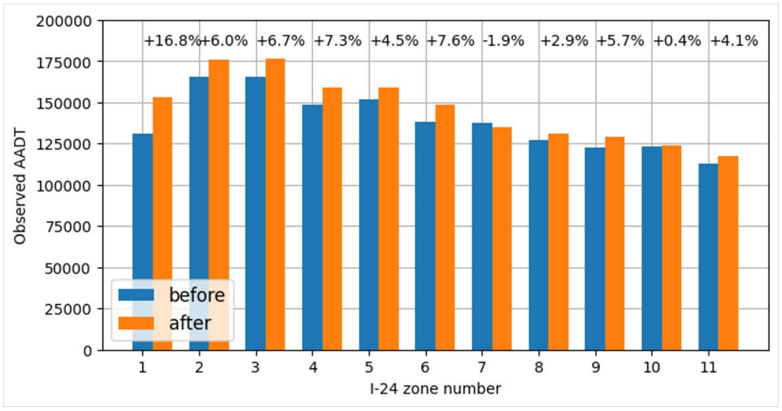


Figure 13 Traffic volume: Analysis of year-over-year traffic volume on Interstate 24, segmented into ten zones on the roadway. RDS detectors provide far more dense volume measurements and the ability to discern changes within different areas of a roadway.

4.2 Development of essential RDS dashboard monitoring tools [Task 6]

A listing of publicly available RDS dashboards was deployed to the I-24 MOTION website at https://i24motion.org/dashboard/ in order to collect and list the available visualizations; this landing page can be seen in Figure 14. The individual dashboards deployed to date are:

1. Live RDS speed plot for every roadway across all TDOT regions (updated and auto-refreshed every 3 minutes).
2. Roadway volume, including freight-specific volume for every roadway across all TDOT regions.
3. Daily RDS speed plot for every roadway across all TDOT regions. Catalog of data reaches back to January 1, 2024.
4. Interactive map of all statewide sensors.
5. Individual sensor inspection, including lane-by-lane speed and volume.
6. Interstate 24 SMART Corridor speed to VSL comparison.
7. Interstate 24 SMART Corridor current status table (RDS speed, VSL speed, open events).

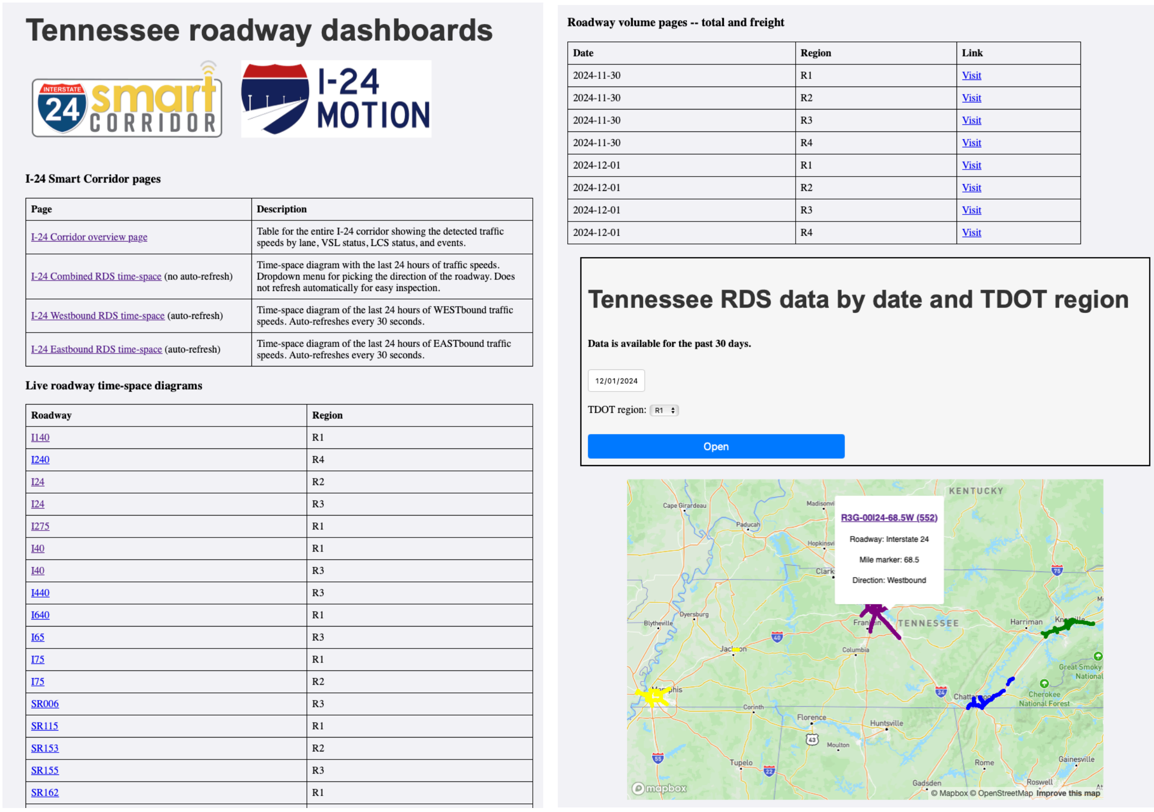


Figure 14 Public RDS dashboards: A variety of high-level and inspection-level interactive dashboards are available at https://i24motion.org/dashboard/.

All dashboards are currently generated in HTML files for portability, cross-platform compatibility (computer operating system, mobile), and deployment ease. They are generated using Python code with a Plotly backend and automated using shell scripts and web host synchronization. In the future, this code can be easily ported to a unified dashboard engine (e.g., Dash) or another website as a Javascript element, since the Plotly backend has software development integrations with these platforms.

Because of the significant size of RDS data contents within a large plot like a time-space diagram for a full roadway, browser-side cacheing of the plot data was problematic. Instead of propagating data updates to the user's browser and allowing it to update the plot iteratively, we elected for the simpler option where a new plot with a complete copy of the data is served each time. This increases network traffic, but eliminates bugs with browser cacheing concurrency and missed update contents.

Prototype dashboards were given feedback from TDOT staff (Traffic Ops in May 2024, TMC managers in June 2024, Long Range Planning in August 2024) in order to refine them and augment data availability.

4.3 Deployment of live data dashboard [Task 7]

The RDS project team worked with Southwest Research Institute and TDOT IT to expand live data feeds for RDS across all TDOT regions. An expansion of the Decision Support System API (DSS-API), which was developed for the I-24 SMART Corridor project to integrate the AI Decision Support System, was implemented on the TDOT partnering server to pass through RDS data from across the state. This required an architectural change to TDOT internal firewall, which we requested and got approved through the Architecture Review Board (ARB) and the Change Advisory Board (CAB).

To receive this data feed at Vanderbilt on a server allocated for the RDS dashboards, we worked with TDOT IT to make a change to the perimeter firewall rules. The live RDS data is fed into a time-series database (TimescaleDB) on premises and read into the public RDS dashboards as static data contents, so as not to expose the database publicly. The approximate scale of the statewide live data feed is approximately 4.1 GB/day. When added to the historical backlog of over three years of RDS data the project team has ingested, the full data catalog sits at approximately 2.5 TB.

4.4 Implementation status

All the work described in Chapter 3 and Chapter 4 has been completed on the actual field hardware and data feeds as described. The dashboards and supporting data infrastructure (data receivers, databases, automation scripts) runs on Vanderbilt servers and virtual machines and is subject to continued operation of these servers as well as the TDOT partnering server and SwCS software (core SwCS and DSS-API). Custom data requests, such as the volume analysis performed for the SMART Corridor evaluation, are simple to perform on the database even at scale.

The extant implementation is best described as an "early version". Further work is needed to ensure the longevity of RDS configuration and standardization without allowing the system to degrade in data quality.

4.5 Future work

This section discusses future development to ensure a long-term high quality data feed from the RDS system and some promising future application areas.

Event data format

Southwest Research Institute is also in the process of writing a software driver for receiving individual vehicle data from Wavetronix HD sensors and ISS RTMS Echo sensors. This will open up a new generation of data from RDS sensors across the state and new applications for the data in the freight and planning domains. We recommend transitioning all detectors to this data reporting mode and performing any necessary data aggregation (i.e., into 30-second averages) within SmartwayCS.

The older vintages of detectors, such as the SX-300, that are still on TDOT's network should be replaced at the earliest opportunity. These do not support this event level data feature as well as some other features helpful for managing the system and maintaining high-quality data (e.g., auto-calibration, 6- or 8-bin length classification).

Improved configuration process

The most significant difficulty encountered by the RDS project team over the course of the standardization and quality enhancement process was the distributed nature of responsibilities when it comes to radar hardware, software, and configuration. In total, we estimate that over 25 people were involved to perform the process across the four regions. Simplifying this process and clarifying roles, responsibilities, and accountability is critical to the system maintaining a high level of quality for years to come.

We recommend **centralizing** the device configuration and software integration responsibilities inside TDOT (hardware/field work would still be performed by the regional ITS maintenance contractors). Ideally, this work should also be automated by computer as opposed to manually inspecting each detector. The major radar device manufacturers offer some software products to perform these configurations in batch. A single person or group responsible for ensuring the detectors are up to date will be much more effective than four or more groups working independently. A step further would be integrating, to the extent possible, the device configuration within SmartwayCS. Given that SwCS already handles the ingestion of incoming data and the mapping of incoming data to lanes and links, it is natural for this to also be the location of device configuration such as protocol, length classification bins, etc.

Improved volume and speed data

A unique benefit of TDOT's radar detection compared with CCTV cameras is the ability to capture accurate and complete volume and speed data. Due to the movable nature of ITS CCTV cameras, these measures are not possible to capture fully. Radar detectors provide this data in a lane-by-lane basis and with minimal effects by line-of-sight occlusion (large vehicles masking small vehicles).

Volume data is particularly useful for stakeholders within TDOT, such as Long Range Planning, Freight and Logistics, and Traffic Design. This data is high-enough quality that the volume difference created by an on/off ramp can be discerned from one detector to the next. When segmented properly into main-line and auxiliary links (as we have done in the standardization process), ramp queue detection can be set up with the possibility to alert TMC operators.

Excessive speeding detection

RDS speed data during late night or early morning hours has shown a remarkable pattern of excessive speeding on Interstate 24. Speeds far beyond free flow expectations – into the 100mph+ territory – are seen frequently. This data has the potential to help Tennessee Highway Patrol perform targeted enforcement and position limited resources most effectively.

Outage monitoring

More frequent monitoring of device uptime will improve data reliability across the RDS network. It seems that most devices are only "pinged" once per month to determine status. This should ideally be much more frequent, such as every 10-30 seconds. Free tools are available for this purpose; they require some "do-it-yourself" setup but are widely used and require no license fees. The I-24 MOTION team uses and recommends Nagios as one such option.

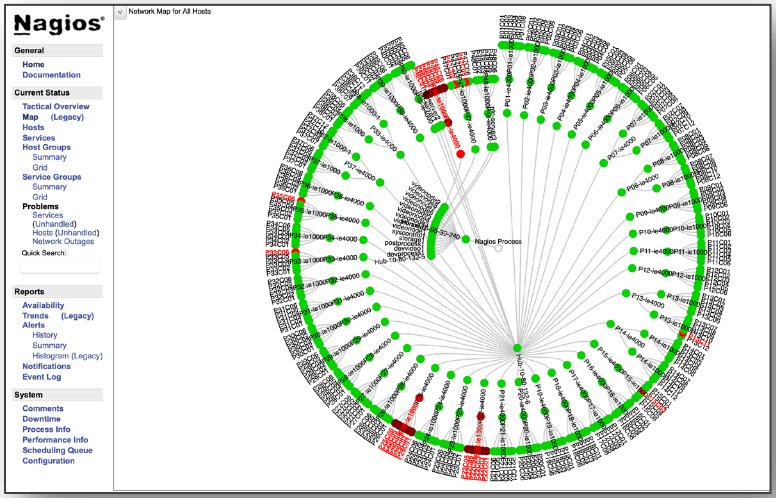


Figure 15 Nagios device monitoring system: Current online status, availability reports, and uptime metrics are available in automated system monitoring tools like Nagios (pictured here for I-24 MOTION).

Automatic incident/congestion detection

An area of further research that is utilizing the improved RDS data is automated incident detection. The motivating theory is that the onset of congestion, measured by radar speed data, is a powerful indicator that a crash or similar event has occurred on the roadway. The tricky part of this process is discerning regular, recurrent congestion from anomalous congestion. One such method of disambiguating is using a neural network trained on historical RDS data. The network learns what recurrent and non-recurrent congestion look like in terms of roadway speed data, and can, in the future, pick out instances of non-recurrent congestion for human TMC operators to evaluate.

Early results from this line of research have been published by the team in a paper entitled, "FT-AED: Benchmark Dataset for Early Freeway Traffic Anomalous Event Detection," authored by Austin Coursey, Junyi Ji, Marcos Quinones-Grueiro, William Barbour, Yuhang Zhang, Tyler Derr, Gautam Biswas, and Daniel Work. The paper was accepted for presentation and publication in NeurIPS, a premier AI and data science conference. There is a potential for future synergies between the RDS data source and other data sources such as video analytics.

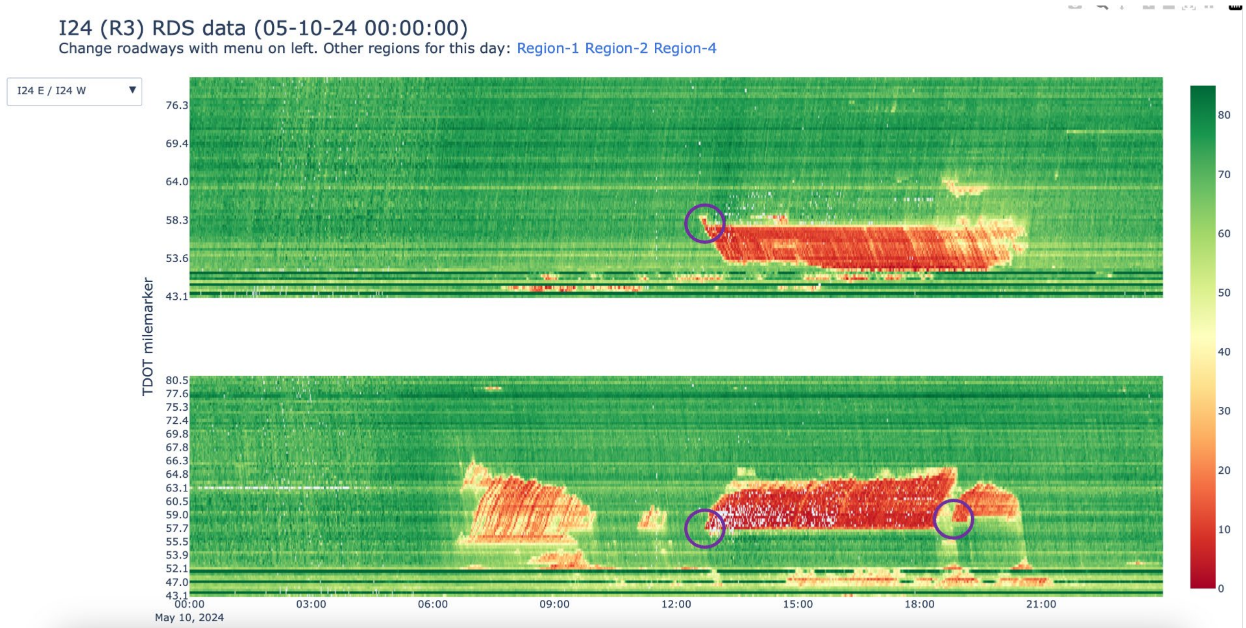


Figure 16 RDS incident detection: Within a time-space diagram, instances of non-recurrent congestion are clear and easy to pick out. Three such events are circled on this diagram and result in a clear point of congestion along the roadway that persists for multiple hours in these cases.

Chapter 5 Conclusion

This project highlights the importance of high-quality, well-maintained data systems for supporting traffic management and planning objectives. The Radar Detection System (RDS) serves as a critical tool for Tennessee's transportation network, providing reliable traffic metrics when properly configured and calibrated. The improvements in data quality achieved through this project demonstrate that the TDOT's RDS can out-perform commercially-available cloud data on highways, show detailed traffic phenomena, and drive a wide range of downstream applications.

5.1 Key Outcomes

1. **Improved Data Quality and Accessibility.** Significant improvements to RDS data were achieved through recalibration, sensor replacement, and configuration standardization. The deployment of real-time dashboards and monitoring tools enhanced data accessibility, enabling stakeholders to make informed decisions.
2. **Enhanced Traffic Management.** The updated RDS system supported critical traffic management functions, including variable speed limit (VSL) control on the I-24 SMART Corridor. These advancements directly contributed to safer and more efficient roadways.
3. **Actionable Insights for Planning and Incident Management.** High-resolution RDS data allowed for detailed traffic analyses, including volume trends, speed stratification, and congestion patterns. Early results with automated incident detection using RDS data show 5-10 minute faster event identification and accurately discern recurrent congestion (not a notable event) from non-recurrent congestion (actionable even tfor the TMC).
4. **Foundations for Future Development.** The groundwork laid by this project positions TDOT to expand the capabilities of the RDS system. Recommendations for centralized device management, automated anomaly detection, and integration of emerging data formats provide a clear path for future improvements.

5.2 Lessons Learned

1. **Identify Data Applications from Stakeholders.** Early and ongoing collaboration with stakeholders within TDOT was essential to refining project goals and ensuring practical implementation. These engagements identified underutilized application opportunities within the RDS system and underscored its potential as a high-fidelity data source. RDS standardization guidelines incorporated feedback from stakeholders to produce the highest utility data stream. We believe that there is heretofore unmet demand within the organization for RDS data, simply because stakeholders are not aware of its existence nor capabilities.
2. **Data Quality as a Foundational Element.** The project confirmed that the reliability of RDS data directly affects traffic management capabilities, particularly for advanced systems like the I-24 SMART Corridor. Sensor miscalibration and configuration issues had

a cascading impact on data usability, emphasizing the need for continuous monitoring and standardized processes.

3. **Distributed Responsibilities Create Complexity.** Managing a statewide system with decentralized configuration and maintenance processes introduced challenges. Clearer role definitions, centralized oversight, and automation tools are critical to maintaining system integrity into the future.
4. **Integration and Compatibility Enhance Usability.** Integrating RDS data with other systems, such as I-24 MOTION, revealed the value of combining datasets to uncover traffic patterns. Additionally, enhancements to the Traffic Management Center's (TMC) Smartway Central Software (SwCS) DSS-API opened up new data capabilities by allowing Vanderbilt to receive a real-time feed and build live visualizations.

In conclusion, this project has demonstrated the transformative potential of high-quality radar detection systems when paired with robust management and data integration strategies. By addressing historical challenges and implementing forward-thinking solutions, TDOT is well-positioned to leverage the RDS network for enhanced, data-driven traffic safety, efficiency, and planning outcomes across Tennessee. Continued investment in these systems will ensure long-term benefits for the state's transportation infrastructure and TDOT should be optimistic about the potential.

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Appendices

Appendix 1: RDS standardization plan

Appendix 2: ITS maintenance RDS standardization data input spreadsheet

Appendix 3: Special Provision 725 RDS excerpt

Appendix 4: New or updated RDS standardization worksheet

APPENDIX 1

RDS Standardization Plan

TDOT RDS standardization plan

The following steps outline the process for standardizing vehicle detector, link, and lane configuration in hardware and software across all TDOT regions. Standardization of data, naming, and numbering conventions allows proper comparison across detectors on a roadway and between different regions in the state.

Background

Smartway CS (a.k.a., SWCS) uses the vehicle detector, link, and lane features for organizing incoming data. A vehicle detector (RDS) in SWCS represents a physical device in the field. Each vehicle detector contains one or more links representing the different portions of the roadway at that location. Each link then contains the appropriate number of individual lane features. As data comes in from the vehicle detector, it is split out to each lane feature based on where the sensor detects vehicles. This scheme for dividing up the roadway helps data processing easily determine which values should be used together for computing values such as roadway average speed or count of vehicles taking an exit.

Procedure

Some of these steps may already be completed for existing vehicle detectors, lanes, or links, and merely need to be verified.

1. Confirm location of RDS detector in latitude/longitude (this is the authoritative/official location of the detector).
2. Confirm sensor metadata in SWCS.
    a. Detector fields: driver, detector type, protocol, host/IP, port, address, poll cycle.
    b. Location metadata: county, roadway, direction (physical side of road), mile marker, latitude/longitude (official location).
    c. Name of detector and location description, using TDOT naming convention (shown in Figure 1).

R	1	A	-	0	I	1	4	0	-	0	0	2	.	5	E
Region		Device Type	-	Location A (Route)					-	Location B (MM & Direction)					

Device Type Legend	
A	CCTV 1
E	DMS
G	RDS
J	Demarcation

Figure 1: TDOT device naming convention.

    d. If the detector is installed in the roadway median, roadway direction for the detector should be ‘M’. *Note that link direction for a median detector should still correspond to the roadway segment direction.*

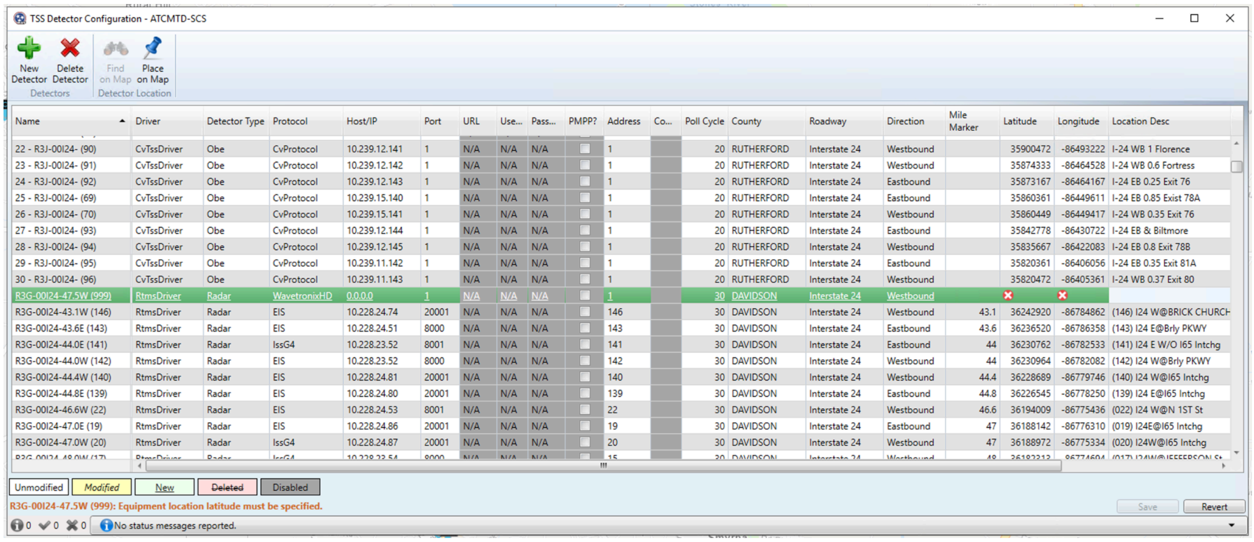

Figure 2: SWCS detector configuration window for confirming or modifying existing detectors and adding new ones. Some fields must be filled manually and others are drop-down menus.

3. Use satellite imagery or field verification to determine proper link/lane configuration at the detector site.
    a. Detector location can typically be confirmed visually in satellite or roadway view imagery unless it was recently installed.
    b. The following values will be used in link and lane configuration:
        i. Note which sides of the main line highway the sensor should detect: (2) in most cases, (1) for areas with median trees or other high barriers, (1) for median-installed detectors. Different directions of travel are always separated into two different links.
        ii. Note any auxiliary road segments that the sensor should detect. These are any portion of the roadway that is not the main line of the installation roadway and are classified into: “on-ramp”, “off-ramp”, and “aux” (other).
            - The exact classification that is chosen for an auxiliary segment is less important than the fact that the links are properly separated at all. We are not overly concerned with what defines a ramp versus an “other” auxiliary link, but emphasize that it needs to be separated from the main line.
        iii. Note the number of lanes for each main line and auxiliary link.
4. Create links for each portion of the main line roadway and each auxiliary portion of the roadway. Split existing links into multiple if necessary.
    a. Main line roadway is named like the detectors; for example: “R3G-00I24-43.6E (143)” and “R3G-00I24-43.6W (143)”. Note the difference in roadway direction for each link.
    b. Auxiliary roadway links are named like the main line, but with an additional suffix. Add “Off Ramp”, “On Ramp”, or “Auxiliary” to the name after the mile marker and direction; for example: “R3G-00I24-56.7E Off Ramp (267)”

c. Length of the link can be estimated by using roadway satellite imagery or a map of the detector locations. The length is defined as half the distance from a detector to its upstream neighbor, plus half the distance from the detector to its downstream neighbor.

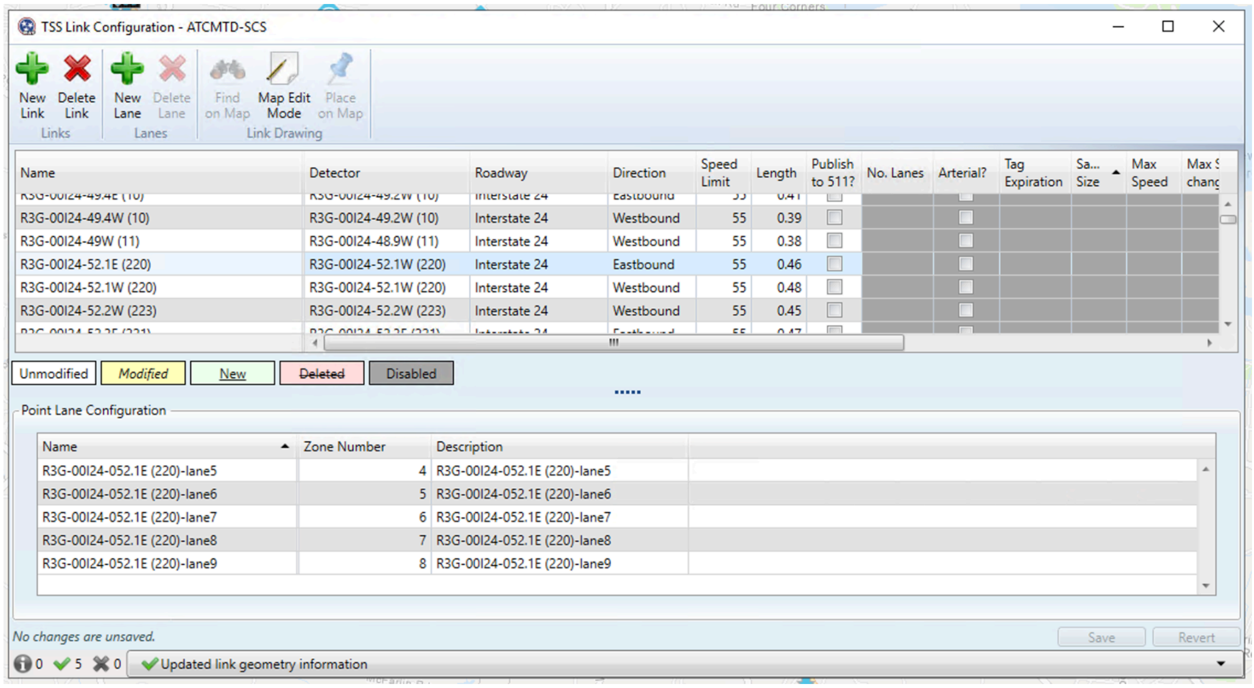

Figure 3: SWCS link and lane configuration window. Each link must have one or more lanes configured as members. Each lane must be assigned a name indicating its position and a detection zone, which maps to the sensor hardware configuration.

5. Create or re-number expected lanes within each link.
    a. Lane number is not the same as the sensor detection zone. In fact, they will typically be reversed. See Figure 4 for illustrations.
        i. Sensor detection zones start at zero and increase moving away from the sensor (e.g., 0-7 for an eight-lane highway).
        ii. Lane numbers start at one (1) in the center of the roadway (left-most when facing in the direction of travel) and increase moving outwards (to the right when facing in the direction of travel). Lane numbering is the same for each travel direction of the roadway, so there is expected to be overlap in numbers.
        iii. Lane numbers for auxiliary lanes re-start at one (1) for the center-most auxiliary lane and increase moving outwards. Again, these are numbered for each auxiliary line independently.
    b. In SWCS configuration, each lane belongs to a given link. Each link, therefore, must have at least one lane created.
    c. Lane names for main line links will use a suffix in the format “-Lane#”; for example, “R3G-00I24-43.6E (143)-Lane1”.

d. Auxiliary lanes will use the auxiliary classification from the link as a suffix in the format "-OffRamp#"; for example, "R3G-00I24-56.7E (267)-OffRamp1". Note that the auxiliary classification is used only once in the lane suffix, not carried over from the link portion of the name. The name has a limited number of characters, so it cannot have both.
e. Assign the expected detection zone to the lane based on what the sensor *should* be seeing. Recall the detection zones start at zero and increase moving outwards from the sensor location.
    i. If the detector is installed in the median of the roadway, keep in mind that the detection zones will increase in the same direction as the lane numbering.

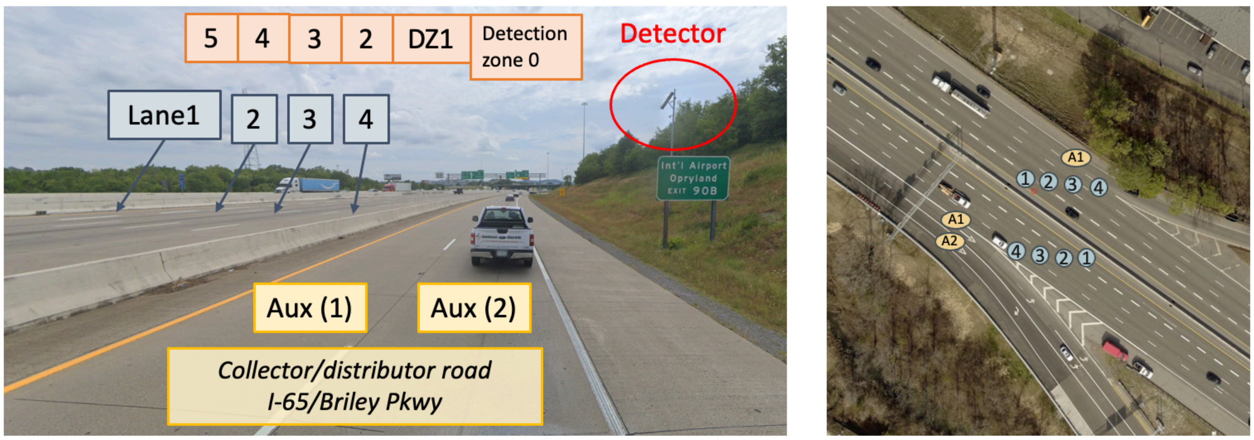

Figure 4: Lane numbering scheme; perspective (left) and overhead (right) views. Note that lane numbering is done separately for each link. East/west or north/south links are numbered independently, with the center-most lane in each direction starting at 1 and moving outwards. The same ordering is done for auxiliary links (or on-/off-ramp links).

6. Detector re-configuration
    a. Each detector make/model may have different configuration software. The following are general guidelines for setting up the sensor and should be supplemented with the installation manual for the device and other resources for installation best practices.
    b. The sensor should be set up to report US/Imperial units for speed and vehicle length.
    c. Calibration of the device for detection zones and speeds should be performed during a moderate- or high-traffic period, because it needs vehicles in detection zones to properly identify them. Especially for on-/off-ramps, the sensor may need to see a couple vehicles use the ramp in order to properly identify it.
        i. The number of detection zones on the sensor should match the number of lanes configured in SWCS.
    d. Update length bin classifications to the following values in Table 1 for detectors that accept 8 bins.

i. Many detector settings regard the bin length as the upper limit of the length that is included in that bin. So the setting should use the upper limit of the range given in the included Table.
ii. For older model detectors that only accept six bin classifications, please refer to Table 2 for the 6-bin ranges. Use this only if absolutely necessary.

Table 1: RDS length classification bins		
Bin #	Description	Length range
1	Motorcycle/small vehicle	0 - 8
2	Most passenger vehicles	9 - 18
3	Large pickup/van	19 - 23
4	Bus	24 - 25
5	Small/single unit truck (SU)	26 - 40
6	5-axle semitrailer | WB-40 intermediate semitrailer	41 - 50
7	6-axle single / 5-axle multi semitrailer | WB-50/WB-62 large/“full” semitrailer	51 - 70
8	6+-axle multi semitrailer | WB-65/67 Interstate s.t.	71+

Table 2: RDS length classification bins ***USE ONLY IF DETECTOR DOES NOT SUPPORT 8 BINS***		
Bin #	Description	Length range
1	Motorcycle/small vehicle	0 - 8
2	Most passenger vehicles	9 - 18
3	Large pickup/van	19 - 23
4	Bus	24 - 25
5	Small/single unit truck (SU)	25 - 40
8	Large/multi-unit truck	41+

Appendix 1

Table 3: Full TDOT length classifications mapping

**4-bin scheme	**6-bin scheme	8-bin scheme	13-bin scheme	Description	Length Range (feet)
1**	1	1	1	Motorcycles	00.0 - 08.3 [08.0]
	2	2	2	Passenger cars	[08.1] 08.4 - 18.1 [18.0]
2**	3	3	3	Light trucks	[18.1] 18.2 - 23.0
	4	4	4	Buses	23.1 - 25.0
3**	5**	5*	5	2-Axle, single-unit	25.1 - 30.0
			6	3-Axle, single-unit	30.1 - 35.0
			7	>3 Axle, single-unit	35.1 - 40.0
4**	6**	6*	8	<5 Axle, single trailer	40.1 - 45.0
			9	5-Axle, semitrailer	45.1 - 50.0
		7*	10	>5 Axle, single trailer	50.1 - 65.0
			11	<6 Axle, multi trailer	65.1 - 70.0
		8*	12	6-Axle, multi trailer	70.1 - 75.0
			13	>6 Axle, multi trailer	75.1+

***[note]**: length ranges from 13-bin scheme must be adjusted to integer values for the 8-bin scheme in order to be compatible with some RDS models.*

**** Note:** aggregations from 13-bin to 8-bin scheme were chosen to be compatible with HPMS summary reports, which defines single-unit trucks (bins 5-7 in 13-bin scheme) and combination trucks (bins 8-13 in 13-bin scheme) as reporting categories.*

***** Note:** 4-bin or 6-bin scheme should ONLY be used on detectors that do NOT SUPPORT 8 bins. The preference should always be for the greatest number of bins supported, up to 13.*

Appendix 2

Current RDS settings	
Bin	Length range (feet)
1	0 - 10
2	10 - 25
3	25 - 50
4	50 - 60
5	60 - 85
6	85 - 110
7	110 - 120
8	>120

Maine scheme F	
Bin	Length range (feet)
1	0 - 10
2	10 - 19
3	19 - 24
4	24 - 50
5	50 - 60
6	60 - 85
7	85 - 110
8	110 - 120

APPENDIX 2

ITS Maintenance RDS Standardization Data Input Spreadsheet

RDS data entry spreadsheet **TDOT Region 3**

Detector name	Detector ID number	Roadway	Milemarker	Installation side of road	Latitude	Longitude	Detector make/model	IP address:port	Total lanes at location	Associated link direction	Link type (main, off ramp, on ramp, aux)	Link lane count	Lane number (within link)	Detection zone	Other notes
R3G-00I40-211.8E (1)	8520	I-40	211.8	E	36.1474852	-86.7446880	G4	10.228.41.58:8000	4	E	main	4	1	3	
													2	2	
													3	1	
													4	0	
R3G-00I40-211.7W (2)	7230	I-40	211.7	W	36.1484320	-86.7450893	G4	10.228.40.58:8000	5	W	main	4	1	4	
													2	3	
													3	2	
													4	1	
											on ramp	1	1	0	
R3G-00I40-211.6E (4)	3174	I-40	211.6	W	36.1515770	-86.7514890	SX-300	10.228.41.57:8000	9	W	off ramp	1	1	0	
											main	4	4	1	
													3	2	
													2	3	
													1	4	
											main	4	1	5	
													2	6	
													3	7	
													4	8	
R3G-00I40-211E (5)	6339	I-40	211.0	M	36.1535116	-86.7565799	ss105	10.228.40.63:8000	4	E	main	4	1	0	
													2	1	
													3	2	
													4	3	
R3G-00I40-211W (6)	20595	I-40	211.0	W	36.1545170	-86.7581595	G4	10.228.40.59:L8000	4	W	main	2	1	3	
													2	2	
											off ramp	2	1	1	
													2	0	
R3G-00I24-49.2W (10)	5813	I-24	49.2	W	36.1627381	-86.7610235	SX-300	10.228.39.59:8001	8	W	off ramp	1	1	0	
											main	3	3	1	
													2	2	
													1	3	
										E	main	4	1	4	
													2	5	
													3	6	
													4	7	
R3G-00I24-48.9W (11)	7232	I-24	48.9	W	36.1672541	-86.7649736	SX-300	10.228.9.50:8000	7	W	main	3	3	0	
													2	1	
													1	2	
										E	main	3	1	3	
													2	4	
													3	5	
											aux	1	1	6	
R3G-00I24-48.6W (13)	7157	I-24	48.6	W	36.1722001	-86.7684149	SX-300	10.228.39.57:8000	4	W	aux	1	1	0	
											main	3	3	1	
													2	2	
													1	3	
R3G-00I24-48.6E (14)	7242	I-24	48.6	E	36.1721798	-86.7689337	SX-300	10.228.9.52:8000	3	E	main	3	1	2	
													2	1	
													3	0	
R3G-00I24-48.0W (17)	5812	I-24	48.0	W	36.1823131	-86.7746948	SX-300	10.228.23.54:8000	6	W	main	3	3	0	
													2	1	
													1	2	
										E	main	3	1	3	
													2	4	
													3	5	
											off ramp	1	1	6	
R3G-00I24-47.2E (19)	7103	I-24	47.2	E	36.1881420	-86.7763103	SX-300	10.228.24.86:20001	4	E	on ramp	1	1	0	
											main	3	3	1	
													2	2	
													1	3	
R3G-00I24-47W (20)	7099	I-24	47.0	W	36.1888788	-86.7752612	SX-300	10.228.24.87:20001	4	W	main	2	2	0	
													1	1	

APPENDIX 3

Special Provision 725 RDS excerpt

12 RADAR DETECTION EQUIPMENT

12.1 Description

12.1.1 General Description

This section specifies the minimum requirements for Radar Detection Systems (RDS) furnished and installed on this project. The work shall consist of providing all labor, materials, equipment, and incidentals necessary to furnish, install, test, and operate a working RDS System for TDOT.

The RDS will provide roadway monitoring capabilities via microwave radar detectors transmitting data over wireline network equipment specified in this SP725. The data provided includes but is not limited to lane occupancy, speeds, classification, and volume. The RDS device shall support high-definition radar consisting of multiple radar beams. 2 receive antennas shall be positioned side-by-side with enough space between to create two, separate high-definition beams.

It shall be the Contractors responsibility to ensure that the submitted RDS is compatible with the travel time module within the TDOT ATMS software and can operate as designed on the Plans. It shall be the Contractor's responsibility to submit a product that is in compliance with this specification and the locations on the Plans. The Contractor shall notify the Engineer of any deviation or issue with the Plans or specifications prior to submitting, furnishing, and installing the RDS.

12.2 Materials

Contractor shall provide all materials according to the requirements in the following sections.

All equipment shall be new and constructed using the highest quality, commercially available components and techniques to assure high reliability and minimum maintenance. The Contractor shall submit, Prior to installation, the Contractor shall submit and receive approval from the Engineer on a complete set of shop drawings of all the equipment and components listed within this Special Provision and included as part of the installation.

All functionality of the RDS data communications shall be ethernet-based and integral to the Device and Data Processor housings. Terminal servers shall not be used to facilitate data communications between the Device and Data Processor.

The firmware pre-installed on the device shall meet the minimum version listed in APPENDIX D at the time of device installation in the field.

12.2.1 Microwave Transmission

1. The microwave radar detector shall transmit on a frequency band of 24.0-24.25 GHz, or another spectral band approved by the Engineer. It shall comply with the limits for a Class A digital device, pursuant to Part 15 of the FCC rules or the appropriate Spectrum Management Authority. The RDS shall not interfere with any known equipment.

12.2.2 Area of Coverage

The RDS's field of view shall cover an area defined by a beam its maximum detection range shall be as follows:

1. Elevation Beam Width 40º or more

2. Azimuth Beam Width 15º or less

3. Range 6’ to 250’, minimum

12.2.3 Detection Zones

1. The minimum number of detection zones defined shall be no less than 12 lanes simultaneously.

12.2.4 Capabilities

The RDS shall be a true presence detector. It shall be suitable for mounting on road side poles or on overhead structures and provide the following:

1. Presence indication of moving or stopped vehicles in either direction in its detection zones, provided by contact closure.
2. The RDS shall have TCP/IP connection.
3. Traffic data, periodically accumulated over user defined time intervals in a 20 to 600 sec range, shall be transmitted via ethernet communications over Category 6 (minimum) cable to the local ethernet switch.
4. Traffic data shall be available simultaneously with detection zone contact closures and ethernet communications.
5. Side-fired configuration data shall include the following in each of up to 12 detection zones (lanes):
    a. Volume
    b. Lane occupancy
    c. Average speed
    d. Vehicle classification by length in a minimum of 8 user defined classes
6. RDS shall allow the user to define the contents of transmitted data.
7. Furnish the unit with the required software for data collection, processing, configuration and set-up, and data logging and retrieval. An operator shall be able to use the software to set detector count periods, sensitivities, and other operational features and parameters. The software must be capable of providing both manual and automatic setup and calibration.

12.2.5 Measurement Accuracy

1. The following error levels shall be achievable and demonstrated during testing:

Parameter	Error Percentage
Presence	5%
Volume	8%
Lane Occupancy	10%
Average Speed	10%
Length Classification Limits	10%

Parameter	Error Percentage
Time Event	10 ms
Input Voltage	2%

12.2.6 Environmental Conditions and Protection

Except as stated otherwise herein, the equipment shall meet all its specified requirements during and after installation subjecting to any combination of the following:

1. Ambient temperature range of -37°C to +74°C.
2. Relative humidity from 5% to 95%, non-condensing.
3. Winds up to 90 mph (sustained) with a 30% gust factor.
4. Rain and other precipitation up to 2” per hour rate.
5. Power surge of ± 1kV (rise time = 1.2 μsec, hold = 50μsec) applied in differential mode to all lines, power and output, as defined by IEC 1000-4-5 and EN 61000-4-5 standards.
6. Printed circuit boards shall be conformal coated for protection against humidity.
7. Except as may be otherwise stated herein for a particular item, no item, component, or subassembly shall emit a noise level exceeding the peak level of 55db when measured at a distance of 3’ away from its surface.
8. The microwave radar detector shall be resistant to vibration in accordance with IEC 60068-2-30 (test Fc), NEMA TS2 (latest edition), or approved equivalent.
9. The microwave detector shall be resistant to shock in accordance with IEC 60068-2-27 – Test Ea and guidance: Shock, NEMA TS2 (latest edition), or approved equivalent.

12.2.7 Mechanical

1. The microwave radar detector shall be enclosed in a rugged weatherproof box and sealed to protect the unit from wind up to 90 mph, dust and airborne particles, and exposure to moisture (IP 66 or greater compliant enclosure).
2. Maximum weight of the microwave radar detector assembly: 10 lbs.
3. The mounting assembly shall have all coated steel, stainless steel, or aluminum construction, and shall support a load of 20 lbs. or more. The mounting assembly shall incorporate a ball-joint, or other approved mechanism that can be tilted in both axes and then locked into place, to provide the optimum area of coverage.

12.2.8 Electrical

1. The RDS unit shall be operable from 12 – 24VDC and shall include necessary power supply to derive this voltage from a 120VAC nominal source.

12.2.9 Electrical Isolation and Surge Protection

1. All power lines, contact closures and the data port shall be surge protected within the unit. Contact closures and the data ports shall be isolated.

12.2.10 Data Processor

Data communications shall be full duplex asynchronous, configurable as:

1. RJ-45 port for ethernet communications.
2. Both point-to-point and multi-dropped configurations shall be supported.

12.2.11 RDS Comm Cable

1. The RDS comm cable shall be outdoor wet/dry rated cable with UV-resistant PVC or polyethylene outer jacket in accordance with UL 444 and wiring that supports a temperature rating of 105ºC.
2. The RDS comm cable shall support Power over Ethernet to supply both data and power over the same cable.
3. Cable connectorization and termination pin-out on all cables shall be in accordance with TIA 568B and the manufacturer's recommendations.
4. Connection between the RDS and the cabinet equipment shall be provided by a single RDS comm cable that is terminated with an IP67-rated shielded RJ-45 8P8C male push-pull connector with eight-position non-keyed and eight gold anodized pins or other Ethernet-compatible locking weathertight connector at the RDS and terminated to a surge suppressor prior to the RDS Data Processor in the equipment cabinet. No splices are permitted in the RDS comm cable.
5. Provide cable labels that meet the following requirements:
    a. Self-coiling wrap-around type.
    b. PVC or equivalent plastic material with UV and fungus inhibitors.
    c. Base materials and graphics/printing inks/materials designed for underground outside plant use including solvent resistance, abrasion resistance, and water absorption.
    d. Minimum size of 2.5" wide by 2.5" long
    e. Minimum thickness of 0.01".
    f. Orange label body with pre-printed text in bold black block-style font with minimum text height of 0.375".
    g. Pre-print the following text legibly on RDS Cable labels:
        i. RDS CABLE
        ii. TDOT ITS
    h. On all cable labels, print the text specified above twice on the label with the text of the second image reversed. The result shall be text which "reads right" when the label is coiled onto a cable.

12.2.12 Programmable Logic Controller (PLC)

If required as indicated on the Plans, the PLC shall process select data from the RDS unit and drive various field devices for turnkey applications.

1. Core requirements:

a. Minimum of 58 MHZ microprocessor
b. Minimum of 1024K of SRAM
c. Minimum of 512K of non-volatile flash memory
d. Real-time clock with battery backup
e. Watchdog timers to prevent device lockup

2. Physical requirements:
   a. Weight less than 0.5 lb.
   b. Din rail mounting
   c. Hot-swappable
3. Power requirements:
   a. Power supply 9-28 VDC
   b. Power consumption: less than 10 W
4. Environmental requirements:
   a. Ambient operating temperature: -34°C to +74° C
   b. Relative humidity: 95%
5. Connectivity requirements:
   a. Four (4) independent physical serial ports (two RS-232 and two RS-485)
   b. Two (2) multi-functional digital input ports
   c. Two (2) solid state contact closure output ports
6. Communication requirements:
   a. Converts RS-232 to RS-485 and vice versa
   b. Support the following baud rates: 1200, 2400, 4800, 9600, 19200, 38400, 57600, and 115200 bps
7. Contact closure to Ethernet device:
   a. Provide a contact closure device that will input contact closure relay signals from the RDS and output onto the 10/100Base-T Ethernet network to local Ethernet Switch.
   b. Device shall be rack, DIN rail, or wall mountable.

12.3 Installation Requirements

Contractor shall abide by the installation requirements in the following sections.

12.3.1 Radar Detection System

1. The RDS shall be mounted in side-fired configuration on poles as shown on the Plans, using mounting brackets. The brackets shall be attached with approved ¾” wide stainless-steel bands. The various mounting configurations include attaching to new light standard poles where the

wiring shall be installed inside the pole; attaching to new CCTV poles where the wiring shall be installed inside the pole and attaching to existing overhead truss structures where conduit risers may be required on the outside of the truss structure.

2. The Contractor shall install the detector unit on a pole at the manufacturer's recommended height above the road surface so that the masking of vehicles is minimized and that all detection zones are contained within the specified elevation angle as suggested by the manufacturer.

3. When installing a detector near metal structures, such as buildings, bridges, or sign supports, the sensor shall be mounted and aimed so that the detection zone is not under and does not pass through any structure to avoid distortion and reflection.

4. The RDS mode of operation, detection zones, and other calibration and set up will be performed using a Microsoft Windows-based software and a Notebook PC. The software shall allow verification of correct setup and diagnostics. It shall include facilities for saving verification data and collected data as well as saving and retrieving sensor setup from a non-volatile memory device.

5. Unused conductors in the RDS unit harness cable shall be grounded or un-terminated in the cabinet in accordance with the manufacturer's recommendations. Un-terminated conductors shall be individually doubled back and taped, then loosely bundled and secured.

6. Contractor shall install a local / remote disconnect switch or a RDS communications wiring module in accordance with Section 8.2.2, 8.2.3, or 8.2.4 and as shown on the Plans.

7. The RDS power supply shall be connected to the UPS within the cabinet.

12.3.1.1 Device Configuration

The RDS shall be configured within the ATMS softwre as part of the setup process. He following configuration parameters shall be followed.

1. Use field verification to determine proper link/lane configuration at the detector site.

2. Create links for each portion of the main line roadway and each auxiliary portion of the roadway. Split existing links into multiple if necessary.
    a. Main line roadway is named like the detectors; for example: "R3G-00I24-43.6E (143)" and "R3G-00I24-43.6W (143)". Note the difference in roadway direction for each link.
    b. Auxiliary roadway links are named like the main line, but with an additional suffix. Add "Off Ramp", "On Ramp", or "Auxiliary" to the name after the mile marker and direction; for example: "R3G-00I24-56.7E Off Ramp (267)"
    c. Length of the link can be estimated by using roadway satellite imagery or a map of the detector locations. The length is defined as half the distance from a detector to its upstream neighbor, plus half the distance from the detector to its downstream neighbor.
3. Create expected lanes within each link.
    a. Lane number is not the same as the sensor detection zone number. In fact, they will typically be reversed.
        i. Sensor detection zones start at zero and increase moving away from the sensor (e.g., 0-7 for an eight-lane highway).
        ii. Lane numbers start at one (1) in the center of the roadway (left-most when facing in the direction of travel) and increase moving outwards (to the right when facing

in the direction of travel). Lane numbering is the same for each travel direction of the roadway, so there is expected to be overlap in numbers.

   iii. Lane numbers for auxiliary lanes re-start at one (1) for the center-most auxiliary lane and increase moving outwards. Again, these are numbered for each auxiliary line independently.

b. In the ATMS configuration, each lane belongs to a given link. Each link, therefore, must have at least one lane created.
c. Lane names for main line links will use a suffix in the format "-Lane#"; for example, "R3G-00I24-43.6E (143)-Lane1".
d. Auxiliary lanes will use the auxiliary classification from the link as a suffix in the format "-OffRamp#"; for example, "R3G-00I24-56.7E (267)-OffRamp1". Note that the auxiliary classification is used only once in the lane suffix, not carried over from the link portion of the name. The name has a limited number of characters, so it cannot have both.
e. Assign the expected detection zone to the lane based on what the sensor is seeing. Recall the detection zones start at zero and increase moving outwards from the sensor location.

4. Detector software configuration:
   a. Each detector make/model may have different configuration software. The following are general guidelines for setting up the sensor and should be supplemented with the installation manual for the device for manufacturer recommendations.
   b. The sensor shall be set up to report US/Imperial units for speed and vehicle length.
   c. Calibration of the device for detection zones and speeds shall be performed during a moderate- or high-traffic period since vehicles must be readily present within the detection zones to properly identify them.
      i. The number of detection zones on the sensor shall match the number of lanes configured in the ATMS software.
   d. Update length bin classifications to the values in the following Table.

RDS Length Classification Bins		
Bin #	**Description**	**Length Range**
1	Motorcycle/small vehicle	0-8
2	Most passenger vehicles	9-18
3	Large pickup/van	19-23
4	Bus	24-25
5	Small/single unit truck (SU)	26-40
6	5-axle semitrailer | WB-40 intermediate semitrailer	41-50
7	6-axle single / 5-axle multi semitrailer | WB-50/WB-62 large/"full" semitrailer	51-70
8	6+-axle multi semitrailer | WB-65/67 Interstate semitrailer	71+

12.3.2 RDS Comm Cable

12.3.2.1 RDS Cable Shipping and Delivery

1. Package the cable for shipment on reels. Each package shall contain only 1 continuous length of cable. Construct the packaging to prevent damage to the cable during shipping and handling.
2. Seal both ends of the cable to prevent the ingress of moisture.
3. Include with each reel a weatherproof reel tag attached identifying the reel and cable that can be used by the manufacturer to trace the manufacturing history of the cable. Include with each cable a cable data sheet containing the following information:
    a. Manufacturer name
    b. Cable part number
    c. Factory order number
    d. Cable length
    e. Factory measured continuity and attenuation of each conductor and shield

12.3.2.2 RDS Cable Installation

1. Do not exceed the maximum recommended pulling tension during installation as specified by the cable manufacturer. Continuously monitor pulling tensions with calibrated measuring devices, such as a strain dynamometer.
2. Before cable installation, carefully inspect the cable reels and reel stands for imperfections or faults such as nails that might cause damage to the cable as it is unreeled.
3. Take all necessary precautions to protect reeled cable from vandals or other sources of damage while unattended. Any damage to reeled cable or the reel itself shall necessitate replacement of the entire cable section.
4. Whenever unreeled cable is placed on the pavement or surface above a pull box, provide means of preventing vehicular or pedestrian traffic through the area in accordance with the approved Maintenance of Traffic provisions.
5. Keep the cable continuous throughout the pull. Terminate the cable only in equipment cabinets on terminal blocks. Cable splices are not permitted.

12.3.2.3 RDS Cable Storage and Labeling

1. Safely store all cable to minimize susceptibility to damage. Maintain proper bend radius, both short and long term, during cable storage. Storage coils shall be neat in even length coils, with no cross over or tangling. Storage coils of different cables shall be kept separate. Storage coils shall be secured to cable racking hardware with tie wraps, Velcro straps, or non-metallic cable straps with locking/buckling mechanism. Do not use adhesive or self-adhering tapes, metal wires and straps, or rope/cord.
2. Unless otherwise noted on the Plans, the following are the requirements for cable storage for underground applications:
    a. Cable in Type C pull box – 20’.
    b. Cable in Type D pull box – 20’.

    c. Cable in Type E pull box – 20’.

3. Install cable labels on all RDS Cables. Clean the installed cable of all dirt and grease before applying any label.
4. Label all cables in or at every location where the cable is exposed outside of a conduit, inner-duct, or pole. As a minimum, install cable labels in the following locations:
    a. Within 12” of every cable entry to a pull box or equipment cabinet.
    b. Every 10’ for the entire length of cable in any storage coil in pull boxes.

12.4 Testing Requirements

12.4.1 General Requirements

1. The Contractor shall conduct a project testing program for all materials specified in this section and as required in Section 2.5 of this SP725.
2. All test results shall confirm physical and performance compliance with this SP725.
3. Payment for all testing is included in the cost of the Radar Detection Equipment.
4. All RDS Cables under test shall be removed from all wiring termination devices until testing is completed. All RDS Cable conductors shall be connected to ground immediately after testing to ensure elimination of all capacitive charges and potentials.
5. The Contractor shall submit all test results documentation to the Engineer within 7 calendar days of completion of the tests. The Engineer will review test documentation in accordance with the Submittal Review Process in Section 2.7. Test documentation shall include:
    a. RDS Cable Identification:
        i. Cable ID and Location – physical location (device ID and station number of equipment cabinet) and conductor/pair/shield ID for both the beginning and ending point
        ii. Operator Name
        iii. Engineer’s Representative
        iv. Date & Time
    b. Setup and Test Conditions Parameters:
        i. Battery charge and proper operation of ohmmeter
        ii. Battery charge and proper operation of insulation resistance tester
        iii. Ambient Temperature
    c. Test Results for Continuity Test:
        i. Conductor continuity
        ii. Resistance (ohms)
        iii. Measured Length (Cable Marking)

d. Test Results for Insulation Resistance Test:
    i. Measured Cable Length
    ii. Insulation resistance (exceeds manufacturer's specifications for at least 60 seconds.)

12.4.2 Factory Acceptance Test

FAT is not required for Radar Detection Equipment.

12.4.3 Bench Test Component

BTC shall be performed in the presence of the Engineer. The BTC shall include the following tests and inspections:

1. Verify the Radar Detection Equipment has no internal or external damage.
2. Test all Radar Detection Equipment functionality using vendor software.
3. Perform continuity test on all conductors and shield in the RDS Cable.

12.4.4 Bench Test System

BTS shall be performed in the presence of the Engineer. The BTS must be performed utilizing the maximum total length of the RDS Cable required in this project. The BTS shall include the following tests and inspections:

1. Verify Radar Detection Equipment attachment compatibility with the mounting bracket.
2. Verify that the Radar Detection Equipment is compatible and supports operational interoperability with the communication equipment, TDOT ATMS software, and any existing equipment at the Radar Detection Equipment site.
3. Verify that the RDS can be configured and calibrated using the vendor software.
4. Verify that the required operational characteristics of the device are valid including the counting of volume and speed.

12.4.5 Stand Alone Site Test

SAT shall be performed in the presence of the Engineer. The SAT shall include the following tests and inspections:

1. Verify all components have been installed per manufacturer requirements.
2. Verify all items have been attached properly (as per manufacturer recommendations and the Plans) to each other and to the Pole Structure.
3. Verify the Radar Detection Equipment has no internal or external damage.
4. Verify the Radar Detection Equipment has been properly connected to the UPS for continuous, conditioned power.
5. Verify the RDS and cabinet equipment are protected by surge suppression.
6. Verify volume and speed data can be observed through the direct local connection.
7. Verify volume and speed data can be observed through the Network Ethernet Switch.

8. Test and document the accuracy of the RDS in accordance with the accuracy requirements specified in Section 12.2.5. A portion of this test requires the contractor to use a calibrated radar gun to compare observed speeds on a per lane basis between the calibrated radar gun and RDS data over a 5-minute period. All data collected during the test shall be documented and submitted to the Engineer for approval.
9. Perform continuity test and insulation resistance test on all conductors and shield in the RDS Cable.

12.5 Warranty

All materials specified in this section shall carry a minimum three-year manufacturer's warranty from the date of Final Acceptance against any imperfections in workmanship or materials. Warranties shall cover complete replacement at no charge for the equipment. Warranties shall be transferred to TDOT upon Final Acceptance of the project as per the requirements in Section 2.6 of this specification.

12.6 Method of Measurement

12.6.1 Radar Detection System

The Radar Detection System (RDS) will be measured in units of each and paid for at the contract price per each. The bid price shall include furnishing and installing of the RDS including the unit, power supply, all conduit, risers, and weather head between the RDS and the cabinet, interconnection wiring to the ethernet switch, connections to support structures (includes all incidental components, attachment hardware, mounting brackets, mounting arms, bolts, or any other items to mount the RDS as intended), and all work, equipment, and appurtenances as required to effect the full operation including remote and local control of the RDS site complete in place and ready for use. Furnishing and installing of RDS harness cabling to be bid under the RDS Comm Cable pay Item. The bid price shall include satisfactory completion of device integration and testing of a complete RDS, including the unit, the RDS harness cabling, and interconnection wiring. The bid price shall also include all documentation including shop drawings, operations and maintenance manuals, wiring diagrams, block diagrams, and other material necessary to document the operation of the RDS. This price shall be full compensation for all labor, tools, materials, equipment, and incidentals necessary to complete the work.

In locations where an RDS is connected to an existing cabinet via RDS Cable, the bid price for the RDS shall include furnishing, installing, and testing of a RDS communication subsystem inside the existing cabinet. This RDS communications subsystem shall meet the specifications in Section 12.2.

12.6.2 RDS Comm Cable

RDS Comm Cable will be measured in units of linear feet and paid for at the contract price per linear feet of actual cable installed as measured from the cable sequential length markings. The bid price shall include furnishing, installing, device integration, and testing of a complete RDS Comm Cable installation with operational RDS units and shall include cable labels and all ancillary and incidental materials, testing, documentation, and all labor and equipment necessary to complete the work. No measurement for payment will be made for cable storage amounts in excess of that required in this SP725 or the Plans.

12.7 Payment

The contract unit price shall be full compensation for all work specified in this section.

Payment will be made under:

Item No.	Description	Unit
725-21.91	RADAR DETECTION SYSTEM	EA
725-21.96	RDS COMM CABLE	LF

Radar Detection System (RDS) will be paid per each as follows:

1. 50% of the contract unit price upon approval of Bench Test Component and Bench Test System test results.
2. Additional 20% of the contract unit price upon approval of Stand Alone Site Test results.
3. Additional 20% of the contract unit price upon approval of Conditional System Acceptance Test results.
4. Final 10% of the contract unit price upon Final System Acceptance.

RDS Cable will be paid per linear foot as follows:

1. 25% of the contract unit price upon delivery and reel test.
2. Additional 35% of the contract unit price for complete installation of cables.
3. Additional 30% of the contract unit price for successful completion of Stand Alone Site Test results of the complete cable in any lineal foot between terminations in equipment cabinets and Stand Alone Site Testing of all RDS units communicating through this section of cable.
4. Final 10% of the contract unit price upon Final System Acceptance.

APPENDIX 4

New or Updated RDS Standardization Worksheet

Location

Roadway	
Milemarker	
Latitude	
Longitude	

RDS hardware configuration

IP address	
Port	
RDS manufacturer	
RDS model	
Certify length classification bins set to SP725 standards (yes/no)	
Number of length class bins	

Lane configuration

	Direction/type	Number of lanes
Installed direction of roadway		
Ramp or aux lane on installed side? (N/A, on-ramp, off-ramp, aux)		
Opposite direction of roadway (if covered by sensor)		
Ramp or aux lane on opposite side? (N/A, on-ramp, off-ramp, aux)		

Roadway lanes	Detection zone	Road direction	Lane type	Lane number within type
	10			
	9			
	8			
	7			
	6			
	5			
	4			
	3			
	2			
	1			
Sensor location				

Instructions:
For each detection zone the sensor will see, enter the roadway direction, lane type (main, on-/off-ramp, aux) and lane number for that particular direction and type. See SP725 or other sheet for example.