Connected and Automated Vehicle Readiness Action Plan

Research Final Report from WSP | Chris Toth, Frank Perry, Armon Keshmiri | March 28, 2025

Sponsored by Tennessee Department of Transportation Strategic Planning, Research & Innovation Division & Federal Highway Administration

wsp

DISCLAIMER

This research was funded through the State Planning and Research (SPR) Program by the Tennessee Department of Transportation and the Federal Highway Administration under ***RES2023-29: Research Project Title: Connected and Automated Vehicle Readiness Plan.***

This document is disseminated under the sponsorship of the Tennessee Department of Transportation and the United States Department of Transportation in the interest of information exchange. The State of Tennessee and the United States Government assume no liability of its contents or use thereof.

The contents of this report reflect the views of the author(s) who are solely responsible for the facts and accuracy of the material presented. The contents do not necessarily reflect the official views of the Tennessee Department of Transportation or the United States Department of Transportation.

Technical Report Documentation Page

1. Report No. RES2023-29	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle *Connected and Autonomous Vehicle Readiness Action Plan*		5. Report Date March 2025 6. Performing Organization Code
7. Author(s) Chris Toth, Frank Perry, Armon Keshmiri		8. Performing Organization Report No.
9. Performing Organization Name and Address **WSP** 216 Centerview Drive Brentwood, Tennessee, 37027		10. Work Unit No. (TRAIS) 11. Contract or Grant No. RES2023-29
12. Sponsoring Agency Name and Address Tennessee Department of Transportation 505 Deaderick Street, Suite 900 Nashville, TN 37243		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

In this report, the Tennessee Department of Transportation (TDOT) has developed a Connected and Automated Vehicle (CAV) Readiness Action Plan to guide the implementation, operation, and maintenance of CAV technologies at traffic signals and along roadways across the state. Through this action plan, TDOT aims to position Tennessee as a leader in CAV deployment ensuring safe and efficient transportation for all road users. Strong leadership support within TDOT will be essential to the success of this initiative.

Building on TDOT's previous investments and lessons learned from peer agencies, this plan outlines strategic and actionable recommendations (over a proposed 5-year period) to incorporate CAV technology into TDOT's standard operations, and considers key industry priorities, such as delivering immediate benefits and achieving interoperability at scale. Recommended actions center around five areas: planning, policy, funding, engagement, and deployment. These recommendations aim to strengthen internal capabilities and foster collaboration with local agencies that are critical for CAV deployment efforts. Recognizing potential resource and expertise limitations of local agencies, the plan proposes models for TDOT's support in assisting with CAV infrastructure deployment, operations, and maintenance. Successful implementation of this plan will establish CAV as a core component of TDOT's standard operations and will position TDOT for continued investment and expansion.

17. Key Words **CONNECTED VEHICLE, AUTOMATED VEHICLE, STRATEGIC PLANNING**		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 45	22. Price $211,976

Acknowledgement

The project team acknowledges the Tennessee Department of Transportation (TDOT) for their generous support and funding of this project, and sincerely thank the many agencies whose participation in interviews and survey responses played a key role in advancing the objectives of this project. These agencies include:

Georgia Department of Transportation, Florida Department of Transportation, Utah Department of Transportation, Pennsylvania Department of Transportation, City of Memphis, Jackson MPO, Shelby County, Nashville DOT, Chattanooga TPO, City of Knoxville, City of Alcoa, City of Kingsport, City of Elizabethton, City of Morristown, Johnson City, City of Bristol, Southwest Tennessee Development District, Middle Tennessee RPO, South Central Tennessee Development District, Center Hill RPO, Dale Hollow RPO, Southeast Tennessee Development District, City of Plainview, TDOT TMC Region 1, TDOT TMC Region 2, TDOT TMC Region 3, and TDOT TMC Region 4.

We also offer appreciation to the staff at TDOT for their active participation, valuable insights, and ongoing collaboration throughout the development of this plan. Their contributions were essential in ensuring the relevance and applicability of the findings.

Executive Summary

Connected and Automated Vehicle (CAV) technology is rapidly transforming the transportation landscape, offering opportunities to enhance safety, efficiency, and mobility. Over the past several years, Tennessee has seen multiple deployments of CAV technologies by TDOT and by local agencies. Currently, TDOT faces challenges in consolidating the institutional knowledge needed to effectively manage and coordinate these projects statewide. To fully realize the benefits of CAV technologies, there is a need to align ongoing and future deployments with a shared vision, ensuring consistency, scalability, and long-term sustainability.

To prepare for this shift, the **TDOT CAV Readiness Action Plan** provides a structured approach to integrating CAV technologies into Tennessee's transportation system. This plan builds on national best practices, existing state initiatives, and stakeholder input to ensure a seamless transition toward an increasingly connected and automated future. This plan focuses on driving CAV communications into common practice and considers the role of TDOT in supporting local agencies in various stages of the CAV deployment process. This plan outlines strategies for leveraging Cellular V2X (C-V2X) and other communication methods while ensuring TDOT can effectively manage, expand, and support CAV services across Tennessee.

Goal of the Readiness Action Plan

By implementing this plan, TDOT will create a foundation for scalable, interoperable, and cost-effective CAV deployment while ensuring Tennessee remains at the forefront of transportation innovation. This plan aims to:

- **Build internal support and secure leadership buy-in** by clearly communicating the value of CAV technologies and identifying strategic opportunities for investment.
- **Assess current policies and capabilities** to identify gaps and define the steps needed to prepare TDOT to undertake and support local agencies in CAV technology deployment.
- **Establish strategic recommended actions** to guide future CAV initiatives, partnerships, and investments aligned with agency goals and community needs.

Key Findings

Several key findings highlight both the current state of CAV technology deployment in Tennessee and the steps needed to establish a coordinated, future-ready approach. These findings include:

- **Fragmented Deployment Efforts –** Tennessee has seen multiple CAV technology deployments, but these efforts have been largely independent, lacking a unified strategy for implementation, operation, and maintenance.
- **Need for a Statewide Vision and Coordination –** Without a common framework, municipalities and agencies are implementing CAV technologies in different ways, leading to inconsistencies in interoperability, data sharing, and overall system effectiveness.

- **Institutional Knowledge Gaps –** TDOT requires a structured knowledge base and capacity-building efforts to effectively manage and coordinate CAV initiatives, ensuring that deployments align with a statewide vision.
- **Existing Infrastructure Investments –** TDOT has already deployed 132 Dedicated Short Range Communications (DSRC) units along SR 1 and 30 units within the I-24 Smart Corridor. However, the Federal Communication Commission's 2nd Report and Order, which went into effect on February 11, 2025, stipulates DSRC systems transition to C-V2X or halt operations by December 14, 2026. Future investments need to be in C-V2X.
- **Evolving Industry Landscape –** As connected vehicle technology shifts toward C-V2X and other emerging solutions, TDOT needs a roadmap for adapting to changing standards, regulations, and industry advancements.
- **Need for Actionable Implementation Strategies –** Beyond research and assessments, the plan needs to emphasizes the need for specific, practical steps that TDOT can take to advance CAV deployments in a coordinated and sustainable manner across the state.

Key Recommendations

This plan outlines a series of recommended actions across planning, policy, funding, engagement, and deployment to ensure TDOT is prepared for CAV integration. The following recommended actions will help prepare TDOT for the deployment of CAV technologies:

Planning
- Build Technical Capacity
- Develop a Deployment Plan for CAV Technology in Tennessee
- Assess Infrastructure improvements and cost
- Prioritize Technology Applications and Locations
- Develop Systems Engineering Documentation and CAV System Architecture
- Build Operations and Maintenance (O&M) Capabilities
- Develop Technical Requirements for CAV devices and supporting infrastructure

Policy
- Develop IT Policy around CAV Devices
- Develop Data Governance Plan
- Review Motor Vehicle Operation Regulations and Recommend Legislation
- Develop Standard Agreements with Local Agencies
- Develop an AV strategy

Funding
- Provide Dedicated Funding for CAV technology projects
- Leverage Federal Funding

Engagement
- Active involvement in CAV Committees and Working Groups
- Set up external webpage dedicated to CAV technologies
- Set Up internal webpage dedicated to Knowledge Sharing
- Use Existing Deployments to Showcase CAV Technology Capability
- Develop Strategic Partnerships

Deployment
- Update to Cellular Vehicle-to-Everything Communications

- Set up Statewide CAV Supporting Systems
- Conduct a Hands-On CAV Deployment to Build Internal Capacity
- Develop a Standard Deployment/Integration Process

Table of Contents

List of Tables

List of Figures

Glossary of Key Terms and Acronyms

ADAS	Advanced Driver Assistance System
ATTAIN	Advanced Transportation Technology and Innovation
AV	Automated Vehicle
BSM	Basic Safety Message
CAV	Connected and Automated Vehicle
CIMMS	Connected Intersection Message Monitoring System
CMAQ	Congestion Mitigation and Air Quality
CV	Connected Vehicle
C-V2X	Cellular Vehicle-to-Everything
FCC	Federal Communications Commission
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications

JPO	Joint Program Office
ICM	Integrated Corridor Management
IT	Information Technology
ITS	Intelligent Transportation Systems
MAP	Map Data
OBU	Onboard Unit
O&M	Operations and Maintenance
PFS	Pooled Fund Study
RAP	Readiness Action Plan
RSU	Roadside Unit
SCMS	Security Credentials Management System
SCRC	Smart Community Resource Center
SMART	Strengthening Mobility and Revolutionizing Transportation
SPaT	Signal Phase and Timing
SRM	Signal Request Message
SS4A	Safe Streets and Roads for All
TDOT	Tennessee Department of Transportation
TaaS	Transportation as a Service
TIM	Traveler Information Message
TMC	Traffic Management Center
TSC	Traffic Signal Controller
TSMO	Transportation Systems Management and Operations
USDOT	United States Department of Transportation
V2X	Vehicle-to-Everything
vRSU	Virtual Roadside Unit

Chapter 1 Introduction

Connected and Automated Vehicle (CAV) technologies are rapidly evolving, offering new opportunities to improve safety, mobility, provide information to travelers, and enhance traffic management capabilities . Recognizing this, the Tennessee Department of Transportation (TDOT) is committed to advancing CAV deployment and ensuring that Tennessee remains at the forefront of transportation innovation. As part of this effort, TDOT identified the need for a CAV Readiness Action Plan (RAP) in its Transportation Systems Management and Operations (TSMO) Program Plan. [1]

This CAV Readiness Action Plan will serve as a strategic guide for the implementation, operation, and maintenance of CAV technologies at traffic signals across Tennessee. The plan will help municipalities integrate new and existing traffic signal infrastructure with emerging CAV technologies, ensuring alignment with industry advancements such as the transition from Dedicated Short-Range Communications (DSRC) to Cellular Vehicle-to-Everything (C-V2X).

Given the diverse ownership and operational models of traffic signals across the state, this CAV Readiness Action Plan will outline scalable alternatives for TDOT's role in supporting municipalities that may not have the capacity to fully manage CAV-enabled traffic signals. The plan will define implementation strategies based on current signal ownership models and potential levels of TDOT support, including operations, maintenance, contracting, information technology, data governance, and funding mechanisms.

A core element of the Readiness Action Plan is the development of project and program recommendations to support TDOT's long-term CAV service investments. These recommendations will be informed by TDOT's existing goals, industry best practices, lessons learned from peer agencies and identified gaps in current programs. The plan will also provide cost estimate ranges and guidance for interagency coordination, ensuring a structured and adaptable approach to CAV integration in Tennessee.

Chapter 2 Background

In preparation for the development of this plan, several preliminary activities were undertaken in order to provide a common reference for what elements are involved with a CAV system, learn from local agencies within Tennessee and peer State DOTs, and to understand opportunities and barriers to CAV implementation. The summaries of these efforts are provided in the subsections below. The intent of these activities is to build a knowledge base for TDOT leaders to better understand the state of the CAV industry, where TDOT stands, and where key stakeholders want to see CAV deployment progress in the region. The findings from these activities were used as a foundation for developing recommendations in Section Chapter 6 of this action plan.

2.1 CAV System Elements

The first step in the process of developing the Readiness Action Plan for TDOT is to understand the current CAV landscape and available technologies. In this section, CAV systems applicable to TDOT's long-term goals will be described and analyzed for benefits and weaknesses.

For this Readiness Action Plan, V2X and AV technologies are treated separately, as they primarily operate independently. Additionally, the timeline for integration of V2X and AV systems on a broad scale is far enough in the future that it does not yet warrant consideration within the scope of this readiness action plan. V2X technology focuses on real-time data sharing for driver alerts and infrastructure communication, while AVs rely on sensors and automation for vehicle control.

AV and Advanced Driver Assistance System (ADAS) technologies have evolved over decades, with ADAS features like collision warning and adaptive cruise control becoming widespread in the 2010s. While ADAS assists drivers, companies like Waymo focus on full autonomy using lidar, radar, and cameras, primarily for transportation-as-a-service (TaaS). These systems rely on perception (sensor data collection), planning (route navigation), and control (steering, braking, and throttle execution). ADAS-equipped vehicles use lower-cost sensors, while AVs require expensive, ruggedized hardware for research and limited deployment. Radar offers long-range detection but lacks clarity, lidar provides precise mapping but struggles in bad weather, and cameras aid object recognition but perform poorly in low light. AVs and ADAS vehicles are strong candidates for V2X integration, making their capabilities critical for infrastructure planning.

The V2X system architecture includes Traffic Signal Controllers (TSCs), Roadside Units (RSUs), On-Board Units (OBUs), and supporting systems like the Security Credential Management System (SCMS), Position Correction Data Server, and V2X Management System. It details various V2X message types, including Basic Safety Messages (BSMs), Traveler Information Messages (TIMs), and Signal Request Messages (SRMs), which facilitate safety and mobility applications. RSUs play a central role in broadcasting messages to vehicles and integrating with traffic management centers. The document also outlines hardware installation considerations, such as RSU mounting requirements, network connectivity, and licensing.

Security, data management, and operational maintenance are critical for system effectiveness. SCMS ensures trusted communication by issuing digital certificates, while network security measures protect against cyber threats. The document highlights the need for staff training in

V2X standards, system configuration, and monitoring. Agencies must also address software updates, data storage, and system interoperability to maintain long-term functionality.

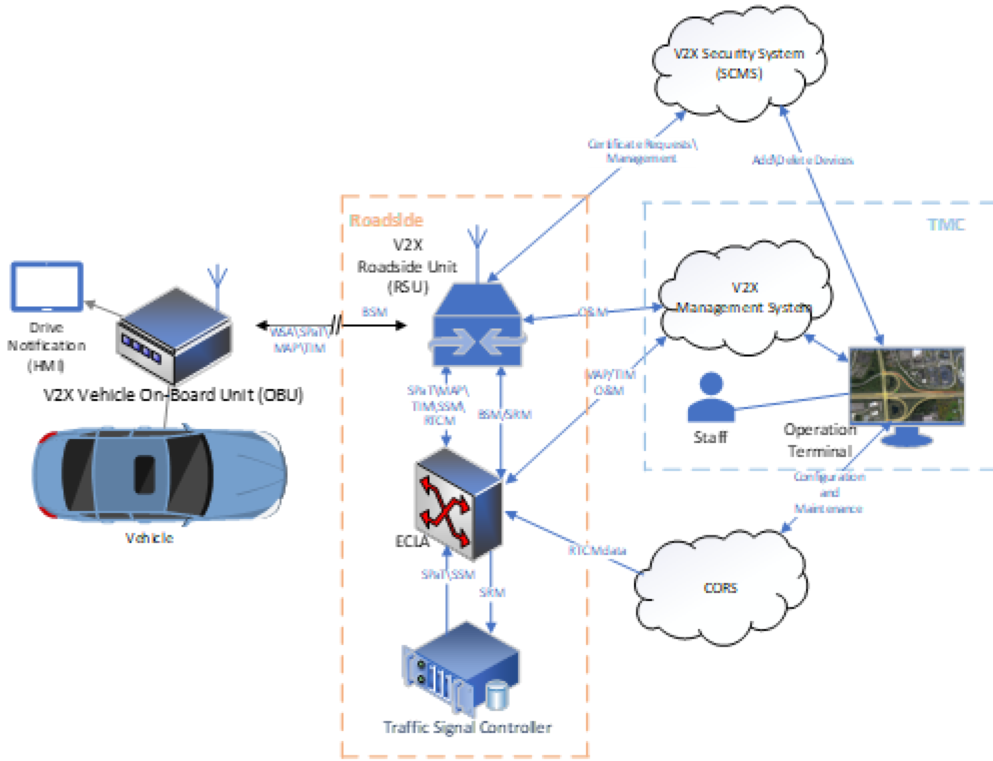


Figure 1. V2X General System Diagram

2.2 Gap Analysis

The CAV readiness gap analysis involved performing outreach with 19 local agencies (12 in urban areas and 7 in non-urban areas) and the 4 regional Traffic management Centers (TMC) in Tennessee with the purpose of identifying the gaps in knowledge, resources, or infrastructure that are necessary for a successful CAV ecosystem. It revealed several key challenges and focus areas for agencies planning to deploy CAV technology. These challenges include limited funding, lack of skilled personnel, inadequate educational resources, insufficient technical support, and unclear legal and regulatory frameworks. Urban and non-urban agencies both face these barriers, although specific concerns differ. Many agencies report an inadequate number of skilled personnel to support research and pilot initiatives, which is exacerbated by limited financial resources and minimal local political support or engagement on the topic. Furthermore, a lack of clarity regarding state policies makes it difficult for agencies to understand the legal and regulatory framework necessary to move forward confidently. This uncertainty hampers efforts to develop strategies for CAV deployment.

In many cases, CAV technology remains a relatively unfamiliar concept leading to a slow adoption pace. Agencies express a need for foundational education on CAV technology, potential funding sources, and insights into practical implementation steps to help stakeholders grasp its benefits.

Some agencies, especially in non-urban areas, indicate that CAV technology is not yet prioritized due to competing demands for transportation funding and a lack of infrastructure, like traffic signals and communication systems. Additionally, gaps in technical support and standards for CAV systems further impede implementation, as agencies struggle to maintain essential operations while adapting to new technological demands. Non-urban agencies face more significant hurdles in terms of staff, funding, and understanding of CAV technology. Most non-urban agencies heard about CAV technologies, however, have little awareness and understanding of how the technologies are used in practice. A lack of funding, staff, and knowledge about CAV technologies are the most prominent themes in responses from non-urban agencies that are barriers to these agencies implementing this technology on their roadways. This is not a surprise, as many of these agencies seem to have limited budgets that primarily focus on preservation and maintenance of existing roadway infrastructure, and do not have programs or discretionary funding available for taking on projects that involve CAV technology.

Urban agencies tend to have more familiarity with CAV technology but still require guidance, especially in terms of funding and operational readiness. Some urban agencies are familiar with CAV technologies, and some (particularly the city of Memphis) have had hands-on experience in CAV technology deployments. There are also some urban agencies that have lower amounts of awareness and understanding.

However, there are agencies from both groups that are actively looking to deploy CAV technologies in the near future. There is a consensus that the technology should be deployed in areas where it is needed the most. However (also drawing on one response from an urban agency), there is a bit of concern that non-urban areas could be left out especially as the technology develops and becomes more prevalent, and that a balanced approach should be taken to ensure urban and non-urban areas are represented in CAV technology deployments. While some agencies will need more assistance than others to get an operational CAV deployment up and running, it is anticipated that all agencies stand to benefit from guidance and direction from TDOT.

In summary, the gap analysis highlights the need for focused efforts in several areas, including:

- **AV and V2X Program Goals**: Establish clear statewide goals aligned with federal strategies, local deployment, and realistic timelines for V2X benefits.
- **Deployment Strategy**: Prioritize use cases, locations, and encourage strategic partnerships for CAV deployment.
- **Infrastructure and Architecture**: Develop the necessary V2X infrastructure, address security and data privacy, and ensure alignment with regulatory standards.
- **Funding.** Explain what TDOTs role will be in funding local initiatives and what grant opportunities are available for deploying CAV technologies.
- **Education/Workforce Development**: A critical finding is the need for foundational education on CAV technologies and practical implementation strategies. Non-urban agencies, in particular, struggle to prioritize CAV deployment due to competing transportation needs and a lack of infrastructure.

- **Operations and Maintenance**: Plan for the ongoing management and support of CAV systems.
- **AV Program Goals**: Define specific goals for autonomous vehicles, including regulatory frameworks and operational strategies.
- **AV Use Cases and Operations.** Define goals and use cases for AV operations in Tennessee.

2.3 Peer Agency Outreach

Numerous state and local agencies have deployed CAV systems over the past several years. While there are some advantages to being first, there are also advantages to being a fast follower, leveraging experiences, advances, and lessons learned from peer agencies that have deployed CAV technology. As a fast follower, TDOT has the advantage of learning from peer agencies about what is ready, what still needs some modification (and what those recommended adjustments are), and what still needs significant development before being implementation ready. Outreach was activities were undertaken with Florida DOT, Georgia DOT, Pennsylvania DOT, and Utah DOT to understand the obstacles and opportunities of implementing CAV systems to the level of detail to the local signal infrastructure.

Feedback from these agencies indicated that initial deployments often focus on a limited number of locations where barriers are lower, allowing agencies to gain practical experience with V2X technologies. Prioritizing deployment sites and applications is crucial, with urban and suburban areas, particularly signalized intersections, being common initial targets due to their existing communications infrastructure and the nature of the issues that V2X aims to address. Developing a methodology for identifying and selecting deployment locations helps address local needs and maximize benefits. Additionally, installing On-Board Units (OBUs) on partner agency vehicles can provide immediate advantages, such as improved mobility through priority and preemption applications, even before widespread V2X adoption.

One significant challenge in deploying V2X technologies is ensuring that all roadside hardware is adequate and compatible, especially traffic signal controllers that need to produce the necessary data for Signal Phase and Timing (SPaT) messages. The mechanism for OBUs to receive security certificate updates via RSUs is not yet refined and supported only by specific vendors. Maintenance complexities arise as V2X technology relies on various hardware and network infrastructures often managed by different groups, necessitating knowledgeable staff to deploy, operate, and maintain these systems. Data management is another critical issue; V2X message data must be accurate, reliable, and consistent. Agencies must budget adequately for procurement, installation, and ongoing operations and maintenance, with costs potentially rising if existing infrastructure needs upgrading to support RSU integration.

Opportunities for agencies deploying V2X technologies include learning from other agencies' experiences and leveraging best practices. Agencies with active programs for maintaining and updating existing infrastructure face lower barriers to entry. Developing strong relationships with IT staff and consultants can support integration, operations, and maintenance, although agencies should build internal V2X expertise. Utilizing various contracting mechanisms and securing agency funding, even when applying for federal grants, is essential. Agencies can benefit from research and development activities that not only advance their V2X deployments but also contribute to the broader industry. Understanding and complying with data privacy laws and developing policies for data retention and access are vital as the volume of V2X message data grows. Deploying V2X technologies today ensures agencies stay current with evolving technologies and avoid outdated plans.

The deployment of V2X technologies offers numerous opportunities, starting with the ability to demonstrate immediate "Day 1" benefits, such as enhanced traffic efficiency and improved safety for vulnerable road users. The ITS America National V2X Deployment Plan [2] and the USDOT's plan, "Saving Lives with Connectivity: A Plan to Accelerate V2X Deployment," [3] (and supplement [4]) highlight the potential for large-scale deployment and optimal spectrum utilization to maximize these benefits. Interoperable connectivity across various platforms ensures seamless communication between different systems, further enhancing the efficacy of V2X technologies. Additionally, multiple grants provide opportunities for agencies to secure matching federal funding, each with unique objectives and requirements that can help tailor deployments to specific local needs while aligning with national goals.

The overarching message from peer agencies is to "Just Do It"—get started with deployment efforts and refine as you go. TDOT can form relationships with these (and other) peer agencies, many of which have expressed a strong willingness to offer support and share insights, creating a culture of cooperation and shared growth. By actively seeking opportunities to learn from others' programs and forming partnerships to implement proven solutions, TDOT can accelerate its progress in deploying CAV technologies. At the same time, TDOT can contribute to this collaborative environment by sharing its own lessons learned and best practices, further enriching the collective knowledge base and fostering advancements in CAV technologies.

2.4 Opportunities and Barriers

Next, opportunities and barriers were identified based on the focus areas outlined in the Gap Analysis. The specific barriers associated with each focus area were highlighted, along with potential opportunities for TDOT to address and overcome them. Similarly, best practices that were identified through the peer review process are further narrowed down to those that are applicable to TDOT as additional opportunities. These identified opportunities will be used to inform the CAV Readiness Plan. The Opportunities and Barriers focused on the following 11 areas:

- Goals and Objectives
- Deployment Strategy
- Infrastructure/Architecture
- Funding
- Regulatory and Standards
- Network Security and V2X Wireless Security
- Data Management and Data Privacy
- Workforce Development
- Inter-Agency Engagement and Public Engagement
- Operations and Maintenance
- AV System Planning and Operations

Chapter 3 CAV Communications

There is ongoing industry discussion about communication methods for supporting connected vehicle applications. C-V2X is designed specifically for direct communications between devices and has historically received most of the attention. However, complimentary methods like traditional cellular and satellite networks are now receiving increased attention. Each approach presents distinct advantages and challenges based on deployment needs, coverage, and reliability. It is essential for TDOT to evaluate both options to ensure preparedness for future developments.

3.1 Cellular V2X (C-V2X)

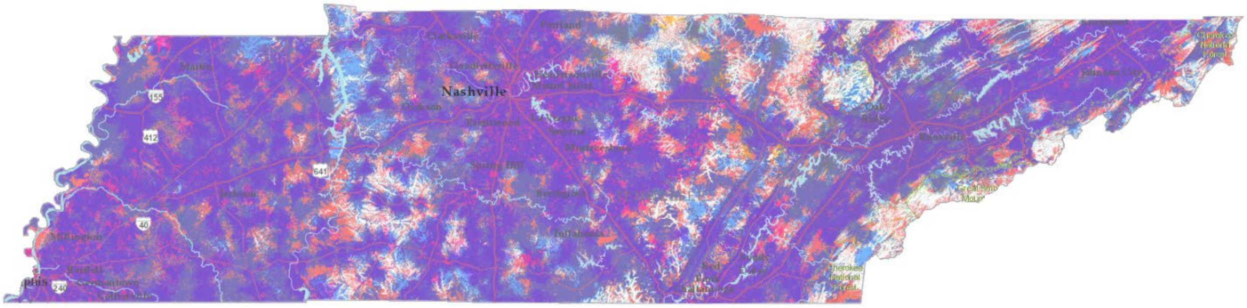
Cellular-V2X (C-V2X) is a communication technology that facilitates **direct** interaction between vehicles, infrastructure, pedestrians, and the broader network using cellular-based protocols. Developed under the 3GPP standards, C-V2X operates within the 5.9 GHz band and is engineered to deliver low-latency, highly reliable communications essential for safety-critical applications such as red light violation warnings and vehicle-to-vehicle collision avoidance. C-V2X can also support many other mobility and information-based applications as well – though these applications do not typically require the superior latency provided by C-V2X. This technology serves as the foundation for realizing the long-term safety benefits promised by CAV systems, which are expected to materialize as more vehicles become equipped with C-V2X.

C-V2X supports both direct communications (vehicle-to-vehicle, vehicle-to-infrastructure, etc.) without relying on the cellular network. These devices, the networks they rely on, and service required to support them must be managed by a deploying agency – typically a state or local department of transportation. This means that deploying agencies must make a large investment in physical infrastructure, and in the near term, strategic approaches are needed to demonstrate benefits to justify continued or expanded investment.

Because an agency owns the C-V2X components, it puts the data generated from vehicles (collected by RSUs) directly into the hands of these agencies, which enables many traffic management types of use cases. This comes at the expense of managing infrastructure needed to ingest, process, handle and store this data.

3.2 Alternative Communications Media

The use of cellular (networked cellular) and other communications mediums, such as satellite, presents a viable and scalable approach for enabling communication with connected vehicles across Tennessee. One of the primary advantages of these technologies is their existing widespread coverage—most drivers already carry smartphones that utilize cellular networks, allowing for data exchange in most areas without the need for new physical infrastructure. According to the Federal Communication Commission's (FCC) 2021 data, cellular coverage is available throughout the majority of Tennessee, with limited gaps in rural or remote areas. In these uncovered zones (shown in white on the map below), satellite communications could serve as a solution, ensuring continuous connectivity even in areas where traditional cellular networks are not available.



Areas with Coverage   Areas without Coverage

Source [5]

Figure 2. LTE Data Coverage in Tennessee

This approach eliminates the need for TDOT to own, operate, and maintain a physical communications network, such as roadside units (RSUs) or dedicated fiber infrastructure, significantly reducing the long-term burden on the agency. However, it does require the development and operation of a robust data-sharing platform to facilitate real-time communication between TDOT, vehicles, and potentially third-party service providers. This platform would enable data to be used by navigation and mobility services like Waze and Google Maps. While these third-party apps are widely used and could amplify the reach of TDOT's information, there is no guarantee they will incorporate or prioritize the state's data in a timely or consistent manner or share data back with TDOT. To ensure the intended use of its data and to directly deliver value to travelers, TDOT may choose to develop its own smartphone application or interface, providing targeted features and services for travelers across the state.

Major mobile network providers, such as Verizon, have introduced virtual RSU (vRSU) solutions, which allow data to be shared with connected vehicles (though a specialized smartphone application) over the cellular network without the need for physical RSU infrastructure. In a virtual RSU model, location-specific data is broadcast via a cellular cloud, and vehicles entering defined virtual geofenced areas can receive relevant messages through the smartphone application. While cellular communications do not yet provide the ultra-low latency required for safety-of-life applications—such as collision avoidance or emergency braking—they are more than capable of supporting mobility and information applications that enhance the driving experience and support broader transportation goals.

It is important to note that this represents a shift from more traditional infrastructure-based approaches. These communication mediums introduce a "middle layer" between TDOT and travelers. Travelers must have access to a cellular or satellite data plan, and in the case of the vRSU solution, TDOT must negotiate access to the underlying data systems and services, often at a cost. However, the tradeoff is a significant reduction in maintenance responsibilities, as the burden of network operation and upkeep is offloaded to private-sector providers. As TDOT plans its approach to communication strategies, the balance between cost, control, coverage, and service delivery should be carefully considered, particularly in light of evolving public-private data-sharing models and the rapid advancement of connected vehicle technologies.

Chapter 4 TDOT Involvement and CAV Expected Benefits

Realizing the full potential of V2X technologies requires a full buildout of roadside and in-vehicle devices. Practitioners have realized that this involves cooperation from State and local transportation agencies, as well as automakers to implement this technology on the roadside and in vehicles, respectively. However, the pathway for achieving this buildout has thus far not been straightforward, as automakers are reluctant to make investment until infrastructure-based V2X messages are trustworthy and consistent from one jurisdiction to the next and the availability of infrastructure-based information is more ubiquitous. Similarly. the promise of future benefits in a fully built-out V2X ecosystem is no longer sufficient for transportation agency decision-makers to invest in these technologies. Day-one benefits are needed to justify long-term investment.

Thus, it is important to consider a strategic pathway to reach this full buildout that considers what can be done and what benefits can be realistically achieved during this timeframe.

The subsections below outline anticipated benefits across three timeframes: less than five years, five to ten years, and beyond ten years. In the short term (0-5 years), the focus will be on foundational deployments, stakeholder engagement, and realizing early operational benefits. In the medium term (5-10 years), efforts will shift toward broader system integration, policy refinements, and enhancing existing technologies. The long term (10+ years) will see the full-scale adoption of CAV, network maturity, and widespread improvements in safety and mobility.

These timeframes align closely with the short-, medium-, and long-term milestones set in the USDOT V2X Deployment Plan. It is important to recognize that the information in this section serves as a roadmap for expected outcomes in V2X deployment, while the USDOT plan outlines ambitious goals, milestones, and targets to accelerate implementation. Understanding this alignment will help TDOT understand its efforts within the broader national framework, balancing realistic expectations with the pursuit of national objectives. While not directly tied to the USDOT plan, anticipated benefits from automated vehicles (AVs) are also presented alongside CV benefits in this section.

Recommendations provided later in this report are centered around the short-term (0-5 year) timeframe, as they lay the groundwork for broader adoption in the medium-term and long-term (making the strides necessary to reach toward USDOT goals during these periods) by addressing key planning, policy, funding, engagement, and deployment challenges. By prioritizing these short-term actions, TDOT can demonstrate initial successes, build stakeholder confidence, and position itself for continued investment and expansion in the medium and long term.

4.1 Near-Term (5 years or less)

In the immediate timeframe, many of the benefits that can be derived From V2X technology will be realized through targeted investment of roadside and aftermarket in-vehicle V2X devices. This will enable day-one benefits to be provided to drivers of those vehicles. The benefits will primarily be limited to applications such as transit signal priority, freight signal priority, emergency vehicle preemption, and traveler information message-based applications.

This can be provided by partnering with local agencies to equip vehicle fleets to provide priority/preemption for transit and snowplows, for example, while simultaneously broadcasting messages that will be used by production-equipped vehicles in the long-term. This will allow TDOT to demonstrate early costs and benefits of deploying V2X technologies while starting to build the functionality needed to bring longer-term benefits once more equipped vehicles are on the road.

In order to provide broader scale safety benefits during this timeframe, it will be necessary to provide indications to drivers using traditional hardware while simultaneously broadcasting V2X messages with the same information (since there will not be many vehicles that can leverage this information yet). For example, a rapid flashing light at a crosswalk is active at the same time as a personal safety message to indicate the presence of a pedestrian within the crosswalk.

Depending on the type of applications that are prioritized for implementation, TDOT can see increased safety for roadway users or vulnerable users such as pedestrians and cyclists, and reduced congestion and traffic on freeway, arterial, or local roads. In addition, the CAV data collected can be used to better understand traffic flow states, volume, and signal timing to optimize each region for its individual needs. Furthermore, the data can help guide decisions regarding the direction TDOT takes in the CAV space toward its evolving long-term goals.

As TDOT begins receiving data from these deployments, it will have the opportunity to explore and analyze this information to better understand its potential applications in traffic management.

During this timeframe, the goal of TDOT should be to build technical capacity and demonstrate the *potential to achieve* benefits that can be realized through CAV technology. This provides a foundation to familiarize with CAV technologies, and to build institutional knowledge and expertise for more widescale deployments in the future.

The current AV environment will largely remain the same over the next 5 years. The first year of an autonomous vehicle deployment will likely be mostly dedicated to data collection and mapping. If autonomous driving does occur it will be confined to previously mapped, relatively controlled environments, such as the I-24 SMART corridor. A driver would almost assuredly be present in the driver seat as the new locale would warrant an extra safety measure from the technology company, and TDOT CAV policy would likely require it. ADAS technology may experience significant gains and allow both freight and personal vehicles to access improvements in adaptive cruise control, lane-keep assist, and automatic emergency braking. Overall, both autonomous and ADAS improvements will be a major factor to increase vehicular safety in the short term. By keeping a finger on the pulse of the autonomous vehicle market, TDOT can ensure that any incoming policy decisions do not hamstring further technological advancements.

4.2 Mid-Term (5-10 years)

The mid-term timeframe of five to ten years after the installation and activation of CAV systems, is where TDOT will start to see small but measurable effects of CAV implementation. One of the major benefits that may start to be realized during this timeframe can be achieved through networked V2X communications, more commonly known as cellular. Through investments in centralized data platforms and creating strategic partnerships with mobile network providers, important data for drivers can be provided to drivers increasingly through smartphones and/or native in-vehicle displays. However, it is important to note that the latency of this delivery mechanism may not be sufficient for providing the safety-of-life benefits that only short-range C-V2X communications can provide.

Over this extended period, it is expected that TDOT works with local agencies to outfit intersections and other roadside locations along high-priority corridors.

At the same time TDOT continues to provide benefits for partner agencies; TDOT can expand roadside functionality and improve the robustness of its CAV ecosystem. This includes enhancing the quality and consistency of broadcasted messages, exploring new applications that utilize V2X messaging in innovative ways, and integrating new data from other supporting systems (such as TMC feeds, work zone data exchanges, and pedestrian detection technologies) into V2X messages.

By continuously improving roadside infrastructure, TDOT can ensure that V2X-equipped vehicles—whether privately owned or operated by partner agencies—can fully leverage these messages for enhanced safety and mobility. This ongoing evolution will be crucial in establishing a strong foundation for the long-term, widespread adoption of V2X technology. Additionally, as TDOT begins to generate V2X data at a larger scale, it will gain hands-on experience in managing and analyzing this information. With increasing data volumes, TDOT may need to reassess its storage capabilities and refine its data management strategy to support efficient processing, analysis, and long-term sustainability.

During this timeframe, autonomous vehicles will become more capable at handling a wider range of driving scenarios, including unpredictable urban environments. This opens the possibilities of ridesharing, freight, or delivery services utilizing autonomy to reduce costs, and increase safety. This will allow automakers and technology suppliers to expand into the metropolitan areas of Tennessee, such as Memphis or Nashville, where there is a higher demand for these types of services. This would offer a significant improvement in accessibility services for elderly, or those with disabilities. Additionally, arterial roads and highways can experience reduced traffic congestion as more CAV technology on the roads can optimize traffic flow. Increased investment into traffic optimization infrastructure and other CAV technologies would have an oversized impact on safety and efficiency on highways and arterial roadways.

4.3 Long-Term (10+ years)

Over the long term—10 years or more—significant advancements in CAV technology are expected, building upon the progress made through today's deployments. C-V2X will be widely implemented along major corridors statewide, with automakers starting to integrate this technology into new vehicle models. Additionally, mobile devices carried by pedestrian and bicyclists may become more fully integrated into the V2X ecosystem. As the adoption of C-V2X-equipped vehicles and connected mobile devices grows, the full life-saving potential of V2X technologies will become increasingly evident.

By this time, fully automated vehicles may begin utilizing infrastructure-provided data and cooperative awareness messages from other automated vehicles to enhance their environmental awareness, fostering greater trust in and reliance on this information for navigation. Traffic signals could also start leveraging real-time data from connected vehicles to optimize signal control, improving system efficiency, reducing congestion, and lowering fuel consumption across all road types.

Furthermore, bus and freight platooning can be integrated with Transit Signal Priority and Freight Signal Priority systems, enhancing efficiency. These advancements, combined with potential full electrification of vehicle fleets, could lead to a substantial reduction in greenhouse gas emissions.

As the number of V2X-equipped vehicles on the road increases, TDOT will be able to begin integrating data from these vehicles into its existing transportation management systems. This data will include key information such as vehicle speed, location, SPaT data, signal priority requests and status updates, and safety messages from VRUs. By leveraging this wealth of real-time data, TDOT can analyze traffic patterns, identify inefficiencies, and gain deeper insights into driver behavior and potential safety concerns. This, in turn, will support more informed decision-making for congestion management, incident response, and roadway safety enhancements.

In the long term, personally owned autonomy could become a reality, while commercialized autonomous vehicles will be commonplace on the roads. This shift would completely transform personal and commercial logistics and transportation industries. Metropolitan areas and highways would see massive improvements in traffic congestion and collision-related injuries and fatalities. There would be reduced need for parking spaces in city centers, which would allow for more efficient use of infrastructure, or an expansion of existing infrastructure to improve city walkability and pedestrian safety.

Chapter 5 Prior and Current CAV Investment

Over the past few years, TDOT has been making investments in CAV technologies to enhance the state's transportation infrastructure. These efforts include the deployment of the I-24 Smart Corridor and the development of V2X-specific plans to support safer and more efficient roadway operations. In addition to TDOT's investments, there are numerous local-led efforts focused on addressing specific transportation challenges with CAV solutions. The subsections below provide an overview of these investments. Figure 3 shows CAV deployment locations across Tennessee per the FCC Universal Licensing System. Zoomed in views of deployments by TDOT and Murfeesboro (Nashville metropolitan area), Memphis, Farragut, and Sevierville are provided in Figure 5, Figure 6, Figure 4, and Figure 7, respectively. RSUs not shown on these maps may be covered under experimental licenses.

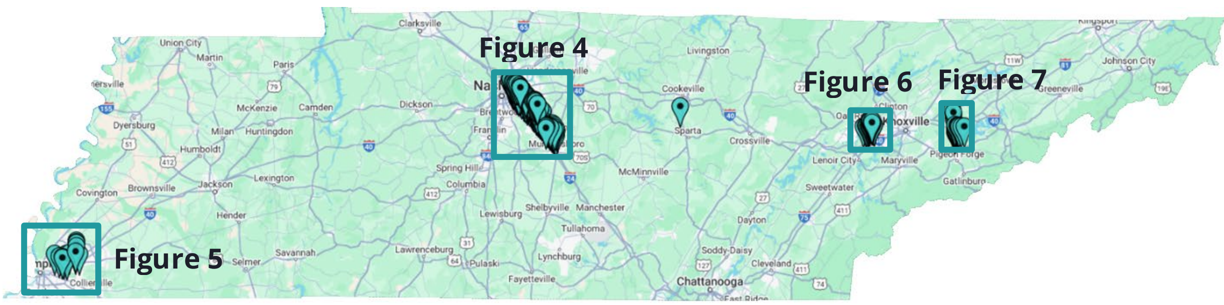


Figure 3. V2X Deployment Locations in Tennessee

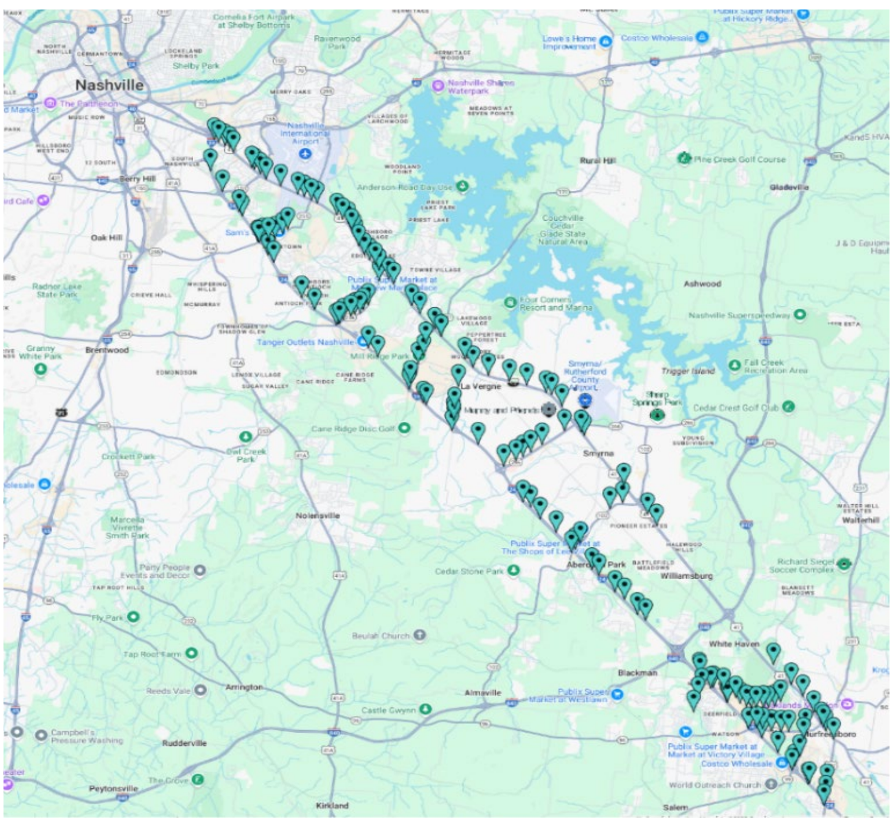


Figure 4. TDOT (153) and City of Murfeesboro (3) V2X Deployment Locations

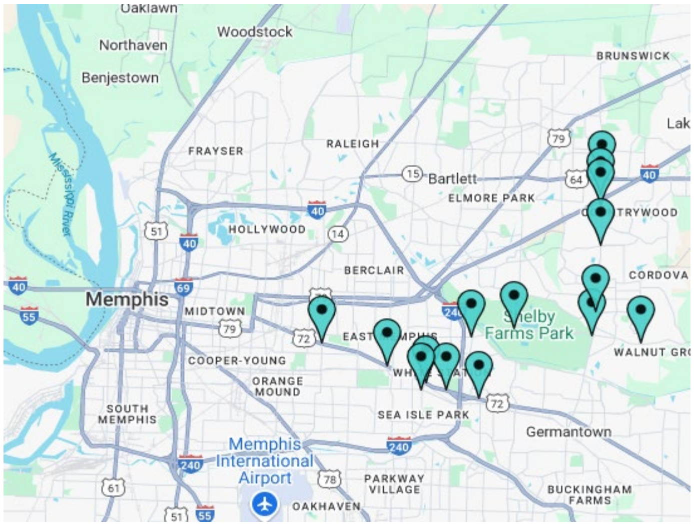


Figure 5. City of Memphis (15) V2X Deployment Locations

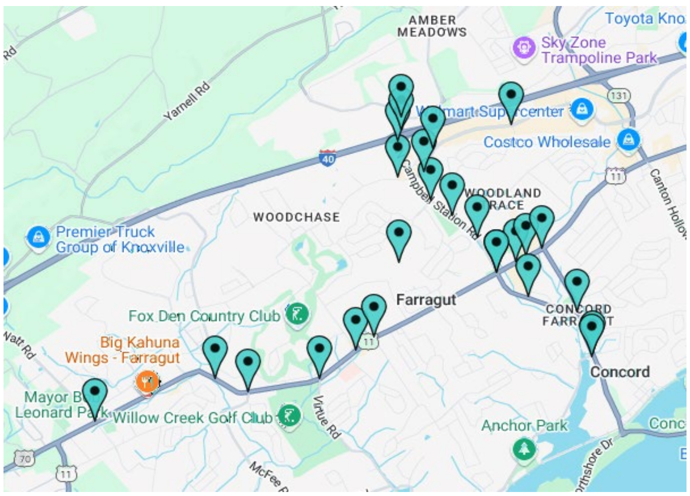


Figure 6. City of Farragut (26) V2X Deployment Locations

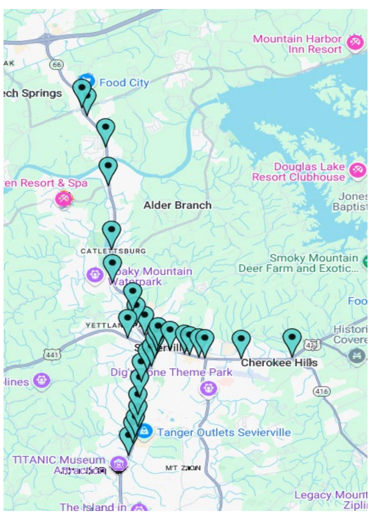


Figure 7. City of Sevierville (29) Deployment Locations

Note: Several of the projects and reports included in this section mention use of DSRC, which was the prevailing communication technology at the time these projects were undertaken. Although DSRC has since been superseded by C-V2X, much of the analysis and key findings remain relevant to current and future deployments.

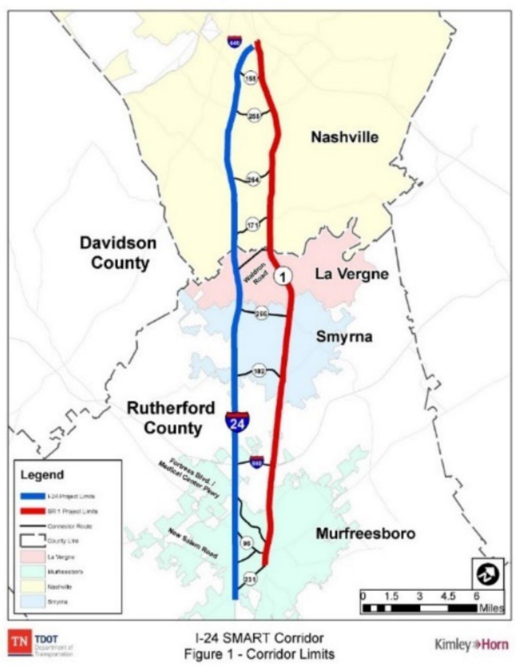
5.1 Deployments

5.1.1 I-24 Smart Corridor Testbed

The Smart Corridor consists of approximately 28 miles along I-24, 28.5 miles along SR-1, and 30 miles of connector routes between I-24 and SR-1. A significant part of the I-24 Smart Corridor is designated as the "I-24 MOTION" testbed, which allows researchers and automakers to test new connected and autonomous vehicle technologies in real-world traffic conditions.

Since 2019, DSRC elements have been deployed in TDOT Region 3 along the I-24 Smart Corridor and are enabled for a variety of transportation operations purposes. The I-24 Smart Corridor utilizes technology that enables vehicles to send and receive data about traffic conditions, potential hazards, and other relevant information to nearby infrastructure via wireless communication. The corridor uses Intelligent Transportation Systems (ITS) technologies like dynamic message signs, lane control signals, and optimized traffic signal timing to actively manage traffic flow based on real-time data.

The goal of the I-24 Smart Corridor is to improve traffic congestion, reduce accidents, and enhance overall travel reliability by utilizing V2X technology.

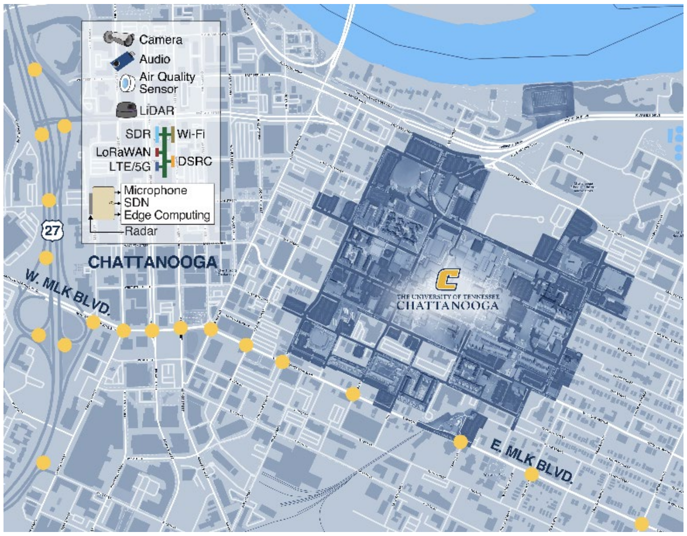


Source: TDOT[1]

Figure 8. I-24 Smart Corridor Testbed

5.1.2 Chattanooga Smart City Corridor Test Bed

The Chattanooga Smart City Corridor Test Bed is a CAV research initiative along a 1.2 mile stretch of U.S. 27 in Chattanooga, and is a collaboration between the City of Chattanooga, the University of Tennessee at Chattanooga, Oak Ridge National Laboratory, and private sector partners. Since its inception, two expansions have been funded which expand the testbed by an additional 27 signalized intersections parallel to the existing downtown portion. The test bed serves as a real-world laboratory for V2X technology, ITS, and urban mobility solutions. The project came out of Chattanooga's broader smart city efforts, leveraging its municipally owned gigabit-speed fiber-optic network to support these data-driven transportation applications. The corridor has been used for testing cooperative driving automation, traffic signal optimization, freight efficiency, and safety applications, contributing to the national CAV research landscape.



Source: The University of Tennessee Chattanooga[1]

Figure 9. Chattanooga Smart City Corridor Test Bed

5.1.3 Chattanooga SMART Grant

In March 2024, the USDOT awarded Chattanooga a $2 million Strengthening Mobility and Revolutionizing Transportation (SMART) grant to implement C-V2X technology to improve safety at mid-block crossings along the 3rd Street "Health" Corridor, benefiting underserved communities accessing transit, schools, and medical facilities. The city will collaborate with partners including the University of Tennessee Chattanooga, Audi, Leidos, Qualcomm, Harman, and the Intelligent Transportation Society of America to achieve these goals.

This project is currently in the development phase.

5.1.4 Other Local Initiatives

Some local municipalities have been deploying or considering deploying CAV technologies. A summary of known efforts from local municipality outreach is provided in the list below.

- **Memphis:** Memphis is upgrading its BlueToad travel time detectors with V2X RSUs to support future CAV applications, deploying 16 RSUs with plans for 80 more and 2 OBUs to broadcast SPaT messages, enable V2X priority and preemption, and enhance safety for both connected vehicles and vulnerable road users. While a pilot SPaT messaging application is active along Germantown Parkway, a key limitation is the reliance on vendor-specific smartphone apps, which may hinder public adoption and require users to keep the app open—highlighting the need for broader on-board unit (OBU) integration for long-term impact.
- **Knoxville.** The Knoxville deployment aims to share SPaT data with newer vehicles and provide signal information to older vehicles via on-board systems and mobile apps, helping motorists align with signal progression and potentially offering additional safety features like pedestrian and preemption warnings, with Congestion Mitigation and Air Quality (CMAQ)-funded transit signal priority planned for Broadway.
- **Johnson City.** Johnson City is planning to leverage existing infrastructure for future CAV deployment, with a proof-of-concept project underway at Eastern Tennessee State University. Funding is still pending, and the city is evaluating the feasibility, costs, and potential safety and congestion benefits of integrating CAV components into its ITS architecture.

5.2 Research and Planning

5.2.1 DSRC Statewide Guidance

In November 2018, TDOT released its *Dedicated Short-Range Communication (DSRC) Statewide Guidance* [6] report, which provides a comprehensive framework for implementing DSRC technology to enhance vehicle-to-infrastructure (V2I) communications. The report provides the purpose and intent of DSRC deployment, emphasizing its role in improving traffic safety and efficiency through real-time data exchange between vehicles and roadside equipment. It highlights the state of the practice and discusses initiatives like the SPaT Challenge, which encouraged state and local public sector transportation infrastructure owners and operators to achieve deployment of DSRC infrastructure with SPaT broadcasts in at least one corridor.

The report also provided implementation guidance, and a physical architecture required for DSRC systems, detailing necessary hardware and software components such as Roadside Units (RSUs), managed field Ethernet switches, and backhaul communication media. It provides specifications for RSUs, guidance on DSRC licensing and spectrum management, and outlines the minimum field equipment needed to support SPaT applications. The report also defines the responsibilities of designers, contractors, TDOT, and signal-maintaining agencies in the deployment process. Additionally, it covers design elements related to equipment cabinets, communication systems, and integration and testing services, offering a holistic approach to DSRC implementation across Tennessee's transportation infrastructure.

5.2.2 Use Case Roadmap

TDOT is in the process of developing a comprehensive CAV use case implementation roadmap to fully harness the capabilities of the I-24 Smart Corridor. This roadmap will serve as a strategic guide for deploying, testing, and refining CAV applications that enhance mobility, safety, and environmental benefits within the Integrated Corridor Management (ICM) system. The I-24 Smart Corridor provides TDOT a unique opportunity to build upon lessons learned from previous deployments while also developing new applications tailored to traveler needs in Tennessee. The roadmap will identify, prioritize, and sequence existing and emerging CAV use cases based on timeliness, expected benefits, and implementation costs. By advancing V2X applications, TDOT can maximize the value of the I-24 Smart Corridor, contributing to progress in the CAV industry. The report for this project, which is currently under development will verify CAV elements, define candidate CAV use cases, prioritize use case implementation, and developing a use case implementation roadmap.

5.2.3 ITS and Fiber Deployment Plan

TDOT has developed an ITS and Fiber Deployment Plan to enhance traffic management and safety across the state. This plan focuses on identifying gaps in current ITS infrastructure, prioritizing deployment of detection devices, traveler information systems, and connected vehicle technologies. A key component is the development of a statewide fiber network to bridge communication gaps and interconnect TMCs. Stakeholder engagement is integral, with multiple regional and headquarters meetings conducted to gather input. The plan also includes a cost-benefit analysis and an addendum to the statewide ITS architecture to incorporate new projects and service packages.

5.2.4 The impact and adoption of CAV (RES2019-06)

The study *The Impacts and Adoption of Connected and Automated Vehicles in Tennessee* [7], released in 2021, analyzed factors influencing the adoption of CAVs among Tennesseans. Based on a survey of 4,602 residents, the research found that social status, peer influence, technological familiarity, and willingness to invest in autonomous technology significantly impact adoption likelihood. A key finding was that Tennessee's four major counties showed higher adoption potential, and a 20% annual price reduction could increase adoption by 17 times. The study recommends policies such as infrastructure development, subsidies, and targeted advertising to accelerate CAV adoption.

5.2.5 CAV investment and smart infrastructure (RES2019-07)

The study *Connected and Automated Vehicles Investment and Smart Infrastructure in Tennessee* [8] release in May 2022 provides a comprehensive analysis of smart corridor projects across the United States, offering insights applicable to Tennessee's transportation landscape. The research highlights that successful smart corridors integrate physical infrastructure, digital communication systems, electric vehicle charging stations, and robust stakeholder collaboration. Key findings emphasize the importance of deploying CAV technologies, such as roadside and onboard units, adaptive signal systems, and ramp metering, to enhance traffic management and safety. The study underscores the necessity of establishing a statewide fiber-optic network to support these technologies, facilitating improved mobility and safety outcomes. Additionally, the report outlines critical evaluation steps for smart corridor performance, including network analysis, vehicle movement studies, traveler feedback, and direct system measurements, providing a framework for assessing and optimizing intelligent transportation systems in Tennessee.

Chapter 6 Readiness Action Plan Recommendations

This section outlines recommended actions for TDOT to continue advancing its CAV initiatives and to foster effective coordination with local agencies. These actions are designed to build on existing efforts, enhance collaboration, and help TDOT to meet the needs and capabilities of local agencies. These recommendations aim to accelerate CAV deployment and ensure successful, scalable implementations across Tennessee. These recommendations are intended to build on existing agency goals, respond to gaps that local agencies may be facing, draw on the latest trends and developments in CAV industry, and based on best practices from peer agencies. The recommendations provide options for coordination with municipalities, an overview of CAV benefits for different levels of implementation, and cost estimate ranges.

As stated above, the recommendations in this section primarily focus on the short-term (0-5 year) timeframe, as they establish the foundation for broader adoption in the medium and long terms. These actions will help TDOT make the necessary strides toward achieving USDOT goals during these periods. By prioritizing these steps in the short-term timeframe, TDOT can build its internal technical capacity, organize efforts, demonstrate early successes, foster stakeholder confidence, and lay the foundation for ongoing investment and growth in the medium and long terms.

Recommended actions are designed using the SMART criteria: Specific, Measurable, Attainable, Relevant, and Time-bound. This approach ensures that each action is clearly defined, has measurable outcomes, is realistically attainable, aligns with TDOT's goals, and includes a timeline for implementation.

- **S**pecific. Recommendation is direct/detailed/meaningful.
- **M**easurable. Recommendation is quantifiable to track progress and success
- **A**ttainable. Recommendation is realistic and TDOT has the means to make it happen
- **R**elevant. Recommendations align with the direction TDOT is heading as an agency
- **T**ime-Bound. The expected timeframe for completing the action.

To promote organization, the recommendations are grouped into five distinct categories: Planning, Policy, Funding, Engagement, and Deployment. This approach helps organize recommendations enabling TDOT to systematically address the various aspects of CAV technology deployment. Each category plays a role in building a strong foundation for successful implementation, from establishing strategic plans and policies to securing funding, fostering stakeholder engagement, and executing deployment efforts.

6.1 Planning Recommendations

Recommended actions associated with CAV planning are provided in this section.

- Build Technical Capacity
- Develop a Deployment Plan for CAV Technology in Tennessee
- Assess Infrastructure Improvements and Cost
- Prioritize Technology Applications and Locations
- Develop Systems Engineering Documentation and V2X System Architecture

- Build Operations and Maintenance (O&M) Capabilities
- Develop Technical Requirements for V2X devices and supporting infrastructure

Build Technical Capacity

Timeframe: less than 1 year

Description: It is recommended for TDOT staff to continue to build technical capacity in the following areas. The intent is to use this technical capacity to support local agencies as needed during the CAV deployment lifecycle.

- **Systems Engineering**: High-level breakdown of the Vee-model systems engineering lifecycle.
- **Architecture**: Intended for ITS engineers to explain how V2X infrastructure fits into the Tennessee ITS Architecture.
- **Function**: Explains functions performed by various components of the V2X system, i.e., data inputs, how/why that data is processed, and outputs.
- **Protocols/Standards**: Seven-layer OSI model-based communications and security standards with added emphasis on the C-V2X communications interface.
- **Interoperability**: Background on the RSU Standard, data elements in V2X messages, and maintaining interoperability.
- **Integration**: Intended for field installation technicians to provide necessary background to install and configure field and in-vehicle equipment.
- **Operations and Maintenance**: Background for activities required to operate and maintain a V2X system, including but not limited to: FCC licensing, Security Certificate management, V2X message development (e.g., MAP and TIM messages), and system configuration.

To the extent possible, TDOT should take advantage of training and technical assistance resources made available through USDOT. A good place for TDOT to start is with the USDOT Smart Community Resource Center (SCRC) [9] which offers a wealth of resources for practitioners involved in ITS, CAV, and smart transportation technologies. The SCRC covers a wide range of topics, including CAV communications, cybersecurity, data management, and interoperability—making it a practical reference for deployers at all stages from capacity-building to implementation. One of the more recently released resources that may be beneficial is the V2X Deployer Resource [10] which provides key guidance for agencies deploying connected vehicle technologies, covering planning, procurement, installation, and operations. It highlights best practices, lessons learned, and strategies to ensure interoperability and scalability.

As TDOT builds internal capacity around CAV technologies, it is particularly important to highlight the availability of V2X Trainings being offered nationwide by USDOT through its ITS Professional Capacity Building Program [11]. This introductory course—currently being delivered in collaboration with ITS America to ITS State Chapters and other transportation stakeholders—offers a basic understanding of V2X concepts. Participants are introduced to the core components of a V2X ecosystem, key messages and standards, and example use cases, with an emphasis on ensuring safety and privacy.

Finally, once TDOT has some on-the-ground experience, they should also invest in building materials tailored to Tennessee's specific context, policies, and systems. These materials should introduce core CAV concepts, communications infrastructure, systems integration, cybersecurity, and deployment challenges, while offering real-world examples and lessons learned. As TDOT gains hands-on experience through deployments—such as the I-24 Smart Corridor—this knowledge can be incorporated into a modular training booklet or guidebook designed for a range of audiences, from planners and engineers to leadership and field personnel.

Note: At the time of this report's publication, the SCRC website is temporarily unavailable. In the interim, it is recommended that TDOT contact the USDOT Joint Program Office (JPO) directly to gain a comprehensive understanding of the resources and offerings typically available through the SCRC.

Develop a Deployment Plan for CAV Technology in Tennessee

Timeframe: 1-2 years.

Description: It is recommended that TDOT develop and publish a strategic deployment plan for implementing CAV technologies in Tennessee that provides a deployment approach that considers TDOT priorities and maintains alignment with national trends.

This deployment plan represents the next step to (and an opportunity to update) the DSRC Statewide Guidance developed in 2018—not only to reflect the shift in communications mediums following recent FCC rulings, but also to incorporate significant advancements in the CAV industry. Since 2018, the landscape has evolved to emphasize interoperable connectivity at scale, the strategic use of the 5.9 GHz band under "use it or lose it" pressure, integration of cooperative communication technologies such as C-V2X and cellular, a focus on delivering Day 1 benefits to justify investment, and an increased emphasis on protecting vulnerable road users (VRUs). Updating the guidance would ensure TDOT remains aligned with national trends and emerging best practices.

A CAV deployment plan is essential for ensuring a structured, efficient, and scalable implementation of CAV technologies. Without a well-defined plan, deployments in Tennessee risk being fragmented, leading to interoperability issues, inefficient resource allocation, and difficulties in achieving broader transportation goals. A deployment plan provides a roadmap for integrating CAVs into the existing transportation environment while addressing technical, regulatory, and operational challenges. It also helps local agencies and stakeholders to align with TDOT on priorities, funding strategies, and performance metrics to evaluate the effectiveness of CAV initiatives.

A comprehensive CAV deployment plan should include key elements such as a vision and objectives aligned with regional (and national) transportation goals, a detailed assessment of existing infrastructure and data systems. Additionally, the plan should address policy and regulatory frameworks, stakeholder engagement strategies, workforce training needs, and funding sources. Performance measurement criteria should also be incorporated to track progress and assess the impact of deployments over time. By including these components, a CAV deployment plan can serve as a strategic guide for scaling up deployments while maintaining consistency, safety, and efficiency across connected and automated vehicle ecosystems.

A deployment plan could be followed by a more detailed implementation strategy. Which provides the CAV system architecture, interoperability requirements, cybersecurity considerations, and communication protocols to ensure seamless integration with existing ITS systems.

Assess Infrastructure improvements and cost

Timeframe: 1-2 years

Description: New instances of CAV technology will require the installation of new equipment on vehicles and roads, or the modification of existing infrastructure. First a comprehensive analysis of existing infrastructure would have to be completed. This will allow TDOT to leverage existing infrastructure where applicable and only deploy new equipment where is needed, therefore reducing the cost of implementation.

Using the data already collected from other DOTs and more specifically the I-24 Smart Corridor Testbed and the UT Chattanooga-MLK Smart City Corridor, TDOT can identify the areas that will see the greatest impact from the implementation of CAV technologies. A staggered rollout of new infrastructure to these areas, as well as OBUs on applicable transit agency vehicles which traverse the area, will prove to be the most cost-effective method of determining the viability of implementation. Depending on the systems chosen, for these initial rollouts, there will need to be other changes made to increase network bandwidth to account for increased data amounts and speed requirements, new processes to handle the increased data at traffic control centers, and new or redesigned roadway markings and signage for signalized crossings and digital signage.

CAV System Deployment Cost Estimates:

- RSU (hardware + integration): $3k-5k per device
- OBU (hardware + integration): $2k-$3k per device
- SCMS (RSU certificates): $30-$40/month/RSU
- SCMS (OBU certificates): $10/month/OBU
- Management System: $50-200/month/RSU
    - Varies based on functionality, vendor support provided
- Costs do not consider additional development or testing costs
- Economies of scale may drive down costs as deployment scales up.

Existing System Upgrade Cost Estimates (if needed):

- Backhaul comms (fiber): $20k+ per location
    - Depends on distance between locations
- Backhaul Comms (cellular): $1k-$1.5k per location + monthly data
- Traffic Signal Controller (new): $4k-$5k
- Power drop: $10k
- *TDOT may have more accurate estimates for these costs*

Prioritize Technology Applications and Locations

Timeframe: 1-2 years

Description: TDOT has begun to identify high-priority use cases for the I-24 Smart Corridor through its V2X Use Case Roadmap project. It should be determined if the same use cases can be prioritized throughout other parts of Tennessee, particularly in parts of the state that are more rural in nature. To the extent possible, it is recommended that high-priority applications be aligned with national goals and objectives in the USDOT Deployment Plan to maximize their impact and potential for funding support. Clearly articulating these alignments within deployment planning efforts can strengthen the justification for investment, demonstrating that TDOT has carefully considered how its initiatives contribute to broader transportation, safety, mobility, and sustainability priorities at the federal level.

This serves as a starting point for defining TDOT priorities, and should focus on applications that deliver immediate, tangible benefits from day one. The goal is to implement solutions that demonstrate clear value, have a high likelihood of early success that build momentum and encourage broader adoption. By showcasing real-world impacts, these initial deployments can help secure ongoing leadership support, paving the way for continued investment and the expansion of connected and automated vehicle initiatives. With this in mind, it is recommended that TDOT develop a holistic methodology for prioritizing deployment locations and applications, considering the following criteria:

1. **Areas with the greatest need** for safety, mobility, and information improvements.
2. **Applications that best address those needs** and provide the most impact.
3. **Readiness of existing infrastructure** and availability of **fleet operating partners** to support V2X deployment.
    - This includes consideration of t**he most effective and practical medium** for enabling V2X communication (C-V2X vs. Cellular).

To the extent practicable, data should be used to measurably quantify the issue at hand. Priority should be given to locations where applications will have the greatest impact. Additionally, the readiness of existing infrastructure to support V2X technologies should be considered to ensure a smooth and cost-effective deployment. Locations with existing power, communications, and infrastructure are ideal for V2X RSU deployment, as adding these elements can significantly increase costs. If a site lacks network connectivity TDOT should evaluate the most cost-effective and technically feasible solution for enabling V2X communications. The cost of deploying fiber-optic infrastructure should be carefully weighed against alternative solutions such as cellular wireless backhaul, which can provide a more flexible and scalable option for connecting RSUs to supporting systems. Additionally, rather than relying solely on direct RSU-to-vehicle communication, TDOT may consider leveraging cellular networks to transmit V2X messages to drivers via smartphone applications or native in-vehicle displays. This approach can extend the reach of V2X services to a broader set of road users, including those without embedded V2X hardware, while also reducing deployment costs by minimizing the need for physical infrastructure upgrades.

Develop Systems Engineering Documentation

Timeframe: 2-3 years

Description: Taking a connected vehicle system from concept, to production, to operation requires adherence to a well-managed process to reduce risk and to integrate experts from various disciplines/specialties into a team effort to provide a quality system that meets both business and technical needs of TDOT and the regions.

To this end, it is recommended that TDOT develop a comprehensive set of systems engineering documentation – including a Concept of Operations, System Requirements Specification, System Architecture, and System Design. The I-24 V2X Use Case Roadmap project should provide a foundation for justifying applications based on the needs of stakeholders.

The purpose of the ConOps is to clearly convey a high-level view of the system to be implemented from the viewpoint of each stakeholder. This document frames the overall system, sets the technical course for the project, and serves as a bridge between early project motivations and the technical requirements. The System Requirements Specification describes a set of requirements that satisfy the expressed needs of the overall system, which is comprised of existing systems, communications infrastructure, ITS and Connected Vehicle infrastructure, messages communicated between devices, and other supporting systems (operations and maintenance, data exchanges, time sources, security systems, etc.).

The architecture defines the structure, behavior, and different perspectives of a system and includes interface specifications, which describes in detail the internal and external interfaces for the system and the data, information, and messages that are communicated across those interfaces. The architecture should align, where feasible, with USDOT's framework (Architecture Reference for Cooperative and Intelligent Transportation, also known as ARC-IT [12]). It is strongly recommended that the architecture also incorporate the communication of V2X messages to vehicles through alternative communication mechanisms, such as cellular networks and satellite systems. This would ensure broader coverage, enhance reliability, and facilitate communication with vehicles using specialized applications that run on smartphones or on the vehicle's native driver interfaces.

The system design documentation provides the level of detail needed to implement the system and to document its configuration with drawings and photos for future operation and maintenance. The purpose of the System Design Document is to document design factors, and the choices made to satisfy the requirements developed in the System Requirements Specification document, as well as to guide implementation of a V2X deployment.

TDOT and local agencies could reference these documents when deploying V2X equipment, streamlining the deployment process.

Note: It is important to periodically consider any changes to standards and best practices, and to update any existing documentation to account for any changes made to the V2X system throughout its lifecycle.

Build Operations and Maintenance (O&M) Capabilities

Timeframe: 2-3 years

Description: To ensure the long-term success of TDOT's CAV deployments, it is critical to establish robust O&M capabilities. O&M for a CAV system encompasses a wide range of activities, including but not limited to:

- Monitoring/Maintaining roadside devices ensuring they have power and are accessible through the communications network.
- Monitoring/Maintaining connectivity between roadside devices, such as RSUs and traffic signal controllers.
- Verifying that RSUs are actively broadcasting messages.
- Configuring and managing connectivity and data forwarding for roadside devices.
- Performing firmware and software updates on RSUs.
- Updating infrastructure-based messages (e.g., MAP and TIM) as needed.
- Adjusting system configurations
- Validation of message content for errors, performance, or potential accuracy issues.
- Maintaining SCMS enrollment and ensuring security certificates remain valid.
- Maintaining FCC licenses to ensure compliance with regulatory requirements.

In the near term, the scale of deployments will be small enough that O&M may not require full-time staff attention, particularly when simply sustaining components that already exist – such as the I-24 Smart Corridor. Many monitoring functions can be automated and managed by current traffic management operations staff, with support from other technical experts as needed. However, as TDOT undertakes improvements to build out functionality on the I-24 Smart Corridor, or expands CAV technology along new corridor/locations, the complexity of managing these devices and maintaining connectivity, security, and performance across a broader network will increase, making the need for dedicated O&M staff more evident.

There are a number of vendor-provided and open-source tools for TDOT to leverage for supporting O&M activities. A list of vendor platforms includes, but is not limited to:

- **Applied Information** Glance
- **Commsignia** Central Device & Data Manager Platform
- **Kapsch** Connected Mobility Control Center.
- **Panasonic** Cirrus
- **Yunex** Cooperative Management System

In addition to these solutions, the USDOT JPO Connected Vehicle Manager (CV Manager) is an open-source tool designed manage and monitor V2X components. Features of CV Manager allow user to:

- Visualize devices on a Mapbox map
- Display the current statuses of devices
  - Latest online status
  - ISS SCMS certificate expiration
  - Other identifying values (tracked on a PostgreSQL database)
- View message counts, sorted by RSU IP (BSM, MAP, SPaT, SRM, SSM, TIM)
- Visualize an RSU's currently active MAP message
- Visualize BSMs relative to a specified geofence and time period
- Device configuration over SNMP (v3) for message forwarding
- Upgrade device firmware (Kapsch, Commsignia and Yunex devices only)
- Add, modify, and remove devices and users

By providing a standardized framework for CV deployments, the CV Manager enhances the scalability, security, and reliability of CAV systems, making it a valuable resource for transportation agencies such as TDOT in implementing CV technologies. Because it is open-source, CV Manager can be customized so it can adapt to an agency's specific needs. For instance, Colorado DOT has developed its own version based on the USDOT CV Manager.

An open-source tool for monitoring the message performance and accuracy is the Connected Intersection Message Monitoring System (CIMMS). Developed by the CV PFS, CIMMS continuously analyzes V2X messages from roadside units (RSUs) to ensure accuracy, compliance, and interoperability with select interoperability standards. The next release of CIMMS will have CV Manager functionality integrated.

Vendor solutions are pre-packaged and ready to deploy but typically involve setup fees and recurring costs based on storage needs and the level of vendor support required. In contrast, open-source tools like the USDOT JPO CV Manager and CIMMS offer a cost-effective alternative but require technical expertise for installation, either in-house or through a contractor. If deployed on TDOT's servers, the operational costs would be minimal, providing flexibility for the agency to manage monitoring and maintenance internally or outsource these tasks to a contractor as needed.

Develop Technical Requirements for V2X Devices and Supporting Infrastructure

Timeframe: 3-4 years

Description: Standard procurement documents and/or a list preferred vendor products should be developed. These documents should either directly reference or copy material from the developed systems engineering documentation. The intent is to use these technical requirements to streamline the procurement process. And promote interoperability, avoid unnecessary customization, and reduce procurement delays. Additionally, establishing clear technical specifications and evaluation criteria will help streamline vendor selection, promote competitive bidding, and ensure that acquired products meet performance, reliability, and security standards

Throughout the development and deployment process, regular engagement should occur between systems engineers, technical stakeholders, and the development team to clarify requirements, ensure alignment with design documentation, monitor progress, and provide guidance as needed. Additionally, system developers should produce supporting documentation, including training materials, user and maintenance manuals, and online help, to assist operations and maintenance staff in effectively utilizing the system and its functionalities.

6.2 Policy Recommendations

Recommended actions associated with CAV policy are provided in this section

- Develop IT Policy around V2X Devices
- Develop Data Governance Plan
- Review Motor Vehicle Operation Regulations and Recommend Legislation
- Develop Standard Agreements with Local Agencies
- Develop an AV strategy

Develop Information Technology (IT) Policy around V2X Devices

Timeframe: less than 1 year

Description: Network connectivity plays a vital role in a V2X system as it simplifies roadside device O&M and allows TDOT to leverage V2X data for traffic management purposes. It is recommended that all deployed V2X infrastructure is able to communicate with supporting systems which includes but is not limited to traffic signal controllers, SCMS, V2X Infrastructure/Data Management system, position corrections system (backhaul), and other potential sources of data that could be leveraged for generation of V2X messages, such as the TMC and optionally third-party data sources.

IT policy, when not accounted for, is often a major cause of delays in V2X deployments, making it crucial to involve IT groups early in the process. Understanding existing IT policies and how V2X infrastructure will integrate with current systems—whether they are on the same network or require internet access—is essential. This is especially important as cybersecurity becomes an increasing concern. Thus, it is recommended an IT policy for V2X systems be developed to ensure the system's security and to assess how these requirements may influence the overall system architecture. It is expected that local agencies adhere to this policy when V2X devices are deployed alongside other ITS infrastructure.

V2X RSUs are often co-located with other ITS equipment, such as traffic signal controllers, and typically have access to a local network that connects them to TMC, and also possibly the internet. In most cases, local connectivity does not pose significant challenges, as the RSUs are communicating within the trusted network. However, the need for an RSU to access the internet can introduce complexities. This is where IT policies become crucial, as they govern how RSUs communicate with external systems, including cloud-based services or third-party applications. The integration of V2X systems with the internet requires a secure and reliable connection, as well as clear guidelines for firewalls, encryption, and other cybersecurity measures. These policies must ensure that communication between the RSU and the internet is secure and does not compromise the overall integrity of the transportation network. Furthermore, considerations for how this internet connectivity impacts system architecture and the potential for future scalability must be part of the planning process.

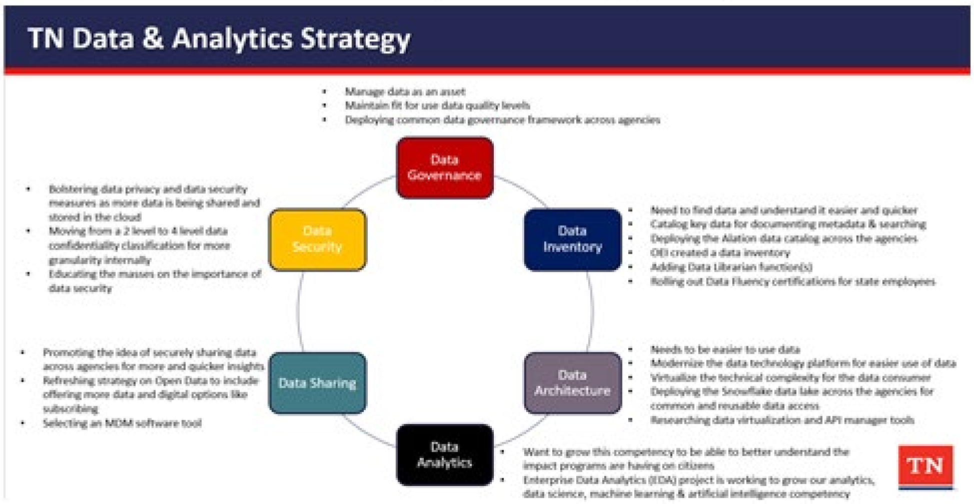
Develop a Data Governance Plan

Timeframe: less than 1 year

Description: Messages produced in a V2X environment have potential use in many applications – particularly for traffic management and operations. It will be important for TDOT to consider how this data is handled and stored, and to take measures to ensure that the privacy of any individuals that may be deduced from V2X data is not compromised.

It is recommended that TDOT develop a Data Governance plan to document how collected V2X data is expected be managed and further detailing how it will be used to enable performance evaluation, innovation, and economic development. It documents the entire data lifecycle within the deployment, covering sources and destinations, data volume and content, communication methods, and long-term storage plans.

When creating the Data Governance Plan for CAV data, it will be important to consider existing frameworks that have been put in place for data governance in Tennessee. The data and analytics strategy that has been devised is provided in Figure 11.



Source [13]

Figure 10. Tennessee Data and Analytics Strategy

Factors that specifically affect V2X message storage needs may include, but is not limited to the following:

- The types and size of raw messages that are stored (J2735 messages SPAT, MAP, BSM, etc.)
    - Message size is related to its complexity and the amount of optional data fields populated
    - e.g., a MAP message for a simple intersection with one lane along each approach which are all straight will be less complex that an intersection with five lanes on each approach and all approaches are along curves
- The format in which messages are stored (hex-encoded UPER, ASN.1, JSON, geoJSON, etc.)
- Compression techniques used
- The quantity of RSUs producing V2X data that will be stored.
- The number of OBUs / mobile devices in communication range of the V2X system
- Data Storage strategies used (e.g., deduplication, downsampling / data thinning, implementing geofences, privacy filters)
- The duration that data is stored.

Table 1provides an estimate for storing MAP, SPaT, TIM, and BSM payloads in a raw format (Unaligned Packet encoding rules hexadecimal) and in JSON format.

Table 1. V2X Message Storage Requirements Estimates

Message	UPER Hex	JSON
MAP[1]	0.7-3.6 GB/RSU/month	14-72 GB/RSU/month
SPaT[1]	1.2-5.0 GB/RSU/month	18-74 GB/RSU/month
TIM[1]	0.1-0.4 GB/RSU/month	2-6 GB/RSU/month
BSM[2]	1.4-7.0 MB/RSU/month/veh	14-70 MB/RSU/month/veh

[1] Assumes messages are broadcast non-stop, and all messages are saved. Saving every message may not be necessary when message contents do not change.

[2] Assumes each vehicle will spend 2 minutes in range of RSU when passing. Scales in proportion with penetration rate (which could vary depending on RSU location).

The plan should also document data privacy controls to mitigate the risk of harm to individuals that would result in the improper handing or disclosure of the data. This at a minimum should include the use of algorithms that eliminate data produced by vehicles outside of the ROW, eliminate data within a certain time/distance from the start and end points of a trip, downsampling, and obfuscation of data in messages that can be used to link them together

Review Motor Vehicle Operation Regulations and Recommend Legislation

Timeframe: less than 1 year - 1 year

Description: In order to determine if TDOT's current policy and regulations are sufficient to support long-term connected and autonomous vehicle goals, first those goals need to be well established in terms of TDOT's mission, whether that be improving accessibility to underserved areas or individuals, pedestrian and vehicular safety, cost savings, or environmental sustainability. After that the development of flexible policies to meet those goals can begin. The policies TDOT implement should guide the development of autonomous vehicles in the direction that TDOT sees the industry moving and that which benefits its users but still be cognizant of and be flexible enough to adapt to an industry that is advancing and shifting more rapidly that any that has come before it. To jumpstart the process TDOT, could incentivize pilot programs to take place in Tennessee and utilize the opportunity to collaborate with these industry stakeholders and community advocates to address key regulatory challenges such as establishing safety, liability, and privacy standards. This will not only serve to build relationships with these providers but also educate the public on what to expect from this rapidly evolving technology. Finally, gathering and analyzing the data from the aforementioned activities can serve as a litmus test as to if the enacted policies have been effective at supporting the development of CAV, or if more or less restrictive measures are needed.

Develop Standard Agreements with Local Agencies

Timeframe: 1-2 years

Description: Historically, TDOT's role in traffic signal operations and maintenance has been to fund and/or perform the design and construction of traffic signals that are warranted for intersections on the state highway system. At the completion of construction, the traffic signal is handed over to the local agency to operate and maintain.

However, applying this same approach to V2X technologies at these same intersections may be problematic as local municipalities are unfamiliar with the tasks involved with the operations and maintenance of V2X systems. Furthermore, local municipalities may not have the funding available for staff to perform these activities or for paying for supporting systems such as the SCMS and V2X Infrastructure Management System.

Thus, it is recommended that TDOT consider what a standard cost-sharing agreement might look like for providing CAV system support to local agencies. These agreements with will help establish clear roles and responsibilities for CAV system operations and maintenance. The standardized agreements should be flexible to accommodate optioned and scaled alternatives for TDOT support when municipalities are not able to completely take on all responsibilities involved with a CAV deployment – this may include but is not limited to installation, physical roadway maintenance, policies and procedures for AV technologies, FCC licensing, Security Certificate management, V2X message development (e.g., MAP and TIM messages), and system configuration, V2X operations and maintenance

Services that TDOT may offer include, but is not limited to providing technical personnel support, providing no or low-cost access to V2X supporting services for the local agency, and may go as far as completely taking control of all O&M responsibilities for the local agency.

Develop an AV strategy

Timeframe: 1-2 years

Description: TDOT should develop an AV strategy - first determining which AV use cases to consider and prioritizing them based on state needs, infrastructure, and transportation goals. By defining these priorities, TDOT can develop targeted strategies for AV integration that align with mobility, safety, and economic objectives.

- **AV Shuttles** – Low-speed automated shuttles can enhance first- and last-mile connectivity, improve accessibility in urban areas, and support transit services on campuses, business districts, and event venues.
- **Robotaxis** – Autonomous ride-hailing services can provide on-demand mobility options, reduce reliance on personal vehicles, and help alleviate congestion in metropolitan areas.
- **Freight Automation** – Long-haul automated trucking can improve supply chain efficiency, reduce transportation costs, and address driver shortages while leveraging Tennessee's role as a major freight hub.
- **Truck Platooning** – Vehicle-to-vehicle connected freight convoys can enhance fuel efficiency, reduce emissions, and improve highway safety through coordinated braking and acceleration.

Once TDOT prioritizes these use cases, planning efforts can focus on infrastructure needs, regulatory considerations, and operational strategies to support safe and effective AV deployment. This includes assessing roadway readiness, identifying key corridors/areas, and coordinating with public and private stakeholders.

While autonomous vehicles are more or less independent entities on roadways, not reliant on the state or municipality owned infrastructure around it, that may not be the case forever, nor in the interests of TDOT or automakers and technology companies. Does TDOT want to foster the deployment of autonomous vehicles and production vehicles with advanced driver assistance or is it content to put the onus on automakers and technology companies to adapt to TDOT's existing infrastructure. For example, TDOT has recently updated its standards for pavement markings to include six-inch line widths, increased contrast markings and retro reflectivity standards. While this will certainly provide increased clarity for manual drivers, driver assistance functions, and fully autonomous vehicles, is this something that TDOT can maintain long-term? Do these improvements have an effect on systems which may utilize those markings? In order to find out TDOT should engage these entities in an open forum to first understand what infrastructure needs would be beneficial to these independent autonomous systems. From there the discussion can begin internally about how and why infrastructure changes should or should not be implemented. Perhaps while something may be useful to autonomous systems, the cost of maintaining a particular infrastructure element statewide will outweigh the potential benefits, for example. To evaluate this, small-scale pilots of the changes could be approved for dedicated corridors where the infrastructure could have the maximum impact. At the end of these pilot projects, TDOT can make the decision to rollout the changes to more areas, restrict the changes to just the corridors originally implemented, or stop supporting the changes all together.

To support this effort, TDOT should review strategic and planning documents from USDOT, such as the Automated Vehicles Comprehensive Plan [14], along with similar efforts from other states. Learning from these initiatives will help TDOT identify best practices, avoid potential pitfalls, and develop an AV strategy tailored to Tennessee's unique needs and priorities.

6.3 Funding Recommendations

Recommended actions associated with funding for CAV projects are provided in this section

- Provide Dedicated Funding for CAV technology projects
- Leverage Federal Funding

Provide Dedicated Funding for CAV Technology Projects

Timeframe: 1-2 years

Description: It is recommended that TDOT establish dedicated program funding for deploying CAV technologies or modify existing funding program(s) to allow for the deployment of CAV technologies. Funding ensures that the necessary infrastructure, equipment, and ongoing maintenance can be supported. This funding could be used to execute many of the recommended actions provided throughout this report.

When budgeting for V2X technologies, it is important to consider the following: transitioning from DSRC to C-V2X, upgrading existing systems to be compatible with V2X components (if applicable), fiber installation (if applicable), hardware costs, software development costs (if applicable), integration and testing costs, and ongoing costs for supporting systems (such as the SCMS, and licensing costs for V2X device/data management platforms), and ongoing operations and maintenance (either in house or outsourced to a contractor).

A dedicated funding source will also enable TDOT to take advantage of grant opportunities as they arise (see recommendation below) and readily participate in engagement opportunities, such as pooled fund study groups (see recommendations in Section 5.4). Additionally, providing funding for ongoing research and development will allow TDOT to address state-specific issues that have not yet been tackled in other existing deployments across the US, while also positioning TDOT to make valuable contributions to the broader CAV industry.

For short-term RSU upgrades and other smaller projects, TDOT should explore use of funding from sources that already exist within TDOT, such as the ITS maintenance budget, to cover more immediate needs.

Leverage Federal Funding

Timeframe: less than 1 year

Description: TDOT should actively seek federal formula funds and grant opportunities to amplify the impact of state funding and speed up V2X deployments. By leveraging federal funding, TDOT can expand V2X infrastructure, improving transportation safety and efficiency. Following the successful example of Georgia DOT, which has effectively used formula funding to implement CV infrastructure, TDOT can scale up its own CAV technology deployments and maximize available funding opportunities.

The grant opportunities outlined below all support the deployment of V2X technologies, providing a valuable pathway for advancing statewide connectivity and innovation. Leveraging these grant opportunities typically requires the applicant to contribute at least 20% of the cost of the project thus it is important to have access to funding (see recommended action above) to take advantage of these opportunities when they arise. It is important to note that pursuing federal grant funding for CAV deployment comes with costs, including the time and resources required to develop a competitive application, align with federal requirements, and coordinate with multiple partner stakeholders. Having a program that is established and highly visible to USDOT (through engagement activities), along with partnerships with partners that share the same vision, and with experienced firms and vendors that have proven expertise in engineering, integration, testing, and O&M, can strengthen a grant application by demonstrating readiness and credibility. Agencies without such a program can still submit a competitive application, but they may face challenges in effectively showcasing their capabilities, especially if grant reviewers are unfamiliar with their experience or require additional clarification on their ability to execute and sustain the project successfully.

One of the best ways to be competitive in grant funding applications is to demonstrate knowledge and understanding of federal initiatives and trends. The TDOT Deployment Plan should be in alignment with these trends and should be referenced in the applications to demonstrate that TDOT has a plan to implement these types of projects (shows forethought).

Note: With the recent change in administration, the focus of federal grant opportunities may shift. While it is too early to determine the full impact on current and future funding opportunities, new grant programs could also emerge as priorities evolve. Organizations like ITS America have shown cautious optimism that ITS technologies may continue to receive focus.

- **Advanced Transportation Technology and Innovation (ATTAIN) –** Also known as the Advanced Transportation Technologies and Innovative Mobility Development program, this grant provides competitive funding in support of advanced transportation technologies. Funding is available each fiscal year up to $60 million with a 20% local match requirement. Examples of applicable projects include the deployment and operation of technologies in support of emergency response, integrated corridor management, and retrofitting DSRC systems to C-V2X among others.
- **Strengthening Mobility and Revolutionizing Transportation (SMART) Grants Program –** This grant funding source consists of an annual appropriation of $100 million through fiscal year 2026. Eligible applicants include State and Tribal governments, local governments, public transit agencies, public toll authorities, metropolitan planning organizations, and a combination of two or more of the listed entities. Projects eligible for funding under the grant include traffic signals, smart grids, delivery and logistics, systems integration, sensors, connected vehicles, and coordinated automation.
- **Safe Streets and Roads for All (SS4A) Grant Program –** The SS4A Program was established under the Bipartisan Infrastructure Law with funding available through 2026. This program is intended to support grants to prevent fatalities and incapacitating injuries on the transportation network. While State DOTs are not eligible to directly apply for funds under this grant, counties, cities, towns, transit agencies, other special districts, metropolitan planning organizations, and Tribal governments are eligible to apply for funds. The grants are divided into two categories: Planning & Demonstration Grants and Implementation Grants. Planning and Demonstration Grants apply to development of Comprehensive Safety Action Plans and related transportation safety strategy development. Implementation Grants applied to implementation of projects previously identified under a Comprehensive Safety Action Plan, including demonstration projects, supplemental planning activities, and project level planning, design, and development activities.

6.4 Engagement Recommendations

Recommended actions associated with TDOT engagement with local agencies and external groups are provided in this section

- Active Involvement in V2X Groups,
- Set up external webpage Dedicated to CAV technologies
- Set up internal webpage Dedicated to Knowledge Sharing
- Use Existing Deployments to Showcase CAV Technology Capability
- Develop Strategic Partnerships

Active Involvement with CAV Groups

Timeframe: less than 1 year

Description: TDOT should maintain active involvement in industry groups that drive advancements in connected and automated vehicle technologies, for example the Connected Vehicle Pooled Fund Study (CV PFS), the Automated Vehicle Pooled Fund Study (AV PFS), and ITS America Future of 5.9 V2X and Beyond 5.9 V2X.

First, TDOT should develop a list of relevant groups for engagement based on priorities and areas of interest. Before proceeding, it is recommended to consult the Planning Bureau to determine appropriate involvement with each group. This approach will ensure alignment with ongoing initiatives within TDOT.

To maximize the benefits of participation, it is strongly recommended that TDOT representatives attending these meetings actively take note of and contribute to discussions on projects. This is especially critical when there are opportunities to address challenges encountered in the deployment of V2X and AV technologies within Tennessee.

TDOT should also maintain active participation in ITS America committees and subcommittees focused on V2X and automated vehicle technologies, and engage with USDOT's technical working groups, such as the Interoperability Technical Working Group, which brings together federal, state, and industry stakeholders to advance V2X interoperability across connected vehicle deployments. These groups play a critical role in identifying and addressing technical challenges, ensuring seamless communication between diverse V2X systems, and aligning deployments with national standards.

Additionally, TDOT should engage with other state DOTs, take advantage of peer exchange opportunities, and present on CAV progress at national conferences . These interactions can provide valuable insights, facilitate knowledge sharing, and places Tennessee in the national spotlight (i.e., visibility with USDOT), helping to ensure that Tennessee remains at the forefront of connected and automated vehicle innovation.

Set up External Webpage Dedicated to CAV technologies

Timeframe: 1-2 years

Description: Setting up an external webpage dedicated to CAV technologies can help to foster greater awareness and adoption of the technology across Tennessee, helping the public understand these technologies in simple, accessible terms. The page can showcase materials such as explainer videos, articles, and infographics that present CAV concepts in a clear and easy-to-understand format, highlighting how CAV technologies will enhance safety, mobility, and sustainability in Tennessee. This website could also be used to communicate progress on CAV projects.

Here are three example CAV websites set up by other state agencies providing a balance of educational and technical materials for public consumption and for use by practitioners:

- Georgia. https://cvprogram-gdot.hub.arcgis.com/
- Ohio. https://drive.ohio.gov/programs/av-cv
- Utah. https://transportationtechnology.utah.gov/

Set up Internal Webpage Dedicated to Knowledge Sharing

Timeframe: 1-2 years

Description: TDOT should establish a dedicated V2X website to serve as a centralized hub for all stakeholders involved in V2X initiatives. This platform would house essential planning, engineering, and architecture documents, ensuring easy access to critical information – critical for promoting workforce development efforts within TDOT and amongst other agencies that partner with TDOT. It would also provide links to important external resources, provide details on current and upcoming V2X deployments, and updates on statewide initiatives.

Additionally, the website could provide access to educational materials. By consolidating this information in one location, TDOT can enhance coordination, streamline communication, and foster greater awareness and adoption of V2X technology across Tennessee.

This internal webpage can host links and materials referenced in the "Build Technical Capacity" planning recommendation, supporting professional capacity building. Additionally, it can serve as a central repository for key documents developed as part of completed and ongoing projects, as well as documents that will be developed in the future from implementation of the recommendations in this report (e.g., deployment plan, systems engineering documentation, etc.).

Use Existing Deployments to Showcase CAV Technology Capability

Timeframe: 1-2 years

Description: TDOT should leverage the existing I-24 SMART Corridor to showcase CAV technology capabilities, using it as a live demonstration site for V2X applications. A specialized OBU should be developed to support V2X use cases that are of the highest priority to TDOT to provide real-world demonstrations to local agency representatives who may not be familiar with the technology and/or the potential benefits it can provide.

Additionally, TDOT can offer operational incentives to automakers and technology companies to utilize, test, and demonstrate CAV capabilities ranging from V2X to automated driving in Tennessee and specifically on the I-24 corridor. The I-24 corridor can serve as a firsthand demonstration site where agency staff can experience the system firsthand, gaining a deeper understanding of its functionality and benefits. This approach aims to generate interest among local agencies, encouraging wider adoption of V2X technology and fostering momentum for further deployment.

It is recommended that TDOT use the V2X Use Case Roadmap that has been developed as a foundation for these demonstrations. Example applications that could be highlighted at signalized intersections include real-time signal information, red light violation warning, and signal priority and preemption. On the freeway, the OBU should display traveler information that aligns with roadside signage, with an emphasis on dynamic messaging such as variable speed limits, lane control signage, and queue warnings—critical for addressing known issues along the I-24 corridor.

Develop Strategic Partnerships

Timeframe: 3-4 years

Description: One of the major areas of focus in the V2X space is providing day one benefits in V2X deployments. This often means deploying V2X technologies not only on the roadside, but also in vehicles with aftermarket devices. It is not reasonable to expect that aftermarket devices can be deployed on a significant enough of a portion of vehicles to enable long-term types of benefits that can only be achieved with significant vehicle penetration rates. However, there are some V2X applications that stand to provide tangible day one benefits. This typically requires the formation of strategic partnerships with local agencies and/or other local companies with vehicle fleets.

TDOT should collaborate with local agencies to identify potential fleet operators for OBU installations, creating mutually beneficial partnerships that support the advancement of TDOT's CAV program. Potential partners include transit agencies, TDOT Vehicle and Asset Management, and trucking or shipping companies, whose fleets could be equipped with OBUs. In return, these partners would receive benefits such as signal priority/preemption, traveler information, or SPaT data along targeted corridors or within designated areas. It is important to also consider that successful implementation requires local municipality alignment, ensuring that the necessary local operations support/policies are in place to support these enhancements.

6.5 Deployment Recommendations

Recommended actions associated with CAV technology deployments are provided in this section

- Update to Cellular Vehicle-to-Everything Communications
- Set up Statewide V2X Supporting Systems
- Conduct a Hands-On V2X Deployment to Build Internal Capacity
- Develop a Standard Deployment/Integration Process
- Expand Communications / Deployment Footprint

Update to Cellular Vehicle-to-Everything Communications

Timeframe: less than 1 year - 1 year

Description: TDOT should upgrade all RSUs from DSRC to C-V2X communication to align with the FCC's Second Report and Order [15]. Upgrading to C-V2X will future-proof infrastructure, support evolving V2X applications, and establish Tennessee as a well-informed and active agency in V2X deployment.

Note: It is further recommended that TDOT apply for funding under the ATTAIN Grant Program, which specifically calls out projects that involve "retrofitting DSRC technology deployed as part of an existing pilot program to C-V2X technology, subject to the condition that the retrofitted technology operates only within the existing spectrum allocations for connected vehicle systems" as eligible for funding.

Set up Statewide V2X Supporting Systems

Timeframe: 1-2 years

Description: Depending on the size and capabilities of the local municipality where V2X technologies are deployed, it may not be practical or cost-effective for the local municipality to stand up its own independent supporting systems required for proper V2X operations.

TDOT and/or regional TMCs should provide critical supporting systems necessary for V2X deployments. By making these services available to jurisdictions that need them, TDOT can effectively reduce technical and financial barriers for local agencies to deploy V2X systems. By offering these systems as shared resources, TDOT can enable agencies to seamlessly integrate V2X technology into their operations without the need for extensive independent infrastructure. This approach streamlines deployment, fosters interoperability, and accelerates the adoption of V2X systems across Tennessee. However, it is important to note that accessing these systems would require connectivity between the V2X deployment site(s) and each of these services.

- **SCMS.** The SCMS ensures secure and reliable V2X communications. All sites leveraging the same SCMS guarantees interoperability between local deployments from a security standpoint.
- **V2X Infrastructure / Data Management System.** This supporting system provides monitoring, management, and control services necessary for V2X devices operating within and data generated from the V2X system.
- **Position Correction Services.** TDOT currently operates a GNSS Reference Network [16] that could potentially be leveraged to support the generation of position correction messages. This system should be evaluated to determine if it can be used to support RTCM Position Corrections message requirements. TDOT can provide support to deploying agencies that could leverage this system.

Conduct a Hands-On CAV Deployment to Build Internal Capacity

Timeframe: 1-2 years

Description: To build internal expertise and ensure long-term sustainability of CAV systems, TDOT should undertake a hands-on exercise designed to give staff direct experience with system design, deployment, integration, and operation. While the I-24 Smart Corridor represented a significant investment in advanced transportation technologies, its contracting approach limited opportunities for TDOT staff to meaningfully engage in the technical aspects of deployment.

To support future deployments and ensure lessons are captured, TDOT should engage an experienced third-party V2X engineering firm to serve as an owner's representative as part of a small-scale deployment effort. This partner would provide technical oversight throughout the project lifecycle, helping TDOT validate design decisions, interpret system requirements, and ensure vendors are delivering solutions that meet expectations. Beyond quality assurance, the owner's representative would play a critical role in knowledge transfer—facilitating workshops, providing real-time explanations during field implementation, and explaining maintenance and operations of the system. This hands-on approach will help ensure proper system implementation while also empowering TDOT staff to build confidence and technical capability—enabling them to lead future deployments, effectively manage and troubleshoot systems, and support the ongoing expansion of the CAV infrastructure over time.

Develop a Standard Deployment/Integration Process

Timeframe: 3-4 years

Description: TDOT can streamline the CAV deployment by developing a structured framework for implementing CAV technologies across the state. These guiding processes will provide a consistent approach to planning, deploying, and integrating CAV infrastructure, helping both TDOT and local agencies navigate engineering, technical, procurement, operational, and regulatory aspects of projects. This structured framework will lower the barrier to entry for agencies considering CAV investments. Additionally, establishing a reference integration framework will promote deployment efficiency and scalability, accelerating the adoption of V2X technologies in Tennessee.

Aspects of this streamlined process could include the following:

- **Planning & Project Scoping.** TDOT needs to assess the potential V2X deployment to determine whether it is technically, economically, and operationally viable. At this stage, it is still important to consider alternative methods of addressing the issues at hand (not necessarily assuming the solution will be V2X-based), and the most viable option is selected and justified. While the concept exploration should be at a fairly high level at this early stage, enough technical detail must be included to show that the proposed concept is workable and realistic. A feasibility study can be performed to provide a basis for understanding and agreement among project decision makers – project management, executive management, and any external agencies that must support the project, such as county and local agencies, transit agencies, and metropolitan planning organizations.
- **Stakeholder Identification & Engagement.** CV systems are complex and require a multi-disciplinary approach for a successful deployment. Thus, it is important to assemble a group of stakeholders that are able to provide different perspectives on a proposed V2X system. Stakeholders may include but are not limited to: TDOT ITS/CV Program staff, deployment partner agencies (that will be installing OBUs and/or RSUs), OEMs, vendors, traffic engineers, signals engineers, network communications and IT staff, operations and maintenance staff, V2X subject matter experts, local staff with knowledge of issues, and members of the community that may be impacted by the V2X system. It is important to note that it may be appropriate to engage certain stakeholders at different points in the engineering, development, and deployment process.
- **Systems Engineering.** Once concepts have been evaluated, the systems engineering process must be followed to further refine the concept and define the project-specific details that will be used to design and build the system. This is expected to include the development of a Concept of Operations, System Requirements, Interface Control, System Architecture, and System Design. To the extent possible, standard systems engineering documentation and procurement requirements should be leveraged (see Recommended Action: Develop Systems Engineering Documentation under 6.1 Planning above). Customizations of these documents may be needed if the scope of the deployment at hand falls outside of the scope of the standard systems engineering documents.
- **Unit Verification and Acceptance Testing.** Before being deployed, any new development should be tested to identify as many defects as possible. The development of test cases which document how the system should behave during testing should be developed. While developers should conduct tests as development progresses, it is recommended that an independent party conducts formal tests. Once the system has been deployed, it should be tested to verify that the system as a whole works as intended. A verification plan should be developed to test that the system is meeting all requirements and design criteria that were documented prior to system development.
- **Operations and Maintenance.** Once a V2X system has been deployed, considerations must be made regarding how it will be operated and maintained. A V2X Infrastructure / Data Management System can provide a platform for managing and supporting V2X components on the network. Most vendors of V2X equipment can provide O&M support

as needed, though it is recommended that a fundamental knowledge of all aspects of O&M are maintained by one or more TDOT staff.

Expand Communications / Deployment Footprint

Timeframe: 5 years and beyond

Description: TDOT should expand its fiber network and V2X infrastructure footprint. Key recommendations to achieving this include:

1. Accelerate V2X Deployment – TDOT should increase the pace of V2X deployments to align with the growing investment and adoption of V2X technologies across the US.
2. Integrate V2X Infrastructure into ITS Deployments – In addition to targeted V2X deployment, TDOT should include V2X infrastructure as a standard component in all future ITS and signal system upgrades. This means ensuring that new traffic signals, management systems, and fiber expansions are designed with V2X in mind.
3. Leverage Fiber Expansion to Support V2X – As TDOT continues to expand its fiber-optic network, efforts should be made to ensure new fiber deployments can accommodate V2X infrastructure.

Integrating C-V2X RSUs into infrastructure expansion projects requires careful planning for power and communications needs, such as adding ports to existing network switches and ensuring reliable internet access to enable SCMS certificate downloads. Fiber optic networks provide the high-bandwidth, low-latency communication backbone necessary to support C-V2X RSUs but often necessitate complementary infrastructure investments—such as new cabinets, poles, network switches, and demarcation points—to ensure effective deployment. When planned holistically, fiber optic corridors can support not only C-V2X applications but also a broad range of TSMO strategies and ITS technologies, delivering significant long-term value.

To support the expansion of CAV and the necessary communications infrastructure, a coordinated and strategic approach is essential. Given the significant costs involved, it is important to carefully evaluate where network investments will deliver the most benefit. This makes it all the more critical to ensure that the process for identifying and selecting deployment locations is clearly defined and data driven. These considerations reinforce the importance of the planning recommendation to **"Prioritize Technology Applications and Locations."**

6.6 Action Plan Anticipated Timeline Summary

The schedule summary provided in Table 2 provides a general sequence of actions that can be taken, with the dates representing what could be accomplished under an aggressive timeline. While meeting these dates is not as critical as the order of actions, it is also important that these steps are not taken in a vacuum—before proceeding, TDOT should consider any developments in the CAV industry and adapt the actions and schedule, as necessary.

Table 2. Action Plan Timeline

Recommended Action	Now	1 year	2 years	3 years	4 years	5+ years
Planning						
Build Technical Capacity	■					
Develop a Deployment Plan for CAV Technology in Tennessee		■	■			
Assess Infrastructure improvements and cost		■	■			
Prioritize Technology Applications and Locations		■	■			
Develop Systems Engineering Documentation and V2X System Architecture			■	■		
Build Operations and Maintenance (O&M) Capabilities			■	■		
Develop Technical Requirements for V2X devices and supporting infrastructure				■	■	
Policy						
Develop IT Policy around V2X Devices	■					
Develop Data Governance Plan	■					
Review Motor Vehicle Operation Regulations and Recommend Legislation	■	■				
Develop Standard Agreements with Local Agencies		■	■			
Develop an AV strategy		■	■			
Funding						
Provide Dedicated Funding for CAV technology projects		■	■			
Leverage Federal Funding	■					
Engagement						
Active involvement in V2X Groups	■					
Set up external webpage Dedicated to CAV technologies		■	■			
Set Up internal webpage Dedicated to Knowledge Sharing		■	■			
Use Existing Deployments to Showcase CAV Technology Capability		■	■			
Develop Strategic Partnerships				■	■	
Deployment						
Update to Cellular Vehicle-to-Everything Communications	■	■				
Set up Statewide V2X Supporting Systems		■	■			
Conduct a Hands-On V2X Deployment to Build Internal Capacity		■	■			
Develop a Standard Deployment/Integration Process				■	■	
Expand Communication / Deployment Footprint						■

Chapter 7 Conclusion

The TDOT CAV Readiness Plan provides strategic and actionable recommendations to guide the integration of CAV technology deployments into the TDOT's standard operations. The recommendations outlined throughout this plan offer a roadmap for building internal capacity, preparing infrastructure, aligning policies, and coordinating with local and external partners to advance CAV readiness in a sustainable and forward-looking manner.

A critical element for the success of CAV in Tennessee is strong leadership support within TDOT and across state government. Gaining the commitment of decision-makers and leadership is essential not only to secure the resources necessary to implement the plan but also to expand program funding and elevate the visibility of CAV technologies as a strategic transportation priority. By clearly demonstrating the safety, mobility, and economic benefits of CAV integration, TDOT can strengthen the case for long-term investment and institutionalize CAV considerations in planning, design, operations, and maintenance practices.

As TDOT moves from planning to implementation, technical leaders will learn valuable lessons through hands-on experience, pilot deployments, and collaboration with peers. TDOT has the opportunity to build upon the foundational work of other leading agencies, tailoring best practices to meet Tennessee's unique transportation needs. Importantly, TDOT also has a key role in serving as a knowledge hub—passing on insights, tools, and strategies to local jurisdictions to ensure that the benefits of CAV technologies extend throughout the state.

Given the dynamic and fast-paced nature of CAV advancements, this Readiness Plan should not be viewed as a static document. Instead, TDOT should periodically revisit and evaluate its progress, measuring accomplishments against the plan's goals and adjusting direction as needed to stay aligned with the latest developments in technology, policy, and industry trends. Regular assessments will help refine priorities, identify new opportunities, and ensure that TDOT remains a leader in the national conversation on connected and automated mobility.

References

[1] Cambridge Systematics, "Transportation Systems Management and Operations (TSMO) - Program Plan," TDOT, 2022.

[2] ITS America, "ITS America National V2X Deployment Plan - An Infrastructure & Automaker Collaboration," 2023.

[3] USDOT, "Saving Lives with Connectivity - A Plan to Accelerate V2X Deployment," 2024.

[4] Noblis, "Interoperable Connectivity — National V2X Deployment Plan Supplement," 2024.

[5] FCC, "4G LTE Coverage as of May 15, 2021 (AT&T Mobility, T-Mobile, UScellular, Verizon)," [Online]. Available: https://fcc.maps.arcgis.com/apps/webappviewer/index.html?id=6c1b2e73d9d749cdb7bc88a0d1bdd25b.

[6] WSP, The Corradino Group, "Dedicated Short Range Communication (DSRC) Statewide Guidance - Summary of Research and Design Considerations," TDOT, 2018.

[7] University of Memphis, "The Impacts and Adoption of Connected and Automated Vehicles in Tennessee," TDOT, 2021.

[8] University of Tennessee, "Connected and Automated Vehicles Investment and Smart Infrastructure in Tennessee," TDOT, 2022.

[9] USDOT, "Smart Community Resource Center," 2024. [Online]. Available: https://www.its.dot.gov/scrc/.

[10] Noblis Inc., Neaera Consulting, "Vehicle-to-Everything (V2X) Deployer Resource," 2024.

[11] USDOT, "Intelligent Transportation Systems Professional Capacity Building," 2024. [Online]. Available: https://www.its.dot.gov/pcb/.

[12] "Architecture Reference for Cooperative and Intelligent Transportation," 2025. [Online]. Available: https://www.arc-it.net/.

[13] TDOT, "Tennessee Data & Analytics Strategy," 2021.

[14] USDOT, "Automated Vehicles - Comprehensive Plan," USDOT, 2021.

[15] FCC, "PUBLIC NOTICE - WIRELESS TELECOMMUNICATIONS BUREAU AND PUBLIC SAFETY AND HOMELAND SECURITY BUREAU PROVIDE GUIDANCE FOR INTELLIGENT TRANSPORTATION SYSTEM LICENSEES TO TRANSITION FROM DSRC TO C-V2X OPERATIONS

IN THE 5.895–5.925 GHZ BAND...," 11 February 2025. [Online]. Available: https://docs.fcc.gov/public/attachments/DA-25-125A1.pdf.

[16] TDOT, "GNSS Reference Network," [Online]. Available: https://www.tn.gov/tdot/engineering-division/geodetics/gnss-reference-network.html.