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Connected and Automated Vehicles Investment and Smart Infrastructure in Tennessee

Part 2: Readiness and Investments in Connected and Automated Vehicles Technologies in Tennessee: A Baseline

Research Final Report from University of Tennessee | Asad Khattak, Iman Mahdinia, & Kinzee Clark | May 1, 2022

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The project has developed a series of five (5) reports that support intelligent mobility strategies in Tennessee. This is report 2 of 5.

16. Abstract

Connected and Automated Vehicles (CAVs) have the potential to substantially improve safety and mobility. To accelerate their diffusion, the purpose of this report is to provide baseline information that can assist with an implementation plan pertaining to readiness and investments in CAV technologies in Tennessee. This information can assist TDOT to develop and improve a strategic plan that accommodates the deployment of CAVs and for related investments in physical and digital/technology infrastructure, electrical vehicle infrastructure, policy and regulation, and public acceptance. To that end, this report focuses on readiness and deployment plans in different US states and compares the strategies that these states are following with Tennessee's activities in CAVs. The report articulates strategies that can enhance vehicle-to-everything interactions, leverage Tennessee resources, and provides strategic recommendations based on a review of statewide CAV readiness plans. By reviewing and analyzing the state of practice for statewide CAV readiness plans, this report identifies opportunities for CAV-related ITS architecture service packages in Tennessee. For instance, a wide range of CAV service applications can be considered including emergency vehicle preemption, broadcast and personalized traveler information, queue warning, work zone management, connected vehicle traffic signal system, road weather motorist and warning, pedestrian and cyclist safety, and electric charging stations management. Detailed strategies and recommendations for CAVs are provided in the report.

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Executive Summary

Background

> *The goals of TDOT's smart infrastructure project are to provide:*
> - *A complete picture of relevant research, development, and deployment (RDD)*
> - *Discuss key research findings and investment opportunities*
> - *Provide recommendations for investments in intelligent mobility*

Connected and automated vehicles (CAVs) are increasingly diffusing through the transportation system. Characterized by Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communications, CAVs can mitigate some of the problems that come with growth, including mobility in Tennessee (especially traffic congestion, costing an estimated $4.2 billion in 2020), safety (1,325 lives lost in 2021 and $25 billion annual economic cost and societal harm from crashes), and energy/environmental issues (with associated potential for non-conformity). CAV technologies can impact a wide range of transportation functions in public agencies. Specifically, several divisions of the Tennessee Department of Transportation (TDOT) may be impacted, including Traffic Operations, Strategic Transportation Investments, Maintenance, Asset Management, Environmental, Long Range Planning, Multimodal Transportation Resources, and Occupational Health and Safety. Partners of TDOT can also be impacted, especially the infrastructure owners and operators (IOOs), which include public agencies working locally.

Focusing on TDOT and IOOs, together, they can facilitate CAV deployment and operation through collaboration and enhanced readiness in terms of roadway infrastructure, digital infrastructure, and electric vehicle infrastructure. New regulations, policies, programs, and partnerships are needed to prepare TDOT for new forms of safe and reliable transportation. Specifically, research, development, and deployment of emerging technologies are critical going forward, as is the management and harnessing of big data from new sensors, e.g., communication of data between roadside units and onboard units. This report is meant to support TDOT's future efforts in terms of readiness for emerging technologies, focusing on investments in smart infrastructure and intelligent mobility strategies. Baseline information is provided to assist with the development of future strategic plans that can guide TDOT in the deployment of CAV technologies, especially smart infrastructure enablers.

Key Findings

A strategic plan that accommodates the deployment of CAVs and related investments in physical and digital/technology infrastructure is needed to accelerate the diffusion of emerging technologies. Emerging technologies also require electric vehicle infrastructure, policy and regulation, and public acceptance. To this end, focus on readiness and deployment plans in different US states are reviewed and compared, i.e., the strategies that these states are following are compared with Tennessee's activities in CAVs. Strategies that can enhance vehicle-to-everything interactions, leverage Tennessee resources, and provide strategic directions based on a review of statewide CAV readiness plans include:

- ***Identifying emerging technology opportunities.*** Specifically identifying opportunities for CAV-related Intelligent Transportation Systems (ITS) architecture service packages in Tennessee.
- ***Leveraging Tennessee-based resources.*** Successful implementation of tactical and long-range plans that will require TDOT to rely on the diverse resources available in Tennessee. The key resources that can be leveraged include: 1) TDOT owned and operated roadways with diverse urban, suburban, and rural characteristics; 2) TDOT capabilities in terms of data systems that include RDS, RITIS, ETRIMS, Traffic volume data (TNTIMES), incident data from the SmartWay Central Software, and TDOT-supported traffic operations centers that collect, process and disseminate data using advanced technologies; 3) a regulatory environment that facilitates testing and on-road deployment of CAVs, e.g., see Tennessee Automated Vehicles Act; 4) research, development and testing capabilities, available at universities and the Oak Ridge National Laboratory; and 5) presence of industry, especially automobile manufacturers and associated industries such as automotive suppliers.

Key Recommendations

Investments are needed in innovative solutions that encompass physical infrastructure, digital and smart infrastructure, electric vehicles, and charging infrastructure. For instance, to realize the full potential of intelligent mobility benefits focusing on smart infrastructure, investments in C-V2X equipment installation solutions are critical for TDOT. A key question is how to best plan for readiness in emerging technologies and work with IOOs when TDOT does not own or operate traffic signals in the state. Options include i) using TDOT Traffic Design Manual and TDOT standard specifications (modified by cities to fit their local needs) and statewide ITS architecture, ii) updating TDOT DSRC V2X guidance, and iii) supporting local agencies and, in some cases, TDOT operating and controlling traffic signals. The State of Georgia provides a good use case of DOT and IOO cooperation. Specifically, TDOT can create a program similar to the "SigOps program" by Georgia DOT. Under this program, traffic signal operations will be divided into regions supported by a separate consultant contract and dedicated funding. This shift will enable all signals to be remotely monitored automatically. In order to prioritize operational needs and resources, TDOT can use a tiered approach to define the level of remote monitoring and field presence required for each intersection. Critical and bottleneck intersections will require a higher level of monitoring and field presence than other locations. Furthermore, staff will be needed for this program. They will include remote signal engineers, field signal engineers, signal technicians, data analysts, and maintenance inspectors. The stakeholders will include TDOT Traffic Operations, TDOT district signal staff, and traffic engineering staff in counties and cities. To summarize, TDOT can consider a SigOps type approach or establish a way that fits with the current structure in Tennessee by supporting local agencies wishing to implement connected vehicle technologies.

Besides installing equipment, readiness also involves CAV data solutions. In this regard, options include i) city traffic management centers (TMCs) themselves or universities serving as repositories of new CAV data; the Tampa connected vehicle (CV) pilot deployment can serve as a relevant use case of new databases needed and it resides at the Center for Urban Transportation Research, University of South Florida. ii) TDOT's regional TMCs serve as repositories (data lakes); e.g., in TDOT's case, data coming from freeway CAV devices can be handled first by regional TMCs. For cities, regional centers can be used as data repositories for CAV data, requiring connectivity between the regional and city-based TMCs, especially for traffic signals. Currently, in Tennessee, regional TMCs are not well-connected with city TMCs, except there seems to be some movement along the I-24 Smart Corridor and surrounding cities.

To further prepare for CAVs in Tennessee, strategies to consider include:

- ***Research, develop and deploy CAV technologies*.** TDOT and partners are demonstrating the capabilities and benefits of CAVs through testbeds, e.g., I-24 Smart Corridor. The Chattanooga MLK Smart City Corridor testbed and other statewide initiatives are also underway. Expansion of such initiatives should be considered.
- ***CAV readiness plans.*** Monitor and understand the current practices of statewide CAV readiness plans in other states, lessons learned, and recommendations while tracking emerging technology advances.
- ***Developing roadmaps****.* Develop roadmaps for physical and digital infrastructure, electric vehicle infrastructure, regulation and policy, user acceptance, partnerships with stakeholders, and workforce development.
- ***Smart infrastructure technologies.*** Identify improvements in roadway, digital, and electric vehicle infrastructure technologies through ITS architecture service packages for implementation. A wide range of CAV service applications includes emergency vehicle preemption, broadcast traveler information, queue warning, work zone management, connected vehicle traffic signal system, personalized traveler information, road weather motorist and warning, pedestrian and cyclist safety, and electric charging stations management. Also, TDOT can identify opportunities in terms of connected, automated, and electric transportation systems that are multimodal, i.e., include freight, transit, pedestrians, and bicycles. TDOT can integrate CAV strategies into long-term planning and programming processes by anticipating the impacts of their increased diffusion; developing data collection and harnessing capability from new sensors, e.g., basic safety messages and traveler information messages; and conducting research on specific issues related to CAV data, harnessing the data, and investing in modeling/simulation capabilities that can directly deal with complexity and fragility of the transportation system when operating in a mixed-mode, where some vehicles are high-level CAVs while others are human-driven.
- ***Future research on CAV readiness*.** Future CAV research can focus on readiness for emerging technologies. In this regard, it is important to invest in conducting interviews/surveys of various stakeholders, including TDOT Division Directors and staff in terms of their readiness for CAV and synergistic technologies, including electric vehicles.

Additionally, TDOT can consider the following actions:

- Accelerate the integration of CAV technologies in TDOT's plans, programs, and projects.
- Consider creating positions for TDOT-based program managers to test and deploy CAVs (their responsibilities can be similar to ITS managers).
- Develop an external stakeholder coordination strategy, especially with IOOs, vehicle manufacturers, information technology companies, and the TennSMART consortium.

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Glossary of Key Terms and Acronyms

ACR-IT - Architecture References for Cooperative and Intelligent Transportation
AV - Automated Vehicle
CARLA - Car Learning to Act
CAT - Connected and Autonomous Technology
CAV – Connected and Automated Vehicle
CMAQ - Congestion Management and Air Quality
CTR - Center for Transportation Research
CUTR - Center for Urban Transportation Research
CV - Connected Vehicle
C-TIER - Center for Transportation Innovation, Education, and Research
C-V2X - Cellular Vehicle-to-Everything
DMS - Dynamic Message Sign
DSRC - Dedicated Short-Range Communication
EV – Electric Vehicle
FHWA - Federal Highway Administration
INC-ZONE - Incident Scene Work Zone Alerts for Drivers and Workers
IOOs - Infrastructure Owners and Operators
ITS - Intelligent Transportation Systems
MPO - Metropolitan Planning Organization
OBU – Onboard Unit
OEMs - Original Equipment Manufacturer
PRIMSA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QDA – Qualitative Data Analysis
RDS - Radar Detection System
RESP-STG - Incident Scene Pre-Arrival Staging Guidance for Emergency Responders
RSU – Roadside Unit
SAV - Shared Automated Vehicles
SCMS - Security Credential Management System
SPaT - Signal Phasing and Timing
SPR – State Planning and Research
SUMU - Simulation of Urban Mobility
TDOT – Tennessee Department of Transportation
THEA-Tampa Hillsborough Expressway Authority
TIM - Traveler Information Message
TMC - Traffic Management Center
US DOT - U.S. Department of Transportation
UTK - University of Tennessee, Knoxville
VECTOR - Vanderbilt Center for Transportation and Operational Resiliency
V2I - Vehicle-to-Infrastructure
V2V – Vehicle-to-Vehicle
V2X – Vehicle-to-Everything

Chapter 1 Introduction

> *The purpose of this report is to provide baseline information that can assist with an implementation plan pertaining to readiness and investments in CAV technologies in Tennessee.*

Connected and Automated Vehicles (CAVs) are increasingly diffusing through the transportation system. The growth of CAVs is partly encouraged by the increasing popularity and accessibility of vehicles by manufacturers such as Tesla, Waymo, and others. Importantly, CAVs can beneficially impact the transportation system. Characterized by Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communications, CAVs can mitigate some of the problems that come with growth, including inefficient and unreliable mobility in Tennessee (especially traffic congestion, costing an estimated $4.2 billion in 2020), safety (1,325 lives lost in 2021 and $25 billion annual economic cost and societal harm from crashes), and energy/environmental issues (with associated potential for non-conformity). CAV technologies can impact a wide range of transportation functions in public agencies. Specifically, several divisions of the Tennessee Department of Transportation (TDOT) may be impacted, including Traffic Operations, Strategic Transportation Investments, Maintenance, Asset Management, Environmental, Long Range Planning, Multimodal Transportation Resources, and Occupational Health and Safety. Partners of TDOT can also be impacted, e.g., the infrastructure owners and operators (IOOs). TDOT and IOOs can facilitate CAV operation through enhanced readiness in terms of roadway infrastructure, digital infrastructure, and electric vehicle infrastructure. To prepare TDOT for new forms of safe and reliable transportation, new regulations, policies, programs, and partnerships are needed. Specifically, research, development and deployment of emerging technologies are critical going forward as is the management and harnessing of big data from new sensors, e.g., communication of data between roadside units and on-board units. This plan is meant to support TDOT's future efforts in terms of readiness for emerging technologies, focusing on investments in smart infrastructure and intelligent mobility. This document provides baseline information to support the development of a strategic plan that guides TDOT in the deployment of CAV technologies and smart infrastructure.

1.1 Research Objectives

The vision for CAVs in Tennessee is to harness their mobility, safety, and environmental benefits to the fullest through investments in smart infrastructure. Building on a foundation of leadership, the state is poised to initiate the next phase of growth in CAV testing and deployment of products and services, by investing in innovations that will transform the transportation industry. These investments in infrastructure will synergize with investments in manufacturing and a skilled workforce that positions Tennessee as a leader in the automotive industry. The investments will attract industry and leaders in government and academia. To reiterate, TDOT's embrace of smart infrastructure investments aims to 1) enhance mobility (through congestion management and improving transportation system reliability), 2) enhance safety (reduce crashes, fatalities, and injuries on Tennessee roadways), 3) efficiently use existing infrastructure (reducing the need for adding conventional infrastructure), and 4) reduce fossil fuel consumption and associated emissions.

1.2 Scope of Work

The deployment of CAV technology and applications will occur over a couple of decades, as the technology is absorbed into the transportation system, similar to the mainstreaming of other intelligent transportation system technologies starting in the 1990s. This document anticipates CAV strategies and actions that can enhance the readiness for CAV technologies and associated changes as higher levels of automation and connectivity diffuse through the transportation system. Unlocking CAV's potential and fostering technological advancement requires a visionary research and development framework: one that aligns smart infrastructure with emerging vehicles and mobile technologies, facilitating their adoption and deployment in environments where CAVs share roadways with non-networked vehicles. Unlike traditional transportation technologies, the promise of connectivity and automation comes with the peril of increased fragility and complexity. Emerging technologies and **lessons learned from other states** are brought to bear on the issues to maintain safety and high performance when a multiplicity of connected and automated vehicles dynamically interact or in the presence of uncertain or changing environments for individual CAVs. The key issue addressed in this report is how to align smart infrastructure with emerging vehicles and mobile technologies, facilitating their adoption and deployment. Complicating this is that in the foreseeable future, the Tennessee and U.S. transportation systems will operate in a mixed-mode, where some vehicles are CAVs while others are human-driven. Addressing these challenges can help realize the mobility, safety, and environmental benefits of CAVs and attract industrial partners to Tennessee.

1.3 Organization of the Report

The report is organized into the following sections:

Chapter 2 – Methodology for national initiatives. This chapter discusses the PRISMA method and artificial Intelligence text analysis methods utilized in the literature collection and analysis (readiness plans) for this project.

Chapter 3 – Findings from National Initiatives. This chapter summarizes the findings from national initiatives and initiatives in Tennessee.

Chapter 4 – Guidance for CAV Strategic Plan in Tennessee. This chapter presents the guidance for preparing the CAV strategic plan in Tennessee.

Chapter 5 – Conclusions and recommendations. The findings are summarized along with the contributions of the reported work. A discussion of recommendations is provided.

Chapter 2 Methodology for National Initiatives

There are many agencies, regulatory entities, private sector companies, and coalitions involved in CAV research, development, and deployment. A sampling of the activities underway by various organizations shows that diverse stakeholders with different agendas are involved in the CAV space. For TDOT to navigate the space involves making strategic decisions about investing limited resources. Efforts in the CAV space can range from regulations, e.g., see Tennessee Automated Vehicles Act to strategic planning (e.g., exploring and incorporating CAV scenarios in travel demand models), to operational improvements in terms of deploying CAV technologies based on the Intelligent Transportation Systems (ITS) architecture (e.g., connected vehicle traffic signal systems, red light violation warnings, pedestrian in signalized crosswalk warnings, curve speed warnings, and work zone alerts) and infrastructure updates needed for CAVs to operate successfully in the future. Currently, the roadside units (RSUs) deployed do not provide communication with vehicles owned by the general public through onboard units (OBUs) as these devices are not widely deployed in private vehicles. Automobile manufacturers are in a position to integrate OBUs in new vehicles and seem to be leaning toward Cellular-Vehicle-to-Everything (C-V2X) technologies. In this regard, TDOT can coordinate the implementation of OBUs with in-state auto manufacturers. THEA Connected Vehicle (CV) Pilot is a good example to demonstrate how OBUs can be deployed widely. Research, development, and deployment activities include pilot projects and testbeds that involve installation of RSUs, incorporation of cybersecurity (Security Credential Management System or SCMS), and other emerging technology applications that enable communication between road users (motorists, pedestrians, bicyclists, and large trucks) and infrastructure.

To synthesize activities in the CAV space, a systematic review was completed using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method to collect statewide CAV readiness plans. Using Artificial Intelligence-based text analysis useful information was extracted from the reports and sources found. The content analysis and results of this research effort (i.e., review) were made specific to the state of Tennessee through the analysis and implications of the results for the I-24 Smart Corridor Plan and the TDOT statewide ITS Plan. The methodology that was used for this research is specified and explained below.

2.1 Review of national initiatives

The PRISMA method shown in Figure 2-1 was utilized in the literature collection (readiness plans) for this project. As the purpose of this research is to prepare the state of Tennessee for CAVs, the reports included in this review must apply to the entire state, be written in English, and be published in or after 2014. The gathered reports were determined to be more valuable for the purpose when produced and/or commissioned by a state or had titles containing terms similar to “CAV plan” or “strategic plan.” The outcomes of this research (text analysis and meta-analysis) use the collected literature as the data source, so the PRISMA method is used to gather the data. More details about this method and data collection are presented in Appendix A.

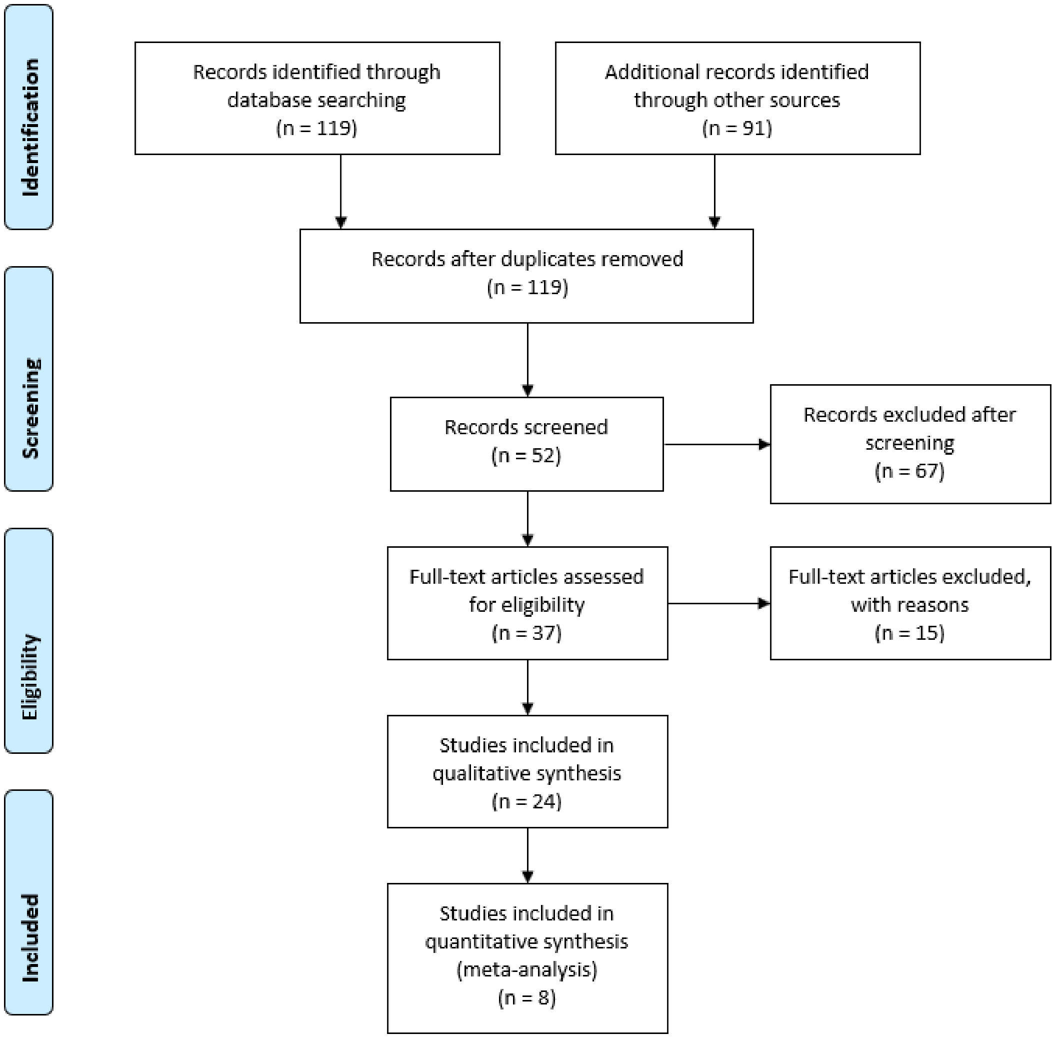

Figure 2-1 The PRISMA Flowchart

This study used Google and State DOT websites to gather relevant literature. Google Scholar was not used as the search engine for this project, as the CAV readiness plans are typically posted on the website of the state transportation department where they are publicly available and are not often published in a scholarly journal. A total of 119 sources were identified through the comprehensive search for statewide CAV readiness plans.

In Figure 2-1, the "additional records identified through other sources" came from either 1) the two compilations of CAV policies that were discovered through the original queries or 2) from a previous project. The discovered compilations of CAV policies include the Clearinghouse of CAT Policy Frameworks and Policy Statements published by the National Operations Center of Excellence and the Connected Vehicles Technology: State Overview published by the Eastern Transportation Knowledge Network. These compilations contributed an additional 61 and 21 documents, respectively, to include in the corpus. The inspiration for this examination into CAV readiness plans began before this specific project and before the implication of the PRISMA method. Therefore, the documents previously sourced on this subject were added to the corpus, which constitutes an addition of 9 documents. Thus, a total of 91 records were identified through other sources for inclusion in this research.

The sources that were identified through the comprehensive search and the records that were identified through other sources were combined. Then the duplicate search results were identified and removed. This process involved the examination of each HTML or pdf source for its title, date, the appearance of the cover page, the number of pages (when applicable), and the area affected by each reference. A total of 91 records were identified as duplicates according to the previously listed criteria were then removed from the dataset, which left a total of 119 records after the duplicates were removed.

The titles and abstracts of the remaining records were then screened. Records were removed when 1) the result was not related to transportation, 2) the result was a website without a clear and direct link to a pdf of a statewide CAV readiness plan, 3) the record did not contain a statewide CAV readiness plan, and 4) the result was labeled as a study. After screening, 67 records were excluded, and 52 records were kept.

Of the records that were kept after screening, the records were examined for eligibility. For this study, records eligible for this research must be applicable at the state level. This process results in 37 records that were eligible for the study; 15 full-text articles were excluded because they were not written at the state level.

The 37 records eligible for this study included CAV readiness reports at the state level and ITS Plans, and long-range transportation plans. The eligible reports were then narrowed down to only CAV readiness plans, therefore removing ITS plans and long-range traffic plans. This process resulted in 24 reports that represented 20 states, see Figure 2- below. Note that some states may not have a specific CAV plan, though their long-range transportation plans can include CAVs as a component. Of the collected 24 state-wide CAV readiness reports, only 8 (*1-8*) reports specified relevant ITS service packages that were similar to the Architecture References for Cooperative and Intelligent Transportation (ARC-IT) reference architecture. The data collected from the literature include the mentioned ITS service packages and the entire text of the report for the review and text analysis, respectively. The data was extracted manually for the review and automatically within the QDA software for the text analysis.

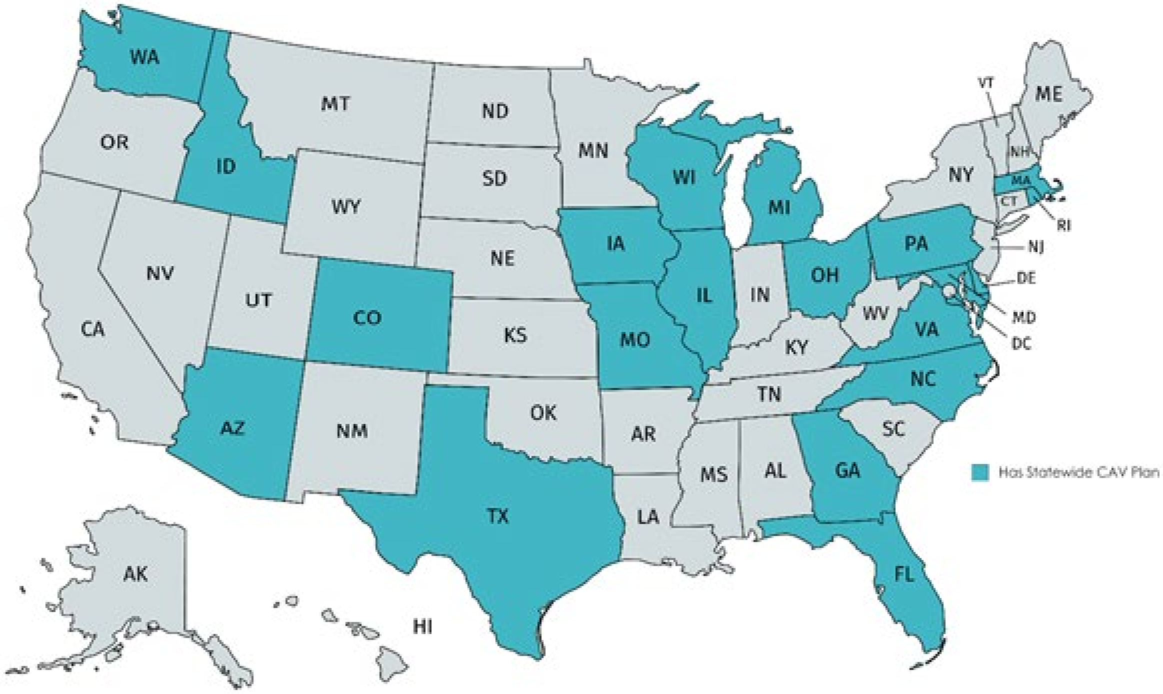

Figure 2-2 States with Specific CAV Readiness Plans, available through State DOT websites

Note: Some states may not have a specific CAV plan, though their long-range transportation plans can include CAVs as a component.

2.2 Meta-Analysis of national initiatives

The collected state-wide CAV readiness plans (*1-27*) were examined to identify the mention of ARC-IT service packages both directly and indirectly. The specific ARC-IT service packages that were recommended within each readiness plan are included as a list in Appendix B. This list contains a total count of the times that each service package was recommended, as well as a citation of each of the specific state-wide CAV readiness plans that recommended that service package. The most recommended service packages from the statewide CAV readiness plans were determined after the literature analysis was completed.

Further, the I-24 Smart Corridor Plan (*28*) and the TDOT ITS Plan published in 2019 (*8*) were evaluated similarly to the previous state-wide CAV readiness plans. Thus, the recommended ARC-IT service packages were gathered from these two Tennessee plans. As the ITS plan contains a broad spectrum of information (spanning from stakeholders to regional planning) within Tennessee, the only portion of the TDOT ITS Plan that was evaluated for this study was "Chapter 5: ITS Needs and Services." The evaluated portion of the I-24 Smart Corridor Plan was the three project phases and the list of the deployments for each phase. Then, possible opportunities in ARC-IT service packages used in Tennessee were identified through the comparison of the service packages recommended in the TDOT ITS Plan, the I-24 Smart Corridor Plan, and the collected state-wide CAV readiness plans. Recommendations for the State of Tennessee were then formed based on the identified opportunities and most recommended ARC-IT Applications from the state-wide CAV readiness applications.

2.3 Text Analysis of national initiatives

Text analysis is a powerful Artificial Intelligence tool that allows for insights into a body of literature that may not be achieved by simply reading and evaluating reference texts. Using text analysis software allows for an unbiased, systematic review of a very large body of literature, with valuable outputs such as word clouds and extracted topics in combination with statistical information about the collected corpus. Text analysis outputs include keyword frequency clouds and tables, key phrase frequency clouds and tables, and a list of detected topics. Thus, the data used in the text analysis was completed on 24 references (*1-24*) using QDA Miner 8 in combination with WordStat 5 software. The data was cleaned to provide meaningful outputs. The outputs generated included: keyword frequency table and figure, key phrase frequency table and figure, list of detected topics, and a co-occurrence map. These text analysis outputs will aid in the unbiased and thorough review of the collected literature. The findings of text analysis are presented in Appendix A.

Chapter 3 Findings from National Initiatives

A key product of this research is the review and the text analysis. The review was completed to provide plans to TDOT for their review and to determine the most frequently recommended ARC-IT service packages within the collected CAV readiness plans. The text analysis was performed to complement the review. The text analysis includes a keyword and key phrase cloud, each accompanied by a table that contains the statistical information used to create the clouds.

An effort was made to uncover reports with different naming conventions and this search resulted in the inclusion of 4 studies based on the terms automated and connected vehicles and connected and autonomous technology.

The review found that the most recommended ARC-IT service packages were emergency vehicle preemption, transit signal priority, broadcast traveler information, and queue warning. The key outcomes from the text analysis are the importance of data, safety, and traffic operations in the collected CAV readiness plans. Many of the gathered reports use previously published CAV readiness plans in the formulation of the new report, which could exhibit bias due to the recommendation of the same ARC-IT service packages and ITS technologies. To avoid this bias, this report was generated through the review of previously published CAV readiness reports in addition to an independent review of the available ARC-IT technologies. This report also reviews other documents containing ARC-IT service packages and ITS technologies recommended by the State of Tennessee to ensure that the State did not miss key opportunities in recommendations compared to other states. Another risk of bias across the results is the exclusion of CAV readiness plans which are not available in a standalone report or do not have a specific and informative title that does not align with the study purpose (such as reports which do not use CAV, automated vehicle (AV), or CV terminology). An effort was made to uncover reports with different naming conventions and this search resulted in the inclusion of 4 studies (*9; 15; 26; 27*) based on the terms ACV (automated and connected vehicles) and CAT (connected and autonomous technology).

Given the rapidly changing CAV space, the research team has identified the following resources to complement the readiness plans and to review the most updated information about CAVs.

US Department of Transportation (USDOT) Connected Vehicle Research Program

More information about the US DOT Connected Vehicle Research Program is available at https://www.its.dot.gov/pilots/index.htm.

NCHRP Connected and Automated Vehicle Research Program

More information about the latest NCHRP research on CAV is available at https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3824.

AASHTO Committee on Transportation System Operations

https://systemoperations.transportation.org/subcommittee-on-technology/working-group-on-cooperative-automated-transportation-cat/

3.1 Initiatives in Tennessee

3.1.1 I-24 Smart Corridor testbed

TDOT is preparing to implement emerging technologies into Tennessee's road networks. The I-24 Smart Corridor is an example of improving capacity and operations to manage congestion and improve safety. Due to physical, environmental, and financial constraints, further widening is not feasible, nor will it permanently reduce congestion on the I-24 Corridor. Accordingly, TDOT is forming partnerships with local authorities to implement the I-24 Smart Corridor initiative. This initiative involves various deployment objectives such as increasing travel time reliability and reducing crashes on the I-24 Smart Corridor. The deployed I-24 smart corridor technologies and improvements include fiber-optic communication, signal controllers, about 150 RSUs, with appropriate security, active lane control and variable speed limits. As these strategies are being deployed, it is essential for TDOT to evaluate and better understand the impacts of these improvements to inform future transportation projects. A key research need is to estimate and quantify the impacts of the deployed technologies and improvements on the I-24 Smart Corridor. The multi-faceted elements of evaluation can include transportation network performance, traveler behavior, vehicle trajectories, and institutional issues. The strategy in Phase 1 entails the use of emergency pull-offs, ramp extensions, and connected vehicle infrastructure; and Phase 2 will implement dynamic lane use control, variable speed limits, and queue warning. Ramp metering will also be installed in Phase 3.

TDOT is providing the DSRC V2X communication platform for existing and future applications that include Transit Signal Priority, Emergency Vehicle Preemption, and Traveler Information Message (TIM). TDOT has identified two CV mobility applications, Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG), which provides input to responder vehicle routing, staging and secondary dispatch decisions, and Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE), which warns on-scene workers of vehicles with trajectories or speeds that pose a high risk to their safety. It also warns drivers passing an incident zone if they need to slow down, stop, or change lanes. Before these developments, the TDOT I-24 Smart Corridor Plan (*28*) was evaluated to determine if ARC-IT service packages were included. The plan further contained direct references to three unique ARC-IT service packages: TM03 – Traffic Signal Control, TM05 – Traffic Metering, and TM09 – Integrated Decision Support and Demand Management. Additionally, the plan included several types of connected vehicle roadside equipment, overhead and roadside dynamic message signs (DMS), and CCTVs. The service package "Traffic Signal Control" allows for coordinated signalization along the corridor, as well as dynamically adjustable control strategies to allow for optimum function in real-time traffic conditions. The service package "Traffic Metering" adjusts the traffic signal interval to ensure even platoon flow through intersections. The service package "Integrated Decision Support and Demand Management" forms recommendations for operational strategies within densely traveled areas such as a corridor or downtown area. These operational strategies are formed based on network performance and environmental conditions, and some of the recommendations may include lane restrictions, parking, transit, or toll strategies. Each of these service packages, which fall within the Traffic Management area of the ARC-IT reference architecture, provide a foundation for future CAV-related ITS expansion in the corridor.

3.1.2 UT Chattanooga-MLK Smart City Corridor

The MLK Smart City Corridor is a testbed in Chattanooga, Tennessee. It is a 1.2-mile, real-world sandbox—designed to facilitate early-stage research and development. Testing and data collection rely on real-world events, providing naturalistic environments. Gathering data from the real world successfully integrates the nuance and complexity of urban living into research. The testbed is specifically designed for collaboration with data made easily accessible to partners and a platform to handle more sensors. Researchers can use this testbed remotely. More broadly, the smart city concept and this testbed aim to address these challenges by exploiting large-scale deployments of Internet of Things and communication technologies. These technologies generate data that provide quantifiable insights into the state of the infrastructure within a city. Using these insights, cities can more effectively allocate resources, manage services, and enhance the lives of their citizens. The data generated by the testbed supports high rates of data ingestion in large volumes. Additionally, low latency response times are supported which is a critical requirement for time-sensitive safety-critical applications. This smart city testbed in Chattanooga provides a real-world testing environment for applications in areas such as intelligent transportation, pedestrian safety, and automated vehicles; 10 roadside units are installed in the testbed, besides other technologies. The testbed acts as an open platform for researchers and developers to test new sensors, algorithms and more in a live urban environment, allowing them to test before deploying a product or application. In addition to the physical testbed and its capabilities, data integration system and applications responsible for collecting, analyzing, and storing the data generated by the testbed are available. Lastly, the testbed is based on an open data platform where researchers can access datasets generated by the testbed. The testbed is also testing dual-mode DSRC V2X and C-V2X roadside units. Besides the MLK corridor, Chattanooga also plans to install fiber networks, new signal controllers, and roadside units in other locations.

https://www.utc.edu/research/center-for-urban-informatics-and-progress/testbed

- Harris, J. Stovall, and M. Sartipi, "MLK Smart Corridor: An Urban Testbed for Smart City Applications," *2019 IEEE International Conference on Big Data (Big Data)*, 2019, pp. 3506-3511, DOI: 10.1109/BigData47090.2019.9006382.

3.1.3 Other Deployments in Tennessee

Besides the I-24 Smart Corridor and MLK Smart Corridor, other deployments in Tennessee that have either planned or installed RSUs include the following:

- The city of Knoxville has plans to install fiber, new signal controllers, and about 50 RSUs.
- The city of Memphis has plans for fiber, new signal controllers, and installing about 10 RSUs.
- The city of Sevierville has plans for fiber, new signal controllers, and installing about 25 RSUs.
- Shallowford Road in Chattanooga is a corridor being used for testing new technologies for signal control and connectivity. Additionally, Oak Ridge National Laboratory is conducting boundary condition testing in collaboration with the city of Chattanooga in this corridor. A key goal of the project is to enhance mobility and reduce energy consumption.

Several cities across the 4 TDOT regions have planned deployment projects using Congestion Management and Air Quality (CMAQ) funds. A list of either planned or installed RSUs in Tennessee from a few years ago is presented in TABLE 3-1.

TABLE 3-1 PLANNED OR INSTALLED RSUS IN TENNESSEE (SOURCE: TDOT STAFF)

Year	*Region*	*Project*	*Contractee's Organization*	*# Intersections*	*# RSUs*	*Project Phase*
2017	1	Oak Ridge Signal Timing Optimization Program Phase II	Oak Ridge	14	14	Design
2017	1	SR-169 Middlebrook ITS – ATMS	Knoxville	24	24	Design
2017	3	Hendersonville Signal Timing Optimization Program	Hendersonville	31	31	Design
2017	4	Memphis New Traffic Signals	Memphis	2	2	Design
2017	3	Mt. Juliet Intelligent Transportation System (ITS) and Signal Improvements	Mount Juliet	13	13	Design
2018	1	Farragut Advanced Traffic Management System: Phase 2	Farragut	26	26	Design
2018	1	Oak Ridge Signal Timing Optimization Program: Phase III	Oak Ridge	11	11	Design
2018	1	Lenoir City Intelligent Transportation System: Phase II	Lenoir City	22	22	Design
2018	1	Traffic Signal Improvements for the University of Tennessee Area	Knoxville	39	38	Planning
2018	1	Knox County Advanced Traffic Management System – Phase II	Knox County	11	11	Design
2018	1	Chapman Highway RSU and Enhanced Detection Traffic Signal Improvements	Knoxville	17	17	Design
2018	1	Kingston Pike RSU and Enhanced Detection Traffic Signal Improvements	Knoxville	44	43	Design
2018	1	Broadway RSU and Enhanced Detection Traffic Signal Improvements	Knoxville	30	29	Design
2019	2	Chattanooga Traffic Signals Communications Upgrade, Phase II	Chattanooga	8	8	Planning
2019	3	The West End Avenue-Broadway Communications Upgrade	Metro Government of Nashville	29	29	Planning
2019	3	Goodlettsville Traffic Flow Improvements and Traffic Signal Upgrades - Phase III	Goodlettsville	15	15	Design
2019	3	LaVergne Advanced Traffic Management System	LaVergne	15	15	Planning
2019	4	The Covington Pike Signal System	Memphis	10	10	Design

Overall, substantial CAV deployment activity is ongoing and anticipated throughout the state of Tennessee.

3.1.4 Tennessee Industry

TDOT staff is working with industry partners through the TennSMART consortium and directly with automakers that have a presence in Tennessee, including Nissan and Volkswagen.

Additionally, freight/logistics with CAV activities in Tennessee include FedEx and Amazon. Partnerships and coordination in the CV space with the automobile industry manufacturers can accelerate the deployment of vehicles with CV technology that can communicate with RSUs. Additionally, Original Equipment Manufacturer (OEMs) are also present in Tennessee. Especially, the presence of DENSO is fortuitous as they are the leading supplier of V2X equipment, i.e., OBUs. DENSO is involved with the Tampa CV pilot to develop a common set of CV applications for communication between vehicles and surrounding infrastructure. DENSO provides a collaborative resource, e.g., they are better positioned to provide information about the future market penetration of OBUs.

3.1.5 Tennessee Research Activities

A substantial amount of research is carried out by Tennessee universities, some of which are highlighted below.

The University of Tennessee, Knoxville

The Center for Transportation Research (CTR) at the University of Tennessee, Knoxville (UTK) is a nationally and internationally recognized research entity since 1972. The group has been the research venue for some of the brightest and most innovative faculty, researchers, and graduate students in the nation's transportation arena. CTR has over $10 million in sponsored research under contract, providing increased opportunities for students and researchers. A substantial amount of research conducted at CTR relates to CAVs and electrification of vehicles. CTR engages in transportation research, education, and technology transfer activities, which are vital to rebuilding the nation's aging transportation infrastructure and encouraging emerging technology solutions to transportation problems. The initiatives underway present new technical challenges, involve specialized personnel skills, and require innovative partnerships and management approaches. CTR collaborates with the TDOT Research Office, and several research universities, e.g., the University of Memphis in the state to provide resources that address research and training needs in Tennessee, the Southeast region, and the nation.

The Boyd Center for Business and Economic Research at UTK has worked on employment implications of AVs in Tennessee. The demand for many support services can ultimately be eliminated or significantly reduced, and with fewer traffic crashes, the need for repair may be eliminated. Higher-level automation can dramatically eliminate motor vehicle operators and other on-the-job drivers (e.g., taxi drivers, rideshare drivers, and truck drivers) as AVs replace them. And AVs can also automate some tasks and thereby make the workers (e.g., delivery workers, ambulance drivers, and plumbers) more productive and lower the cost of providing the services. The report also points out that Tennessee could become an assembler of AVs. For more information, please see:

https://ctr.utk.edu/history/

https://haslam.utk.edu/wp-content/uploads/2021/08/TN-AV-012120.pdf

University of Memphis

The Center for Transportation Innovation, Education, and Research or C-TIER has actively examined the adoption of Connected and Autonomous Vehicles in Tennessee. A recent project, sponsored by TDOT, models and predicts CAV market penetration in Tennessee over time based on the residential social networks. More information about C-TIER is available at:

https://www.memphis.edu/ctier/research/index.php

Vanderbilt University
The Vanderbilt Center for Transportation and Operational Resiliency (VECTOR) has worked on cutting-edge transportation issues, e.g., using Artificial Intelligence techniques such as deep reinforcement learning and self-driving cars to improve traffic flow and reduce energy consumption. The center is also involved in I-24 MOTION, which is an interstate camera tracking system for high-resolution vehicle trajectory data collection and analysis. More information about VECTOR is available at:

https://www.vanderbilt.edu/vector/

3.1.6 TDOT Statewide ITS Plan (2019)

The most recent TDOT statewide ITS Plan (*8*) includes several ARC-IT service packages, and these service packages are included in TABLE 3-. This table contains sections of the TDOT ITS plan, and then lists the ARC-IT service packages (either directly or indirectly). There are 34 individual suggested ARC-IT service packages included in the entire TDOT ITS report: Commercial Vehicle Operations, Data Management, Maintenance and Construction, Parking Management, Public Transportation, Support, Traveler information, Traffic Management, Vehicle Safety, and Weather.

TABLE 3-2 ARC-IT SERVICE PACKAGE EXTRACTION FROM TDOT ITS PLAN (8)

TDOT ITS PLAN SECTION	*Related ARC-IT Service Packages*
5.1 ARCHIVED DATA MANAGEMENT	DM01, DM02
5.2 CENTER-TO-CENTER COMMUNICATIONS	SU07
5.3 INCIDENT MANAGEMENT	
5.3.1 Vehicle Detection	TM02
5.3.2 Oversize Detection	VS11
5.3.3 Wrong Way Detection	VS03
5.3.4 Work Zone ITS	MC06, MC07
5.3.5 Comprehensive Detour Plan	TI03, TM06
5.3.6 Automated Incident Detection	TM08
5.3.7 Runaway Ramp Detection	
5.4 COMPUTER AIDED DISPATCH INTEGRATION	PS01
5.5 PARKING MANAGEMENT SYSTEM	PM01, PM02
5.6 VIDEO DISTRIBUTION SYSTEM	
5.7 TRAVELER INFORMATION	
5.7.1 Highway Advisory Radio	TI01, TM06
5.7.2 Fog Warning System	WX03
5.7.3 social media	TM06
5.7.4 Road Weather Information System	WX01, WX02, WX03

Note: The acronyms used in the table match with the definitions of the acronyms provided by the ARC-IT National Reference Architecture.

Within the TDOT ITS Plan, there are 2 ARC-IT service packages specified in the CAV section. These two service packages are both included in the vehicle safety service package area. The specific ARC-IT service packages are VS02 – V2V Basic Safety and VS04 – V2V Special Vehicle Alert. The service package V2V Basic Safety enables the exchange of basic safety messages between connected vehicles which contain information that allows for the following safety applications: emergency electronic brake lights, forward crash warning, blind spot warning/lane change warning, intersection movement assist, left turn assist, and control loss warning. The service package V2V Special Vehicle Alert allows for driver alerts that share information regarding the location and movement of special vehicles such as public safety vehicles responding to an incident, oversized vehicles, or slow-moving vehicles. The service packages recommended for the CAV-specific ARC-IT service packages, as well as the other suggested service packages in the TDOT ITS Plan encourage CAV usage and operability along the specific roadways.

3.1.7 Identified Opportunities in Tennessee

To make recommendations for the state of Tennessee, the opportunities of ARC-IT service packages were identified. To identify opportunities, the most frequently recommended statewide ARC-IT service packages from the collected statewide CAV readiness plans were compared to the I-24 Smart Corridor Plan (*28*) and the 2019 TDOT ITS Plan (*8*). This process is explained visually in Figure .

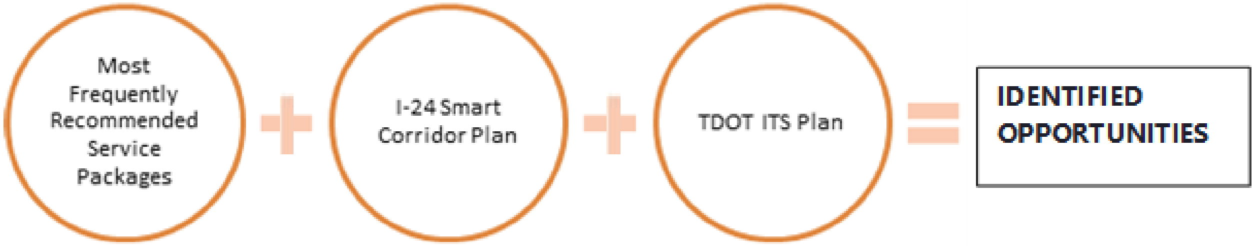

Figure 3-1 Identified opportunities Methodology

The below ARC-IT service packages have been identified as opportunities in the state of Tennessee, and therefore areas for meaningful improvement within the state. These service packages include areas of public safety, traveler information, and vehicle safety.

The most frequently recommended service packages that provide further opportunities based on TDOT documents and wider deployment are PS03 - Emergency Vehicle Preemption, TI02 – Personalized Traveler Information, VS07 – Road Weather Motorist Alert and Warning, VS08 – Queue Warning (in-vehicle), and VS12 – Pedestrian and Cyclist.

- The service package "Emergency Vehicle Preemption" provides signal preemption to minimize travel delays for priority first responder vehicles.
- The service package "Personalized Traveler Information" uses a traveler's request via smartphone, tablet, computer, or in-vehicle technology to provide a report with tailored information including traffic conditions, roadway maintenance, and construction, transit services, ride share/ride match, parking management, detours, and pricing information.

- The service package “Road Weather Motorist Alert and Warning” develops warnings for motorists by gathering roadway and weather conditions from connected vehicles.
- The service package “Queue Warning (in-vehicle)” uses connected vehicle communication technologies to alert upstream drivers of queue information to minimize the need for crash avoidance behaviors. This package specifically aids in the detection of a queue and the dissemination of queue information.
- The non-motorized travelers are represented by the service package “Pedestrian and Cyclist”, which uses appropriate sensors, detectors, and real-time Signal Phase and Timing (SPaT) information to provide warnings for these users along roadways or paths that cross roadways. This service package also can be used to provide specific accommodation to persons with disabilities via a mobile device message to the traffic controller.

Each of the service packages that were identified as opportunities within the state of Tennessee provides multi-faceted assistance to roadway users. Specifically, the potential safety improvements related to the public and vehicle safety service packages could ensure an increase in the safety of Tennessee roadways in the face of expansion related to CAVs.

As these service packages are recommended in many other statewide CAV readiness plans and are only lightly covered in the TDOT statewide ITS Plan and the I-24 Smart Corridor Plan, it becomes apparent that these packages should be considered for application within the state of Tennessee. By considering these opportunities, Tennessee can ensure that it maintains its position as a state that is ready for the deployment of CAVs.

Chapter 4 Guidance for CAV Strategic Plan in Tennessee

The vision for CAVs in Tennessee is to harness their mobility, safety, and environmental benefits to the fullest through investments in smart infrastructure. Building on a foundation of leadership, the state is poised to initiate the next phase of growth in CAV testing and deployment of products and services, by investing in innovations that will transform the transportation industry. These investments in infrastructure will synergize with investments in manufacturing and a skilled workforce that positions Tennessee as a leader in the automotive industry. The investments will attract industry and leaders in government and academia. To reiterate, TDOT's embrace of smart infrastructure investments aims to 1) enhance mobility (through congestion management and improving transportation system reliability), 2) enhance safety (reduce crashes, fatalities, and injuries on Tennessee roadways), 3) efficiently use of existing infrastructure (reducing the need for adding conventional infrastructure), and 4) reduce fossil fuel consumption and associated emissions.

The deployment of CAV technology and applications will occur over a couple of decades, as the technology is absorbed into the transportation system, similar to the mainstreaming of other intelligent transportation system technologies starting in the 1990s. This document anticipates CAV strategies and actions that can enhance the readiness for CAV technologies and associated changes as higher levels of automation and connectivity diffuse through the transportation system. Unlocking CAV's potential and fostering technological advancement requires a visionary research and development framework: one that aligns smart infrastructure with emerging vehicles and mobile technologies, facilitating their adoption and deployment in environments where CAVs share roadways with non-networked vehicles. Unlike traditional transportation technologies, the promise of connectivity and automation comes with the peril of increased fragility and complexity. Emerging technologies and lessons learned from other states are brought to bear on the issues to maintain safety and high performance when a multiplicity of connected and automated vehicles dynamically interact or in the presence of uncertain or changing environments for individual CAVs. The key issue addressed in this report is how to align smart infrastructure with emerging vehicles and mobile technologies, facilitating their adoption and deployment. Complicating this is that in the foreseeable future, the Tennessee and U.S. transportation systems will operate in a mixed-mode, where some vehicles are CAVs while others are human-driven. Addressing these challenges can help realize the mobility, safety, and environmental benefits of CAVs and attract industrial partners to Tennessee.

4.1 US DOT Guiding Principles

In order to have a consistent approach to shape the policy of automated vehicles, US DOT has introduced ten principles for automated vehicles (*29*). The strategic readiness plan of each state DOT needs to be aligned with these principles to have a clear and uniform policy across the country. These ten principles are shown in Figure (https://www.transportation.gov/sites/dot.gov/files/2021-01/USDOT_AVCP.pdf).

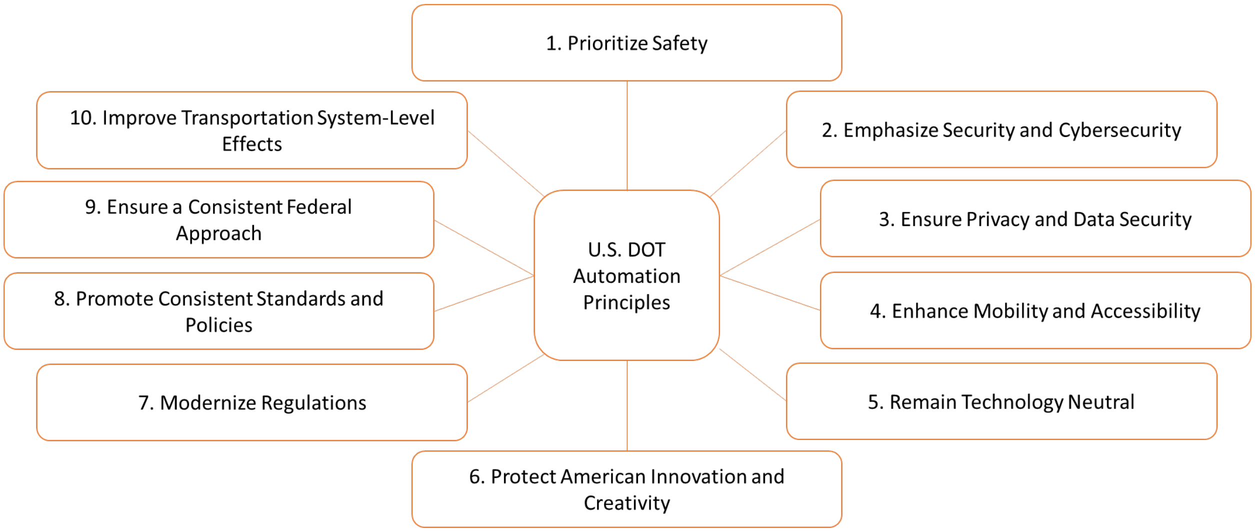

Figure 4-1 US DOT principles for automated vehicles

4.2 Considerations for CAV Applications in Tennessee

Service packages related to ITS architecture ensure communication between connected vehicles and infrastructure with substantial mobility and safety impacts. A systematic review of readiness plans determined the most frequently adopted ARC-IT service applications. They represent a wide variety of services and include emergency vehicle preemption, transit signal priority, broadcast traveler information, queue warning, work zone management, connected vehicle traffic signal system, personalized traveler information, road weather motorist alert and warning, and pedestrian and cyclist safety. Accordingly, and depending on locations where they will be most effective, consideration can be given to emergency vehicle preemption, broadcast traveler information, queue warning, work zone management, connected vehicle traffic signal system, personalized traveler information, and road weather motorist and warning (ARC-IT packages PS03, TI01, VS08, MC06, TM04, TI02, and VS07, respectively). Additionally, the electric charging stations management (ST05) service package can be considered to cover electrification technologies. These service packages were most frequently recommended within the collected state-wide CAV readiness plans, and some were already identified for application in Tennessee (*8*). Specifically, "TI01 – Broadcast Traveler Information", "MC06 – Work Zone Management," and "TM04 – Connected Vehicle Traffic Signal System," were most frequently recommended by other states, and the ones already recommended by studies in Tennessee include TM21 - Speed Harmonization, VS02 – V2V Basic Safety, VS04 - V2V Special Vehicle Alert (especially for emergency response vehicles). To illustrate the benefits of these services, "Speed Harmonization," can be considered. The package integrates traffic conditions and weather data to form speed recommendations, which can be particularly relevant to smart corridor projects, e.g., the I-24 project. The use of speed harmonization encourages the maintenance of flow, which can reduce incidents related to traffic congestion, bottlenecks, and other incidents. To address safety, packages can include queue warning, road weather motorist alert and warning, curve speed warning, red-light running violation, and pedestrian in signalized crosswalk warning.

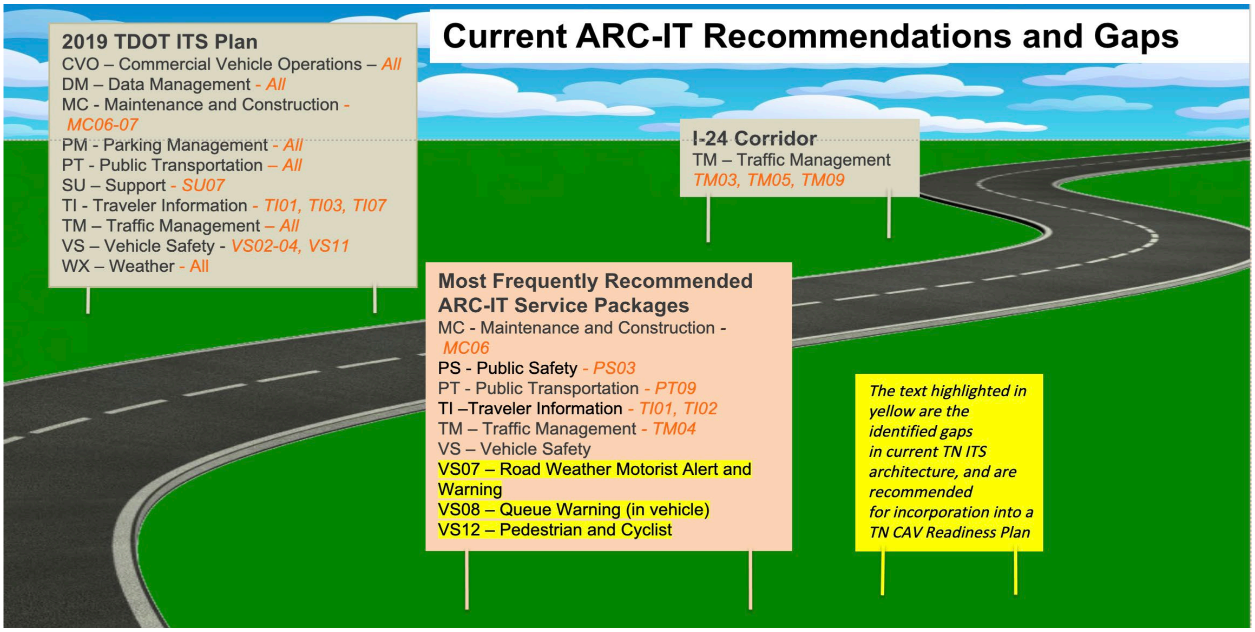

Figure 4-2 Intelligent Transportation Systems architecture-based opportunities

4.3 Surveys of Stakeholders

The research team has designed and surveyed some of the stakeholders (TennSMART members) for their readiness to adopt emerging technologies as part of this project. Conducting interviews and surveys of stakeholders, including planning and local agencies and especially TDOT Division Directors, can be very beneficial to enhancing readiness for connected and automated vehicles and more generally for intelligent mobility strategies. TDOT Division Directors perform diverse functions that include planning, design, construction, operations, and maintenance. A focused and customized survey of TDOT Division Directors' can provide a baseline of practices that can enhance the diffusion of emerging technologies. The generated information can be harnessed to provide concrete action items for the next steps in terms of diverse functions performed by TDOT Divisions. These functions are multimodal and include roadways, public transit, waterways, railroads, and cycling and walking. TDOT Division Directors can take many steps to integrate and implement specific strategies that enhance emerging technology deployment. The research team strongly encourages TDOT staff to design, implement and analyze readiness surveys and interviews for diverse stakeholders.

4.4 Tennessee CAV Readiness Plan Focus Areas

It is necessary for TDOT to have a strategic plan to clear the roadmap for the safe deployment of CAVs into Tennessee transportation networks. The purpose of this study is to provide baseline information pertaining to strategic planning for CAVs in Tennessee. This information may be used to assist TDOT to develop/improve a strategic plan to accommodate the deployment of CAVs and for related investment in physical and digital/tech infrastructure, electrical vehicle infrastructure, policy/regulation, public acceptance and education, partnership of stakeholders, and workforce development. To that end, this section focuses on strategic readiness and deployment plans in different US states. The research team considers 8 focus areas to reflect TDOT CAV functions.

CAV strategies and recommendations can be considered under the umbrella of these focus areas as shown in Figure 4-3.

- *Research and Test CAV Technologies*
- *Physical Infrastructure*
- *Digital/Tech infrastructure*
- *EV infrastructure*
- *User Education and User Acceptance*
- *Policy and Regulations*
- *Partnership of Stakeholders*
- *Workforce Development*

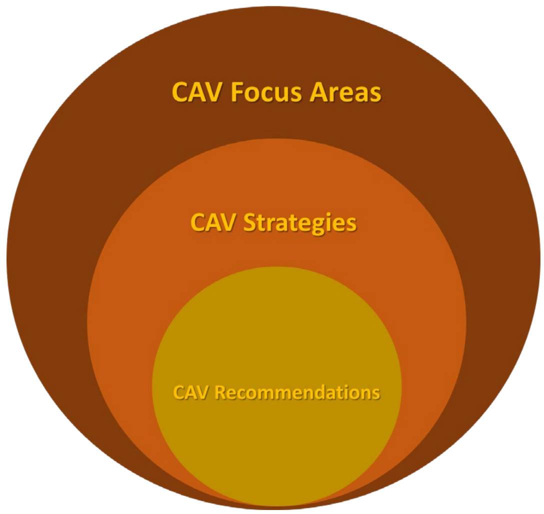

Figure 4-3 CAV focus areas, strategies, and recommendations hierarchy

4.5 Statewide CAV Readiness Plan Strategies and Recommendations

Many DOTs have explored CAV strategies and recommendations, which were collected from their CAV readiness plans. The collected strategies from the pioneer states are categorized under the Tennessee CAV focus areas and shown below. TABLE 4-1 presents a summary and synthesis of the statewide CAV readiness plan strategies and recommendations provided in those plans.

Research and Test CAV Technologies Strategies:

- Promote Testing of CAV Technologies
- Use CAV Data to Streamline DOT Operations
- Encourage Third-Party Research and Development
- Lead National Research and Innovation
- CV Pilot Activities
- Promote Pedestrian, Bicyclist, and Road User Safety
- Research CAV Technologies to Support Rail Crossings and Freight Network Safety

Physical Infrastructure Strategies:

- Assess CV Infrastructure Needs
- Assess and Prepare Infrastructure for CAV

- Develop and Implement Enhanced Pavement Marking and Signage Program

Digital/Tech infrastructure Strategies:

- Develop IT Network Management and Security Policies for CAV
- Improve Work Zone Safety by Leveraging CAV Technologies and Data
- Intelligent Transportation Systems Deployment

EV infrastructure Strategies:

- Develop and Implement Electric Vehicle (EV) Strategy

User Education and User **Acceptance Strategies:**

- Support Small and Disadvantaged Business Capacity Building
- Promote Internal Awareness of CAV
- Public Engagement and Education

Policy and Regulations Strategies:

- Update State Laws and Administrative Rules
- Update Internal DOT Policies
- Develop a Transit CAV Program
- Review Planning Measures, Assumptions and Methods
- Incorporate CAV Considerations into DOT Plans
- Multimodal

Partnership of Stakeholders Strategies:

- Facilitate Statewide CAV Stakeholder Collaboration
- Industry Outreach

Workforce Development Strategies:

- Evaluate and Plan for CAV-Related Operations and Maintenance
- Evaluate Organizational Capabilities to Support CAV
- Staff Recruitment, Training and Retention

Table 4-1 Statewide CAV Readiness Plan Strategies and Recommendations

Focus Area	Strategy	Recommendation	Lesson learned from:
Research and Test CAV Technologies	*Promote Testing of CAV Technologies*	• DOTs can consider new legislation to establish standards for safely testing CVs/AVs on public roads and to establish testbeds to be used under different conditions.	MassDOT, IDDOT
	Use CAV Data to Streamline DOT Operations	• Identify Data Needs and Data Sources to Support DOT Operations • Develop a Framework for a CAV Data Management System • Invest in data analytics and cybersecurity for the large stream of data that will be generated by CAVs	MnDOT MnDOT, IDDOT MassDOT
	Encourage Third-Party Research and Development	• Encourage Third-Party Testing to Validate Deployed CV Systems • Designate and Market On-Road CAV Test Corridors	MnDOT MnDOT
	Lead National Research and Innovation	• Research CAV Impacts • Seek Research Panel Assignments Aligned with DOT Interests • Further Collaborative Research with Academic Institutions • Research Data Use and Models • Monitor Research on CAV Dedicated Lanes • Provide dedicated lanes for CAVs once market penetration is high enough, especially on freeways serving longer trips.	MnDOT, IDDOT MnDOT MnDOT MnDOT MnDOT MassDOT
	CV Pilot Activities	• Strategic Investments in CV Test Corridors • Conduct Pilot of CV Technologies for Rural Applications • Pilot Alternative Communications Technologies and Business Models • Conduct Pilots of CAV Technologies on DOT Fleet Vehicles	MnDOT MnDOT MnDOT MnDOT
	Promote Pedestrian, Bicyclist, and Road User Safety	• Conduct Pedestrian and Bicyclist Stakeholder Outreach	MnDOT, IDDOT
	Research CAV Technologies to Support Rail Crossings and Freight Network Safety	• Research and Pilot CAV Freight Technologies • Monitor Research on CAV Technologies to Support Safety at Rail Grade Crossings	MnDOT MnDOT

CONTINUED TABLE 4-1 STATEWIDE CAV READINESS PLAN STRATEGIES AND RECOMMENDATIONS

Focus Area	Strategy	Recommendation	Lesson learned from:
Physical Infrastructure Strategies:	*Assess CV Infrastructure Needs*	• Assess Communications Infrastructure and Public-Private Partnership Feasibility Study to Support CV Technologies • Build Traffic Signal Infrastructure for CV Readiness • Implement signal priority strategies to improve mobility and safety and accelerate the market penetration of CAVs. • Invest in transportation infrastructure to develop strategies to regularly inspect for future investments in CAV infrastructure • Design the digital infrastructure required for the deployment of CVs	MnDOT MnDOT MassDOT MassDOT IDDOT
	Assess and Prepare Infrastructure for CAV	• Research Scan of Platooning Impact on Pavements • Update Design Standards to Accommodate Platooning • Develop Truck Platooning Network Plan • Review and Revise Parking Codes • Consider vehicle parking implications for highly automated vehicles deployed in urban areas • Equip parking systems with I2V capabilities • Expand efforts in preventing maintenance, including pothole repairs, edge wear, and rutting • Use contrast markings on light-colored pavements in minor arterials and collectors	MnDOT MnDOT MnDOT IDDOT RIDOT USDOT USDOT USDOT
	Develop and Implement Enhanced Pavement Marking and Signage Program	• Pilot Pavement Marking to Support Automated Vehicles and Human Drivers • Support Industry in Advancing Signing to Support CAV • Improving pavement marking characteristics in the areas of uniformity, design, and maintenance for automated vehicles	MnDOT MnDOT USDOT
Digital/Tech Infrastructure	*Develop IT Network Management and Security Policies for CAV*	• Develop CAV Network Integration Guidance and Security Policy • Pilot a CAV Network Management System	MnDOT MnDOT
	Improve Work Zone Safety by Leveraging CAV Technologies and Data	• Pilot Work Zone Data Collection Project and Data Sharing System	MnDOT, PennDOT
	Intelligent Transportation Systems Deployment	• Implement greater standardization of active traffic management and dynamic management signage (e.g., variable speed limits, lane controls, work-zone management) • Equip signal-controlled intersections with I2V hardware, including SPaT-capable technology and hardware capable of communicating the presence of vulnerable road users	USDOT USDOT
EV Infrastructure	*Develop and Implement Electric Vehicle (EV) Strategy*	• Develop EV Infrastructure Deployment Strategy at State Facilities • Implement EV Infrastructure Deployment Strategy at State Facilities	MnDOT MnDOT

CONTINUED TABLE 4-1 STATEWIDE CAV READINESS PLAN STRATEGIES AND RECOMMENDATIONS

Focus Area	Strategy	Recommendation	Lesson learned from:
User Education and User Acceptance	*Support Small and Disadvantaged Business Capacity Building*	• Conduct CAV Workshop for Small Business Community • Develop Small Business and Workforce CAV Mentorship Program • Prepare the workforce so new state DOT employees will be able to understand the opportunities and challenges brought by CAV technologies	MnDOT MnDOT MassDOT
	Promote Internal Awareness of CAV	• Create a CAV Email Newsletter • Host CAV Brown Bag Discussions and Create CAV Ambassadors • Develop Institutional Knowledge and Understanding Among Policymakers	MnDOT MnDOT RIDOT
	Public Engagement and Education	• Develop CAV Public Engagement and Communications Plan • Rebrand the CAV-X Website • Conduct Public Demonstrations throughout Tennessee • Create and Implement a Survey to Gauge Public Opinion	MnDOT, RIDOT, IDDOT MnDOT MnDOT MnDOT
Policy and Regulations Strategies	*Update State Laws and Administrative Rules*	• Authorize the Safe Testing of Automated Vehicles in State Law • Assess State Utility Laws for CV Infrastructure Opportunities • Modify driver training and licensing requirements • Develop liability requirements, limits, and responsibilities for AV operations.	MnDOT, RIDOT, IDDOT MnDOT MassDOT IDDOT
	Update Internal DOT Policies	• Review Agency Utility Accommodation Policy to Address CAV Partnerships • Assess whether Automated Delivery Vehicles are Permissible under State Law • Develop Policy on CAV Priority • Update Agency Data Stewardship and Records Retention Policies to Address CAV Data • Support Local Government Shared Mobility Policy • Encourage the use of shared AVs (SAVs) by providing operating guidelines to ensure a safe and efficient SAV system	MnDOT MnDOT MnDOT, PennDOT MnDOT MnDOT MassDOT
	Develop a Transit CAV Program	• Develop a Transit CAV Program • Update Transit Investment Plan	MnDOT, IDDOT, RIDOT
	Review Planning Measures, Assumptions and Methods	• Review Performance Measures to Address CAV • Evaluate Ways to Forecast CAV Trends	MnDOT MnDOT
	Multimodal	• Adopt mode separation policies (e.g., Complete Streets) • Anticipate growing curbside demand in site design, street design, and access-management practices • Conduct curb-space management and safety audits • Retrofit BRT lanes with AV technologies to provide opportunities for automated transit-system testing	USDOT USDOT USDOT USDOT
	Incorporate CAV Considerations into DOT Plans	• Review Planning Strategies to Account for CAV • Review and Update DOT Plans to Account for CAV	MnDOT MnDOT

CONTINUED TABLE 4-1 STATEWIDE CAV READINESS PLAN STRATEGIES AND RECOMMENDATIONS

Focus Area	Strategy	Recommendation	Lesson learned from:
Partnership of Stakeholders	*Facilitate Statewide CAV Stakeholder Collaboration*	• Develop Statewide CAV Workshop • Prepare for Grant Opportunities and Partnerships • Promote Industry Partnerships • Participating in the USDOT, FHWA, ITSA, NHTSA and other national and local initiatives	MnDOT MnDOT MnDOT, PennDOT PennDOT
	Industry Outreach	• Conduct Regular Industry Outreach	MnDOT
Workforce Development	*Evaluate and Plan for CAV-Related Operations and Maintenance*	• Develop Strategy to Maintain CAV Infrastructure	MnDOT
	Evaluate Organizational Capabilities to Support CAV	• Develop Employee Engagement Plan • Evaluate CAV Staffing Abilities • Develop Plan to Address Skill Gaps	MnDOT MnDOT MnDOT
	Staff Recruitment, Training and Retention	• Review and Update Civil Service Requirements • Develop a CAV Talent Pipeline • Develop internal workforce skills by participating in CAV related training and seminars.	MnDOT PennDOT

4.6 Integrating CAVs in TDOT: Long-term planning

It is critically important to integrate CAVs into the fabric of all relevant TDOT Divisions, as connectivity and automation are expected to impact every aspect of TDOT. For example, the future changes that CAV technologies will bring will alter how TDOT plans for the state's transportation system and the tools used for planning. For example, travel demand models used for strategic planning must account for changes in roadway, digital and electric vehicle infrastructure. TDOT can consider how planning tools may be updated to better anticipate future changes in mobility and safety, explore how to harness the new microscopic-level data coming from CAVs to support planning activities, and assess the value of modeling and simulation tools in reflecting uncertainty associated with future implementation of connectivity and automation technologies. The role of Metropolitan Planning Organizations (MPOs) will be critical and coordination between TDOT and MPOs with regards to CAVs is critical for successful deployment.

4.7 CAV Program Manager

To accelerate the deployment of CAVs at the organizational level, creating positions for a TDOT-based program manager and staff can be helpful. The manager can oversee the testing and deployment of CAVs, with their responsibilities, similar to ITS managers. The TDOT CAV manager and a team can develop and maintain a CAV readiness, testing, development, and deployment plan that is well-coordinated between TDOT Divisions and external stakeholders. The plan will provide details about activities and projects and directions on effective CAV strategies. For example, besides covering digital infrastructure, the plan will have details about roadways, e.g., maintaining roadway signage and markings in a good state of repair that support CAV operation. In this example, the manager can facilitate TDOT's work with stakeholders such as automobile manufacturers, OEMs, manufacturers of signing and striping, in terms of best strategies for maintenance.

The manager in coordination with TDOT Division Directors and administration can prioritize smart infrastructure investment decisions and intelligent mobility strategies that ultimately improve transportation accessibility and economic development. Additionally, the manager will keep him-/herself informed about the state of practice for CAV technologies and ensure CAV cybersecurity, e.g., the use of Security Credential Management System (SCMS). In coordination with the Department of Motor Vehicles, the manager can create a CAV Tester Program (similar to the program in California) that can monitor CAV performance, monitor crashes and disengagements when higher levels of automation are tested in the field. The manager will also be responsible for CAV data processing, using, and archiving data, and identifying new deployment opportunities.

4.8 Stakeholder Outreach

TDOT can identify a key set of stakeholders that will be critical to the success of the CAV Program. TDOT can reach out to stakeholders about the strategy and readiness for CAV technologies. They can develop deployment guidance and outreach to external stakeholders, including local agencies (IOOs), first responders, and industry, e.g., automobile manufacturers in the state and commercial vehicle operators. TDOT can also work further with universities and Oak Ridge National Laboratory as well as the TennSMART consortium to enhance CAV research, development, and deployment. Guidance can be based on investments in smart infrastructure and enhancements in roadway, digital, and electric vehicle infrastructure. TDOT can articulate stakeholders' actions needed for readiness in CAV adoption, including hardware and software needed for more efficient CAV fleet operation, identifying locations where local transportation agencies (IOO) can deploy C-V2X or other communication technologies, stakeholders sharing and harnessing of data, and how stakeholders can assist in testing CV technologies through their fleet vehicles.

4.9 Data Analysis, Modeling and Simulation

Managing and harnessing CAV Data will be a key opportunity and challenge in the future. If a CAV Program Manager is designated by TDOT to deal with CAV issues in Tennessee, then the manager can assist TDOT's traffic operations division and others in managing the collection, processing, integration, security, storing and harnessing of data generated from CAVs. This effort may include (besides the use of data by CAVs themselves to safely navigate) identifying potential uses of data, e.g., providing short-term traffic performance predictions, improving the performance of traffic signals by incorporating driving volatility of the CAV trajectories at intersections, using CAV data in high-uncertainty situations such as incidents and special events for lane recommendations and dynamic speed limits. The data can also be used by TDOT's partner agencies, such as Fire and EMS. Further, CAV data can perhaps fill data gaps for various functions provided by TDOT, e.g., maintenance or environmental division. All the potential uses will require analysis of the CAV and related data.

Connected and automated vehicles can further leverage modeling and simulation capabilities available in Tennessee through the universities and Oak Ridge National Laboratory. This can involve leveraging high-performance computing, data science, and advanced sensors and communications protocols to develop, test and deploy emerging technologies and algorithms for vehicle-to-everything (including of course infrastructure and grid) interactions that enable applications for smart routing, smooth and safe traffic flow, and higher operational efficiency of the network. TDOT investments in applied research, e.g., using big data and machine learning to improve delay and safety performance of traffic signals in Tennessee or harnessing basic safety message data from CAV, should continue. More investments in virtual testbeds through simulation methodologies such as digital twins and the use of software SUMO and CARLA simulations can be applied, e.g., for data integration and processing, as well as identifying Tennessee-specific "edge" (fringe) cases. More information on the role of modeling (including AI techniques), simulation, and visualization capabilities that can help with diffusions of CAVs will be provided in subsequent reports.

Chapter 5 Conclusions and Recommendations

A strategic plan that accommodates the deployment of CAVs and related investments in physical and digital/technology infrastructure is needed to accelerate the diffusion of emerging technologies. Emerging technologies also require electrical vehicle infrastructure, policy and regulation, and public acceptance. To this end, focus on readiness and deployment plans in different US states are reviewed and compared, i.e., the strategies that these states are following are compared with Tennessee's activities in CAVs. Strategies that can enhance vehicle-to-everything interactions, leverage Tennessee resources, and provide strategic directions based on a review of statewide CAV readiness plans include:

- ***Identifying emerging technology opportunities.*** Specifically identifying opportunities for CAV-related ITS architecture service packages in Tennessee.
- ***Leveraging Tennessee-based resources.*** Successful implementation of tactical and long-range plans that will require TDOT to rely on the diverse resources available in Tennessee. The key resources that can be leveraged include: 1) TDOT owned and operated roadways with diverse urban, suburban, and rural characteristics, 2) TDOT capabilities in terms of data systems that include RDS, RITIS, ETRIMS, Traffic volume data (TNTIMES), incident data from the SmartWay Central Software, and TDOT-supported traffic operations centers that collect, process and disseminate data using advanced technologies, 3) a regulatory environment that facilitates testing and on-road deployment of CAVs, e.g., see Tennessee Automated Vehicles Act, 4) research, development and testing capabilities, available at universities and the Oak Ridge National Laboratory, and 5) presence of industry, especially automobile manufacturers and associated industries such as automotive suppliers.

Investments are needed in innovative solutions that encompass physical infrastructure, digital and smart infrastructure, electric vehicles, and charging infrastructure. For instance, to realize the full potential of intelligent mobility benefits focusing on smart infrastructure, investments in C-V2X equipment installation solutions are critical for TDOT. A key question is how to best plan for readiness in emerging technologies and work with IOOs when TDOT does not own or operate traffic signals in the State. Options include i) using TDOT Traffic Design Manual and TDOT standard specifications (modified by cities to fit their local needs) and statewide ITS architecture, ii) updating TDOT DSRC V2X guidance, and iii) supporting local agencies and, in some cases, TDOT operating and controlling traffic signals. The State of Georgia provides a good use case of DOT and IOO cooperation. Specifically, TDOT can create a program similar to the "SigOps program" by Georgia DOT. Under this program, traffic signal operations will be divided into regions supported by a separate consultant contract and dedicated funding. This shift will enable all signals to be remotely monitored automatically. In order to prioritize operational needs and resources, TDOT can use a tiered approach to define the level of remote monitoring and field presence required for each intersection. Critical and bottleneck intersections will require a higher level of monitoring and field presence than other locations. Furthermore, staff will be needed for this program. They will include remote signal engineers, field signal engineers, signal technicians, data analysts, and maintenance inspectors. The stakeholders will include TDOT traffic operations, TDOT district signal staff, and traffic engineering staff in counties and cities. To summarize, TDOT can consider a SigOps type approach or establish a way that fits with the current structure in Tennessee by supporting local agencies wishing to implement connected vehicle technologies.

Besides installing equipment, readiness also involves CAV data solutions. In this regard, options include i) city TMCs themselves or universities serving as repositories of new CAV data; the Tampa CV pilot deployment can serve as a relevant use case of new databases needed and it resides at the Center for Urban Transportation Research (CUTR), University of South Florida. ii) TDOT's regional TMCs serve as repositories (data lakes); e.g., in TDOT's case, data coming from freeway CAV devices can be handled first by regional TMCs. For cities, regional centers can be used as data repositories for CAV data, requiring connectivity between the regional and city-based TMCs, especially for traffic signals. Currently, in Tennessee, regional TMCs are not well-connected with city TMCs, except there seems to be some movement along the I-24 smart corridor and surrounding cities.

To further prepare for CAVs in Tennessee, strategies to consider include:

- ***Research, develop and deploy CAV technologies*.** TDOT and partners are demonstrating the capabilities and benefits of CAVs through testbeds, e.g., I-24 smart corridor. The Chattanooga MLK Smart City Corridor testbed and other statewide initiatives are also underway. Expansion of such initiatives should be considered.
- ***CAV readiness plans.*** Monitor and understand the current practices of statewide CAV readiness plans in other states, lessons learned, and recommendations while tracking emerging technology advances.
- ***Developing a roadmap.*** Develop a roadmap for physical and digital infrastructure, electric vehicle infrastructure, regulation and policy, user acceptance, partnerships with stakeholders, and workforce development.
- ***Smart infrastructure technologies.*** Identify improvements in roadway, digital, and electric vehicle infrastructure technologies through ITS architecture service packages for implementation. A wide range of CAV service applications includes emergency vehicle preemption, broadcast traveler information, queue warning, work zone management, connected vehicle traffic signal system, personalized traveler information, road weather motorist and warning, pedestrian and cyclist safety, and electric charging stations management. Also, TDOT can identify opportunities in terms of connected, automated, and electric transportation systems that are multimodal, i.e., include freight, transit, pedestrians, and bicycles. TDOT can integrate CAV strategies into long-term planning and programming processes by anticipating the impacts of their increased diffusion; developing data collection and harnessing capability from new sensors, e.g., basic safety messages and traveler information messages; and conducting research on specific issues related to CAV data, harnessing the data, and investing in modeling/simulation capabilities that can directly deal with complexity and fragility of the transportation system when operating in a mixed-mode, where some vehicles are high-level CAVs while others are human-driven.
- ***Future research on CAV readiness*.** Future CAV research can focus on readiness for emerging technologies. In this regard, it is important to invest in conducting interviews/surveys of various stakeholders, including TDOT Division Directors and staff in terms of their readiness for CAV and synergistic technologies, including electric vehicles.

Additionally, TDOT can consider the following actions:

- Accelerate the integration of CAV technologies in TDOT's plans, programs, and projects.
- Consider creating positions for TDOT-based program managers to test and deploy CAVs (their responsibilities can be similar to ITS managers).
- Develop an external stakeholder coordination strategy, especially with IOOs, vehicle manufacturers, information technology companies, and the TennSMART consortium.

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Appendix A: Text Mining on National CAV Plans

A.1 Text Mining Methodology

This research includes the analytical text analysis of 24 references (*1-27*) using QDA Miner 8 in combination with WordStat 5. Within the text analysis software, an inclusion dictionary was developed to perform a content analysis of the references used in this study. After the initial analysis, data processing was completed to exclude words from the analysis with little discriminative value. These excluded words were added to an exclusion list. The selected outputs of the software include the most frequently used topics and keywords. The most frequent keywords from the text analysis were then used to inform the literature synthesis.

The data from the collected literature was cleaned through the revision of the inclusion and exclusion dictionary. An inclusion dictionary was developed to perform a content analysis of the references used in this study. After the initial analysis, data processing was completed to exclude words from the analysis with little discriminative value. Examples of words with little discriminative value for this research include figure, table, staff, public, provide, identify, etc. were added to an exclusion list. Additional processing was completed to combine words with a similar meaning relating to the study topic. For example, the terms "CVs," "AVs," "CAVs," "autonomous vehicles," and "automated vehicles" were all combined into the single term "CAV." Additionally, many words appeared in the initial screening in both the singular and plural versions; these words were combined in a manner that the plural form was altered to the singular form of the word. All processing was completed on the data before the creation of the outputs that are contained within this report.

The outputs of the text analysis software include word clouds for key phrases and keywords. These word clouds are a visual representation of the most common words in the studied literature. In this word cloud, word size increases with the number of times a word is included in the literature base. The information that is visually represented in the word clouds is duplicated as a table to demonstrate the specific frequency of the term, the percent of case documents the term appears in (% Cases), and "TF • IDF". The column entitled "TF • IDF" indicates the frequency of the keyword multiplied with the inverse document frequency (IDF). This measure represents the concept that if a phrase appears more frequently in a document, it is more likely to be representative of the content within the document.

Another output of text analysis is a list of topics that have been detected in the literature. Each of the detected topics includes a list of the words that were included in the topic. The detected topics can aid in the identification of topics in the literature, and some of these topics may have been missed by the human review of the collected literature. The number of detected topics can be chosen or altered to match the amount of collected literature and the desired amount of specificity. For this research, a total of 15 topics were generated from the analysis of the 24 studied reference documents.

A.2 Text Analysis Findings-national initiatives

The text analysis software programs QDA Miner 5 and WordStat 8 present the results of analyses as both images and tables. The images included in the body of this report represent the keyword frequency, the key phrase frequency, and a word map. The table that has been included contains a list of the detected topics. The word clouds representing keyword frequency and key phrase frequency have corresponding tables that have been included in the appendix. These tables contain statistics that support the information presented in the word clouds.

A.2.1 Keyword Frequency

The keyword cloud in Figure A-1 was created as a visual representation of the most common words in the studied literature. In this word cloud, word size increases with the number of times a word is included in the literature base. The statistical information which was used to create this keyword cloud is included below (Table A-1). This table contains the measures entitled "frequency," "% Cases," and "TF • IDF." Frequency refers to the number of occurrences of the keyword in the corpus of collected literature. The measure "% Cases" refers to the percentage of cases in the corpus in which the keyword appears, while the term "TF • IDF" represents the concept that if a phrase appears more frequently in a document, it is more likely to be representative of the content within the document.

It can be determined that the most frequently observed term in the literature was "data," with a frequency of 3800, with a presence in 100% of the cases. The terms in Table A-1 which can be tied directly to ARC-IT service packages are "data," "planning," "safety," "operations," and "traffic," with frequencies of 3800, 2710, 2465, 1925, and 1691, respectively.

These most frequent keywords represent the three concepts of safety, data, and traffic operations. Additionally, the frequent keyword "planning" can be aligned with many of the titles and goals of the gathered corpus of literature, as these reports were plans themselves and are therefore more likely to contain the word plan within them.

Figure A-1 Keyword Frequency Word Cloud

TABLE A-1 KEYWORD FREQUENCY

	FREQUENCY	*% CASES*	*TF • IDF*
DATA	3800	100%	0.0
TECHNOLOGY	3698	95.83%	68.4
PLANNING	2710	100%	0.0
SAFETY	2465	100%	0.0
OPERATIONS	1925	95.83%	35.6
DEPLOYMENT	1795	100%	0.0
TRAFFIC	1691	100%	0.0
PROGRAM	1626	100	0.0
TEST	1484	95.83%	27.4
INFRASTRUCTURE	1474	100	0.0
MANAGE	1414	87.50%	82.0
PROJECT	1408	91.67%	53.2
DRIVER	1330	100%	0.0
COMMUNICATIONS	1202	100%	0.0
WORK	1198	95.83%	22.1
COST	1124	95.83%	20.8
APPLICATIONS	1054	91.67%	39.8
SERVICE	941	100%	0.0
POLICY	919	91.67%	34.7
GOAL	908	91.67%	34.3

A.2.2 Key Phrase Frequency

A key phrase cloud (Figure A-2) and table (A-2) were generated similarly to the keyword cloud and table above. The key phrases which can be connected directly to ARC-IT service packages are "traffic signal," "work zone," "traveler data," "highway safety," and "traffic operations." These phrases have a frequency of 312, 259, 195, 155, and 113, and they have appeared in 87.5%, 79.17%, 58.33%, 70.83%, and 58.33% of the cases, respectively.

It is understandable that "traffic signal" is included as the most frequent key phrase, as many CAV readiness plans that did not include specific ARC-IT service packages, did mention the need to improve infrastructure, typically through traffic signal upgrades. Further, most of the frequent key phrases heavily imply the importance of safety, data, and traffic operations in the collected CAV readiness plans. The concept of safety is included in the key phrase "work zone" and "highway safety." The phrases "traffic operations" and "traffic signal" can be combined as they can both be contained within the single phrase "traffic operations." Additionally, the identified key phrase "traveler data" confirms the relevance of data within CAV readiness operations for many state departments.

The key phrases relate to the relevant service packages and these connections are listed below. Specifically, the key phrases "traffic operations" and "traffic signal" relate to the service package type traffic management, which was included in the I-24 Smart Corridor, the TDOT ITS Plan, and the most frequently recommended ARC-IT service packages. Additionally, "work zone" refers to the service packages area of maintenance and construction that was represented by the service package "Work Zone Management" that appeared in the TDOT ITS Plan and the most frequently recommended ARC-IT service packages from the collected statewide CAV readiness plans. The key phrase "highway safety" is represented in the service package area of vehicle safety which appears in the TDOT ITS Plan and the most frequently recommended ARC-IT service packages from the collected statewide CAV readiness plans. The key phrases relate to the following service package areas of traffic management, vehicle safety, and maintenance and construction which are present in the TDOT ITS Plan, the I-24 Corridor Plan, and the most frequently recommended ARC-IT service packages from the collected statewide CAV readiness plans.

Figure A-2 Key Phrase Frequency Word Cloud

TABLE A-2 KEY PHRASE FREQUENCY

Key Phrase	*FREQUENCY*	*% CASES*	*TF • IDF*
TRAFFIC SIGNAL	312	87.50%	18.1
WORK ZONE	259	79.17%	26.3
JOINT STATEWIDE CAV STRATEGIC PLANNING	222	4.17%	306.4
TRAVELER DATA	195	58.33%	45.6
TEST AND DEPLOYMENT	169	66.67%	29.8
CONCEPT OF OPERATIONS	163	37.50%	69.4
TRAFFIC MANAGE	161	75.00%	20.1
HIGHWAY SAFETY	155	70.83%	23.2
HUMAN DRIVER	144	54.17%	38.3
SERVICE PACKAGE	134	4.17%	184.9
LAW ENFORCEMENT	131	62.50%	26.7
ADVISORY COUNCIL	127	25.00%	76.5
IMPROVE SAFETY	121	79.17%	12.3
PERFORMANCE MEASURES	114	66.67%	20.1
TRAFFIC OPERATIONS	113	58.33%	26.5
ARCHITECTURE CONCEPT OF OPERATIONS	112	4.17%	154.6
EXECUTIVE ORDER	111	33.33%	53.0
DATA SHARING	102	83.33%	8.1
TASK FORCE	102	50.00%	30.7
ACTIVITIES ROADMAP	97	4.17%	133.9

A.2.3 Generated Topics

Table A-3 lists the results of the completed topic extraction of the text mining software QDA Miner. The software was used to identify 9 topics that most frequently appeared in the created corpus. Within this table, the terms “coherence,” “frequency,” and “% Cases” respectively refer to the eigenvalue, the number of occurrences of the keyword in the corpus, and the percentage of cases in the corpus in which the keyword appears.

The most frequent generated topics include communication systems, ARC-IT service packages, and safety, with respective frequencies of 4876, 3874, and 3010. The generated topic of “ARC-IT service packages” shows the value of using the ITS services as defined by the current national reference architecture. Additionally, the previously identified concepts of “data,” “traffic operations,” and “safety” are each represented in the generated topics list. The idea of data is included by topic 1, and in this context, data is closely associated with communication systems. Traffic operations are represented in both topics 5 and 7, “Travel Time & Congestion Reduction” and “Traffic Signal Phasing and Timing”. Additionally, the concept of safety is directly mentioned in both topics 3 and 9, indicating that safety was mentioned very frequently in the studied corpus.

TABLE A-3 TOPIC EXTRACTION FROM TEXT MINING

Topic	Keywords	Coherence	Freq.	%Cases
Data and Communication Systems	Communications; DSRC; Cellular; Wireless; Device; Range; Roadside; Data; Infrastructure; Applications; Equipment; Technology; Message; Mobile; Connectivity;	0.417	4876	100%
Traveler Information and Traffic Management	Emergency; Incident; Response; Transit; Operations; Centers; Coordination; Payment; Electronic; Concept; Architecture; Toll; Service Package; Traveler Information; Concept of Operations; Traffic Management; Incident Management; Data Collection;	0.346	3874	100%
Safety	ADSS; NHTSA; Practices; Test; Safety; Regulation; Design; Guidance; Laws; Standards; Industry; Deployment; Policies; Vehicle Safety; Testing and Deployment;	0.356	3010	100%
Driving Task	Automation; Control; Task; Dynamic; Operate; Assistance; Warning; Human Driver; Driving Task; Automated Driving; Dynamic Driving Task;	0.363	2277	100%
Travel Time and Congestion Reduction	Congestion; Travel; Demand; Fuel; Mobility; Parking; Urban; Capacity; Efficiency; VMT; Cost; Transit; Shared; Travel Time; Travel Demand;	0.341	2039	100%
Pavement Markings and Traffic Management	Markings; Signs; Lane; Construction; Zone; Traffic; Weather; Maintenance; Device; Roadside; Message; Work Zone; Pavement Markings; Message Signs; Traffic Management; Traffic Control;	0.385	1810	100%
Traffic Signal	Signal; Timing; Phase; Intersection; Warning; Pedestrian; Traffic Signal; Signal Phase and Timing; Signal Priority; Traffic Management; Red Light; Transit Signal Priority; Traffic Control;	0.420	1616	95.83%
Laws and Regulations	Licensing; Enforcement; Law; Training; License; Requirements; Operator; Liability; Regulation; Law Enforcement; Vehicle Registration; Traffic Laws; Driver Education; Driver Training;	0.376	1580	100%
Safety and Performance Measures	Performance; Measures; TSM; Division; Manage; Incident; Performance Measures; Performance Reporting; Performance Management;	0.342	1310	91.67%

A.2.4 State-wide CAV Readiness Reports

A total of 24 unique statewide CAV readiness plans (*1-27*) from 20 states were gathered using the PRISMA method. These plans provided recommendations for physical infrastructure, telecommunications infrastructure, and ITS architecture.

Of the gathered references, eight plans (*1-8*) reference specific ITS services. In this study, the ITS recommendations contained within these plans were extracted and compiled to determine the most frequently recommended CAV-related ITS architecture. The compilation of the recommended architecture applications from the collected reports is available in the appendix.

The most frequently suggested architecture applications (with 5 recommendations each) include emergency vehicle preemption (*2-4; 7; 22*), transit signal priority (*2; 4; 7; 22*), broadcast traveler information (*1-4; 8*), and queue warning (*1; 3; 4; 6; 22*).

The next most frequently recommended service packages (each with 4 recommendations) include work zone management (*1-3; 22*), connected vehicle traffic signal system (*1-3; 22*), personalized traveler information (*2-4; 22*), road weather motorist alert and warning (*1; 8; 22; 28*), and pedestrian and cyclist safety (*1-3; 5*).

The most frequently recommended service packages span across a wide range of network users from pedestrians, cyclists, and transit users to emergency personnel, connected vehicle drivers, and interstate drivers. Active transportation modes are represented by "pedestrian and cyclist safety" and "transit signal priority," As TDOT typically influences the design of the interstate system and does not operate transit, the transit and pedestrian-related ARC-IT service packages may not be useful recommendations for TDOT. On the other hand, interstate and highway drivers are represented in the most frequently recommended ARC-IT service packages by "connected vehicle traffic signal system," "emergency vehicle preemption," "queue warning," "work zone management," and "road weather motorist alert and warning.

Appendix B: Complete List of Opportunities in Architecture with References

- Commercial Vehicle Operations
  - CVO06 - Freight Signal Priority (*4; 30*)
  - CVO09 – Freight-Specific Dynamic Travel Planning (*5*)
  - CVO10 – Road Weather Information for Freight Carriers (*31*)
- Data Management
  - DM01 – ITS Data Warehouse (*3; 31*)
  - DM02 – Performance Monitoring (*5; 31; 32*)
- Maintenance and Construction
  - MC04 – Winter Maintenance (*4; 31*)
  - MC05 – Roadway Maintenance and Construction (*4*)
  - MC06 – Work Zone Management (*1-3; 22*) (suggested 4 times)
  - MC07 – Work Zone Safety Monitoring (*3; 31*)
- Parking Management
  - PM01 – Parking Space Management (*32*)
  - PM02 – Smart Park and Ride System (*5; 31*)
- Public Safety
  - PS03 - Emergency Vehicle Preemption, (*2-4; 30; 32*) (suggested 5 times)
  - PS04 – Mayday Notification (*4*)
  - PS06 – Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (*4; 31*)
  - PS07 – Incident Scene Safety Monitoring (*3; 31; 32*)
  - PS14 – Disaster Traveler Information (*1; 4; 22*)
- Public Transportation
  - PT03 - Dynamic Transit Operation (T-DISP) (*4*)
  - PT09 - Transit Signal Priority, (*2-4; 30; 32*) (suggested 5 times)
  - PT17 – Transit Connection Protection (*4*)
- Sustainable Travel
  - ST09 – Connected Eco-Driving (*5*)
- Traffic Management
  - TM03 – Traffic Signal Control (*2; 5*)
  - TM04 – Connected Vehicle Traffic Signal System (*2-4; 32*) (suggested 4 times)
  - TM05 - Freeway Metering (*2; 4*)
  - TM09 – Integrated Decision Support and Demand Management (*4*)
  - TM10 - Electronic Toll Collection (*31*)
  - TM11 - Road Use Charging (Congestion Pricing) (*2; 31*)
  - TM12 – Dynamic Roadway Warning (*4*)
  - TM14 – Advanced Railroad Grade Crossing (*3*)
  - TM20 – Variable Speed Limits (*31*)
  - TM21 – Speed Harmonization

- TM22 – Dynamic Lane Management and Shoulder Use (*2*)
- Traveler Information
  - TI01 – Broadcast Traveler Information (*1-4; 22*) (suggested 5 times)
  - TI02 – Personalized Traveler Information (*1; 2; 4; 22*) (suggested 4 times)
  - TI06 – Dynamic Ridesharing and Shared Use Transportation (*4*)
  - TI07 – In-Vehicle Signage (*31*)
- Vehicle Safety
  - VS01 - Autonomous Vehicle Safety Systems, (*33*)
  - VS02 - V2V Basic Safety, (*3; 32; 33*)
- Forward Collision Warning, Emergency Electronic Brake Light (*32*)
  - VS03 - Situational Awareness, (*33*)
  - VS04 - V2V Special Vehicle Alert, (*33*)
  - VS05 - Curve Speed Warning, (*3; 31; 33*)
  - VS06 - Stop Sign Gap Assist, (*33*)
  - VS07 - Road Weather Motorist Alert and Warning, (*1-3; 6*) (suggested 4 times)
  - VS08 - Queue Warning, (*1; 3; 4; 6; 22*) (suggested 5 times)
  - VS09 - Reduced Speed Zone Warning/ Lane Closure, (*31; 33*)
  - VS10 - Restricted Lane Warnings, (*33*)
  - VS11 - Oversize Vehicle Warning, (*33*)
  - VS12 – Pedestrian and Cyclist Safety (*2-4; 30*) (suggested 4 times)
  - VS13 – Intersection Safety Warning and Collision Avoidance (*2; 4; 32*)
  - VS14 – Cooperative Adaptive Cruise Control (*4*)
  - VS15 - Infrastructure Enhanced Cooperative Adaptive Cruise Control, (*33*)
  - VS17 - Traffic Code Dissemination, (*33*)
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- Weather
  - WX03 - Spot Weather Impact Warning (*31*)