Connected and Automated Vehicles Investment and Smart Infrastructure in Tennessee

Part 5: A comprehensive view of Intelligent Mobility in Tennessee

Research Final Report from University of Tennessee | Asad Khattak, Iman Mahdinia, Mohammad SafariTaherkhani, & Steve Lee | May 31, 2022

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16. Abstract

Transportation innovations captured through intelligent mobility strategies are critical to achieving economic development, safety, mobility, energy, environmental, and equity goals. Intelligent mobility is broadly defined to encompass connected and automated vehicles, electric vehicles, and multi-modal personal and freight movements, all done safely and securely. It is enabled by large-scale data, tools for transportation modeling and artificial intelligence, simulation and visualization, multi-scale connectivity, and high-performance computing. To assess intelligent mobility strategies in Tennessee, this report first provides a framework by exploring focus areas, including physical infrastructure, digital infrastructure, electric vehicle infrastructure, policies, regulations, and associated public knowledge and acceptance. Specific topics covered in the report include 1) an overview of intelligent mobility in Tennessee, 2) a business case for intelligent mobility strategies by predicting their benefits and impacts, 3) results of a readiness survey and assessment based on the focus areas defined in the framework, and 4) benchmarking of aspirational states in the US with regards to intelligent mobility strategies. The readiness assessment results are based on an extensive survey of TennSMART consortium members that included government agencies, private sector companies, and universities. Finally, the report provides recommendations on intelligent mobility readiness.

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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*

The Tennessee Department of Transportation (TDOT) and the TennSMART consortium, consisting of academic institutions, government agencies, and private sector companies, have led the development of a vision that covers not only connected and automated vehicle technologies but also solutions encompassing electrification, and multimodal personal and freight movements, while ensuring cybersecurity. Transportation innovations captured through these intelligent mobility strategies are critical to achieving economic development, safety, smoother movement of people and goods, and energy and environmental improvements.

Intelligent mobility encompasses connected and automated vehicles (CAVs), electric vehicles (EVs), and multi-modal personal and freight movements, all done safely and securely. It is enabled by large-scale (big) data, tools for transportation modeling and artificial intelligence, simulation and visualization, multi-scale connectivity, and high-performance computing. To assess intelligent mobility strategies in Tennessee, this report first provides a framework by exploring focus areas, including physical infrastructure, digital infrastructure, electric vehicle infrastructure, policies, regulations, and associated public knowledge and acceptance. A key focus is on developing supporting information for readiness to enhance intelligent mobility in Tennessee. Readiness or preparedness in this context applies to emerging solutions that include physical infrastructure, digital infrastructure (e.g., connectivity and automation), electric vehicle infrastructure, policy and regulations, and public acceptance. To develop and implement actionable and innovative strategies for new technology solutions, stakeholders should be willing to invest in research, development, pilot testing, and deployment. Also, they should be willing to invest in proactive strategies to improve the transportation system rather than responding to problems after they occur. Specific topics covered in the report include:

- An overview of intelligent mobility in Tennessee.
- A business case for intelligent mobility strategies by predicting their benefits and impacts.
- A readiness survey and assessment were based on the focus areas defined in the framework.
- Benchmarking of aspirational states in the US with regards to intelligent mobility strategies.

The readiness assessment results are based on an extensive internet survey of TennSMART consortium members, including government agencies, private sector companies, and universities. Through input from these stakeholders, including TDOT's management and staff, this study contributes to pushing the boundaries on research, testing, and deployment of innovative solutions to position the entire state of Tennessee for ingesting emerging technologies in transportation. The responses provide baseline inventory for current intelligent mobility activities and help identify options for future activities that will enhance mobility in Tennessee.

Key Findings

The findings on intelligent mobility strategies are structured in terms of intelligent mobility overview, expected benefits, readiness, and benchmarking.

Readiness for emerging technologies is high in electric vehicle infrastructure, followed by digital infrastructure, roadway infrastructure, and modest levels of public knowledge and acceptance.

Overview of intelligent mobility in Tennessee. This report summarizes intelligent mobility in Tennessee, with a statewide review focusing on available digital infrastructure. While Tennessee faces physical infrastructure challenges regarding roads needing repair and improving structurally deficient bridges (4.4%), there is a need to explore innovative solutions for growth-related congestion in major cities, examine evidence-based safety countermeasures, and consider environmentally friendly technologies. In this report, relevant information on innovative intelligent transportation system inventories across Tennessee comes from several sources, including Intelligent Transportation Systems (ITS) architecture reports for 11 cities in Tennessee (from Bristol to Memphis) and the statewide ITS architecture report. Other TDOT sources include the integrated ITS SmartWay systems and the Tennessee Department of Environment and Conservation (TDEC) for electric vehicle charging infrastructure. Additionally, summaries of national-level inventories for transportation infrastructure technologies are presented.

Traffic Management Centers (TMCs) are the backbone of intelligent transportation systems in Tennessee. They operate in different regions of Tennessee to monitor traffic operations and communications. The TMCs in Tennessee have sufficient equipment and resources to enable the diffusion of emerging technologies. These resources include TMC operators, HELP vehicles and operators, information technology (IT) technicians, closed-circuit television (CCTV) cameras, speed detectors, dynamic message signs (DMSs), highway advisory radio transmitters, and portable variable message signs. However, inventories are either low or non-existent for 1) changeable speed limit signs, 2) DMSs and over lane signs for active lane management, 3) roadside and onboard devices for connected vehicles (CVs) and new sensors, 4) software for context-relevant applications/user services, 5) fiber for fast communication of data, and 6) latest traffic control devices (e.g., new signal controllers that can communicate with roadside units (RSUs), radar detection sensors, and 360-degree cameras for detection and traffic surveillance).

Notably, establishing the appropriate cyber-physical ecosystem is critical, which also entails the collection, processing, management/storage, and harnessing of CAV (Vehicle-to-Everything) communications data. Providing web-based platforms for vehicle location and geo-referencing, signal phasing and timing, MAP data, traveler information message, and message authentication are important considerations for readiness. Additionally, software applications from the ITS architecture can be beneficial in different contexts. There is a need to identify connected vehicle mobility and safety applications/user services, e.g., lane management and control system or work zone alerts, in different regions of Tennessee.

The business case for intelligent mobility strategies: Expected benefits. The business case for intelligent mobility readiness should cover the expected benefits from intelligent mobility solutions. The intelligent mobility report covers a review of ongoing research on the impact of intelligent mobility strategies, a composite of research done at the national and state levels. Information about the extent of problems and impacts of innovative transportation solutions in terms of economic growth, safety, mobility, energy, and environment is provided in Tables E-1 and E-2. There is a strong case for adopting emerging technologies, given their benefits. To achieve the benefits, investments are needed in the readiness of roadway, digital, and electric vehicle infrastructure, increasing emerging technology (e.g., CAV, EV) awareness across Tennessee, broader testing of new technologies through pilot projects, establishing business processes to support future CAV and EV deployment and dedicating new workforce to CAV and EV implementation.

TABLE E-1 TRANSPORTATION IMPACTS IN TENNESSEE

Economic Costs	*Safety*	*Traffic flow & congestion*	*Energy and Efficiency*	*Health and Environment*
• Congestion costs the economy $4.2 billion in 2020 • $25 billion annual economic cost and societal harm from crashes	• 1,325 lives were lost in 2021 on TN roadways • Estimated 66,000 people were injured in crashes in 2021 • Vulnerable road user/bike and ped crashes (177 pedestrian deaths in 2021)	• 225 million hours spent in delays annually	• 83 million gallons of fuel are wasted annually • $0.29 trillion in goods shipped by truck each year	• Greenhouse gases • Public health impacts

TABLE E-2 ESTIMATED BENEFITS IN TENNESSEE WITH FULL AUTOMATION AND ELECTRIFICATION ADOPTION

Economic Costs	*Safety*	*Traffic flow & congestion*	*Energy and Efficiency*	*Health and Environment*
• Savings in congestion cost $2 billion • Reduction of $8 billion annual economic cost and societal harm from crashes • Savings in the environmental cost of damage by $70 million • Higher GDP due to redevelopment of real estate by about $4.3 billion	• 430 lives can be saved per year on TN roadways • Estimated 21,500 reductions in people injured in crashes annually • 20% reduction in vulnerable road user/bike and ped crashes	• About 48% reduction in hours spent in delays annually	• Increase in energy efficiency due to adoption of hybrid vehicles by about 50% more MPG • 40% reduction in fuel wasted annually • $0.6 trillion in goods shipped by truck each year	• Reduction in greenhouse gases due to electrification by about 33% • Public health impacts

Intelligent mobility funding. Tennessee is poised to receive $6.2 billion (2021 to 2026) through the Infrastructure Investment and Jobs Act (IIJA), which can be a critical source of funds for intelligent mobility projects. Specifically, investments in intelligent mobility projects can come from sources with the IIJA legislation for "Building a Better America." Among other objectives, the act encourages investments in new and emerging technologies such as connected and automated vehicles and associated broadband deployment, electric vehicle infrastructures such as charging stations; safety for all road users, particularly vulnerable road users; addressing environmental impacts of transportation, especially emissions; and equity and inclusion of disadvantaged and under-represented groups in CAV accessibility, planning and project selection. Notably, IIJA prioritizes projects that advance choices across all modes and are sustainable. The sources of funds for intelligent mobility can include core programs (NHPP-National Highway Performance Program, STBG-Surface Transportation Block Grant, HSIP-Highway Safety Improvement Program, RR-Refuge Roads, CMAQ-Congestion Mitigation and Air Quality, Metropolitan Planning, and Freight), as well as new programs related to electric vehicle infrastructure, carbon and green initiatives, protection and resiliency of infrastructure, bridge rehabilitation, and ferry transportation. For Tennessee, there is new funding of $139 million for carbon reduction, $88 million for electric vehicle infrastructure, $302 million for bridge rehabilitation, and $158 million for Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT). Notably, some of the IIJA funds are grants that need resources to prepare proposals and plans. TDOT can take steps to adopt the broader zero-emissions vehicles mandate and envision electric vehicle infrastructure in smart corridors to increase the chances of success in competitive grants.

Intelligent mobility readiness survey. As mentioned, a framework to study intelligent mobility across Tennessee was developed. The framework focuses on physical roadway infrastructure, electric vehicle infrastructure, digital infrastructure, policy/regulation, and public knowledge/acceptance. Each area contains a series of subcategories to broadly explore intelligent mobility readiness across TennSMART members, including representatives from cities, agencies, a national lab, the private sector, and academia. A questionnaire was designed and developed to assess intelligent mobility readiness. After its distribution to TennSMART members, 22 responses are analyzed. The framework assesses readiness on a scale of 0 (no activity – 0% Readiness) to 3 (strong activity – 100% Readiness). The survey asked respondents whether their organization had researched, developed, or deployed roadway improvements or emerging technologies.

The results range from the high activity and readiness in electric vehicle infrastructure, digital infrastructure, roadway infrastructure, and modest levels of public knowledge and acceptance (Figure E-1).

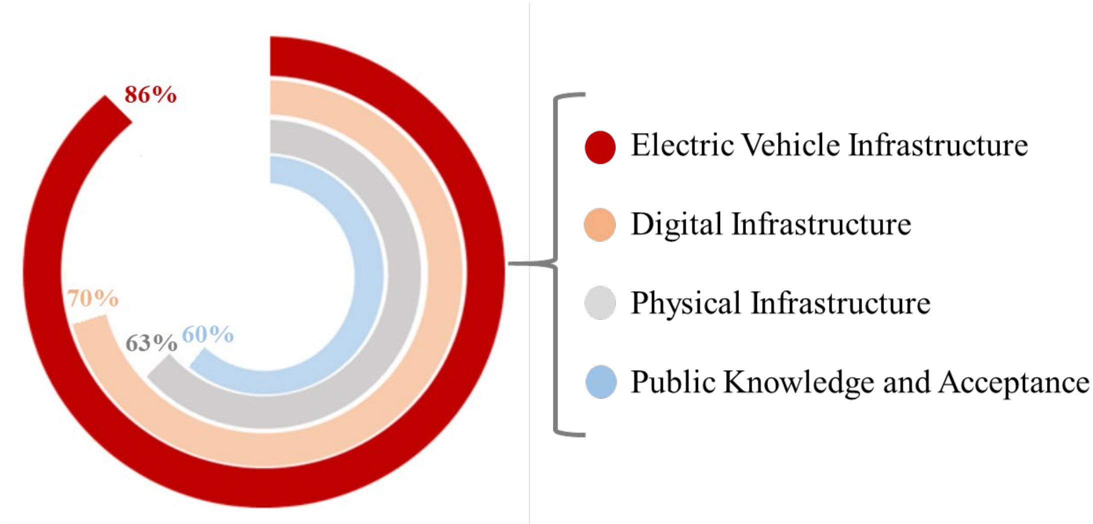

Figure E-1 Readiness index for each area

To support electrification, the transportation system needs "a network of EV charging stations" with different charging levels, i.e., Level 1, Level 2, and DC Fast charging. Despite the substantial potential for improvement in charging infrastructure, the results show high levels of readiness in terms of installing charging stations and electricity generation and distribution, assessing future demand for charging infrastructure and expanding charging stations.

Notably, CAV technologies can exchange information with digital infrastructure, e.g., cellular vehicle-to-everything (C-V2X) capable roadside units can warn drivers for red-light running or high speeds on curves. Within this category, low readiness in C-V2X communication is quite apparent, showing 44% on the readiness scale (this may also be due to the fact that this question applies more to agencies than the entire spectrum of TennSMART members). The next category that has readiness improvement potential is harnessing the C-V2X data to improve mobility and safety. Furthermore, cybersecurity also ranked relatively low in terms of readiness. More attention is needed on C-V2X communication and the secure collection and harnessing of CAV data.

Within physical infrastructure, the least readiness is observed for the ability of CAVs to detect pavement markings at 42%, followed by road sign improvements at 49%, truck platooning readiness (56%), and expanding operational design domain (ODD) at 69%. Clearly focusing on improving pavement markings and road signs for CAVs, expanding ODDs, and facilitating truck platooning can improve physical infrastructure readiness.

The area that shows more significant potential for improvement is public knowledge and acceptance reflected in information about automation and electrification in passenger travel by personal vehicles, transit, and freight. Informing the public about automation in passenger vehicles and the freight industry (e.g., truck platooning) has the lowest index among all, which can receive attention in the future.

CAV readiness of cities in Tennessee. To further enhance understanding of readiness in Tennessee cities, the study explored infrastructure elements required to accommodate CAVs. Several measures are used to evaluate readiness for CAVs, based on cities' readiness in terms of digital and physical infrastructure. Analysis of cities' ITS architecture reports is conducted.

The research team first identified several variables that can promote CAV diffusion. The Tennessee cities analyzed include Clarksville, Nashville, Memphis, Knoxville, Johnson City, Jackson, Bristol, Kingsport, Chattanooga, Cleveland, and Lakeway. Generally, larger cities with more population are likely to have more resources, though smaller cities may leapfrog more quickly as they are nimbler with less inertia. Cities across Tennessee vary in terms of their readiness for CAV adoption. Memphis, Chattanooga, and Nashville have received high readiness ratings based on the information contained in the Tennessee Regional ITS Architecture reports analyzed in this study. Whereas Knoxville, Clarksville, and Johnson City received relatively low readiness ratings. At the same time, larger cities that have encouraged innovation in transportation seem more prepared than smaller and medium-size cities; modest infrastructure investments in such cities, as appropriate, can significantly enhance their readiness.

Analysis of ITS architecture plans for cities in Tennessee shows Tennessee's focus on a set of strategies. These include 1) installing digital infrastructure, especially fiber optic networks and field sensors, 2) responding to emergencies—planning, operation, and routing of emergency vehicles when responding to incidents, traffic signal preemption and emergency traffic control, area alerts, evacuation if needed, and traffic incident management, 3) enhancing safety, especially reducing deaths and injuries and damages to TDOT property—through a collection of information (e.g., CCTV cameras) and dissemination of information through dynamic message signs and radio transmitters, and 4) workforce development.

A key opportunity is to integrate inventories for electric vehicle infrastructure, e.g., a fast-charge network to enhance the diffusion of EVs in Tennessee by reducing barriers to electrification. Based on the analysis of Tennessee inventory data, substantial efforts are needed to increase the inventory of digital infrastructure to enhance readiness for emerging technologies.

Benchmarking of aspirational states. The team has identified the leading states in emerging technologies (CAV and EV) research and development, summarizing their success stories. A vital aspect of this research is that the holistic approach developed in this study gives insights into planning for the future of emerging technologies. Initial information about benchmarks for Tennessee's readiness relative to aspirational agencies in other states is provided. Notably, TDOT has not previously conducted such a readiness benchmarking project. The research team provides information that a TDOT benchmarking team can use to enhance readiness further. The performance measures relevant to the goals include safety, mobility, energy, and environment to reduce the costs associated with these goals, e.g., reducing the costs of crashes, injuries, and death. The aspirational agencies selected for use case analysis include Michigan, Florida, California, and Minnesota. They were selected due to their leadership in developing, testing, and deploying emerging technologies. The research team collected and analyzed information from the four states to identify innovative readiness strategies, approaches, and best practices that may be adopted in Tennessee to boost readiness. The results for consideration in Tennessee are discussed as follows:

- *Physical infrastructure.* TDOT can consider improving signs and pavement markings, upgrading traffic signals to absorb new technologies, and creating CAV park-and-ride facilities in the long-term regarding changes to physical infrastructure.

- *Digital infrastructure.* More research, development, and pilot testing are needed for CAV technologies, including truck platooning and autonomous shuttles. For example, truck platooning can be tested to examine fuel economy improvements and capacity enhancements along freight corridors. This will require coordination between several stakeholders, including TDOT divisions—traffic operations, freight and logistics, and long-range planning. Generally, TDOT can adopt pilot testing as a near-term goal. Additionally, more efforts and resources can be allocated to workforce development in digital infrastructure/emerging technologies and enhancing cybersecurity.
- *Electric vehicle infrastructure.* TDOT can consider adopting the Zero-Emission Vehicle concept and mandate, which is broader than electric vehicles, e.g., they include fuel-cell vehicles that use hydrogen and associated infrastructure. Besides increasing their coverage, TDOT can consider Innovative strategies for charging stations, e.g., solar energy charging at stations. Consideration can be given to incentives for EVs to use High Occupancy Vehicle (HOV) lanes, assuming that HOV lanes are strictly enforced and enhance the availability of EV charging throughout the network and destinations, e.g., activity centers, hotels, vacation spots, and parks. It is noteworthy that currently, TDOT and TDEC are collaborating to develop the "Tennessee Electric Vehicle Infrastructure (TEVI) Deployment Plan" to receive funds from the National Electric Vehicle Infrastructure Formula Program (NEVI Formula).
- *Public knowledge and acceptance.* TDOT can consider conducting stakeholder meetings to increase awareness of intelligent mobility strategies. TDOT can design a campaign to send information through various media, e.g., text messages, to inform the public about intelligent mobility strategies that include adopting and using CAVs and EVs. Public knowledge strategies can be implemented in the near term.

Ultimately, TDOT Division managers and staff should select the relevant best practices from these aspirational states that can be adopted in Tennessee. Over time, the transportation system's performance should be monitored to assess the effectiveness of the new practices and processes, realizing that improvements can take multiple years to show results.

> *To reduce unintended consequences of emerging technologies, such as job losses in specific sectors, use collaborative approaches to coordinate mitigation solutions.*

Unintended consequences. Emerging transportation technologies will automate some tasks and make some of the workforces (e.g., delivery workers, ambulance drivers, and plumbers) more productive, lowering the services' cost. Also, automation technologies can lower crash costs - their clear benefits. However, the repair costs may be higher if such vehicles with more sensors and technologies are involved in crashes. The sensors and other technology components that enable automation may be damaged during collisions, and they are typically more expensive to repair. On a broader scale, automation may be disruptive to manufacturing employment in Tennessee, with potential job losses in car manufacturing. While factory automation itself can reduce the number of tasks performed by workers [1], vehicle support industries may be affected directly as demand for many support services can be significantly reduced, e.g., fewer crashes can eliminate much of the need for repair. Vehicle intensive-use occupations can see substantial impacts, e.g., AVs 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. Thus, anticipating some of the unintended consequences, especially negative social impacts on labor, the insurance industry, and equity in access to automated vehicles, is crucial as they may disproportionately and negatively affect different strata of the society, creating equity issues. The business case should also consider collaborative approaches and strategies for mitigating the disruptive consequences of innovation adoption.

Key Recommendations

Successful implementation of intelligent mobility strategies requires that TDOT and partners rely on the diverse resources available in Tennessee. To prepare for intelligent mobility in Tennessee, recommendations are partly based on rankings received in the readiness survey of TennSMART consortium members. The recommendations are based on physical, digital, and electric vehicle charging infrastructure and public knowledge and acceptance.

The application of new tools, large-scale data, modeling, simulation, visualization, and artificial intelligence can help Tennessee plan for the future of intelligent mobility.

- ***Enhancing readiness in physical roadway infrastructure.*** Several aspects of roadway infrastructure can be considered by TDOT. These include 1) Designing and increasing the width of pavement markings and improving signs, where needed, to enhance their visibility for CAVs throughout Tennessee. Notably, TDOT is enhancing pavement markings and signs, with appropriate staffing and funding devoted to this endeavor. Also, TDOT can consider creating CAV park-and-ride facilities in the long term to make the CAV deployment in Tennessee smoother. 2) Partnering with organizations, e.g., TennSMART and academic institutions, to hold workshops addressing many individual aspects of intelligent mobility, especially roadway design changes, pavement performance changes (e.g., due to reduced wheel wander), improving pavement condition, and other physical infrastructure issues.
- ***Enhancing readiness in digital infrastructure.*** TDOT can allocate more resources to 1) Using sensing technologies such as smart cameras to detect different object types and road users, e.g., identifying trending volatile behaviors among all road users and implementing mitigation measures for stable flow. 2) In partnership with infrastructure owners and operators (IOOs), ensure that traffic signals are upgraded and their operation is smooth. 3) Developing and training a technology-savvy workforce, e.g., by arranging to offer courses in emerging technology and their safe, secure, and effective operation. 4) Establishing strong cooperation with data science experts from different organizations such as universities to harness connected vehicle data. Real-time traffic and CAV data dashboards can be developed to improve the ability of TMC operators to access and harness the data. TDOT can work with universities and the private sector to deploy a field solution for vehicle-to-everything (V2X) communications and conduct pilot testing of new dual-mode OBUs and RSUs in laboratory settings and on-road. Furthermore, research can be conducted on cooperative driving automation and scenario generation to expand operational design domains for highly automated vehicles.

- ***Enhancing readiness in electric vehicle infrastructure.*** Regarding support for transportation electrification, TDOT, TDEC, and diverse stakeholders such as the Tennessee Valley Authority and private sector companies can partner to 1) Deploy EV charging stations along interstates and critical routes in Tennessee (efforts are underway in this regard through Tennessee Electric Vehicle Infrastructure, or TEVI). 2) Develop and use an infrastructure location planning tool for creating a network of charging stations based on the future demand for EVs in Tennessee and undertake other supportive actions related to EV charging. A plan can guide the efficient deployment of charging stations by considering the development of partnerships that can help prepare communities for locating DC fast charging. Also, constructing electric vehicle parking facilities through partnerships with public building authorities can be pursued. 3) TDOT can also consider adopting the zero-emission vehicle program and mandate, which includes several types of alternative fuel vehicles.

- ***Strategies for readiness in public knowledge and acceptance.*** TDOT can improve public knowledge and acceptance using either internal resources or through the participation of universities, especially centers or institutes that focus on technology transfer activities and public awareness. Strategies to consider can include educating travelers about CAV capabilities, re-engaging AVs in complex situations when driver attention is needed and communicating the intent of CAVs to conventional vehicle drivers. Also, knowledge about alternative fuel vehicles (including EVs) can be disseminated through the Tennessee Clean Fuel Coalition, a DOE Clean City program (an initiative that TDOT's Long-Range Planning can coordinate and pursue). TDOT can seek and incorporate public feedback into intelligent mobility policies and programs. TDOT can cooperate with other private or public organizations to study EV/CAV adoption based on their specific models. One example is the Oak Ridge National Laboratory Market Acceptance of Advanced Automotive Technologies model.

To deploy smart infrastructure enablers for intelligent mobility strategies, such as automated and electric vehicles, all stakeholders need

- ***General strategies for enhancing intelligent mobility.*** The strategies mentioned below can be adopted by TDOT, with some of them supporting TDOT's Transportation System Management and Operations Program Plan. The strategies include several action items that can be easily implemented to show demonstrable progress.

  1) **Creating Roadmaps.** TDOT can develop roadmaps for physical and digital infrastructure, electric vehicle infrastructure, regulation and policy, user acceptance, partnerships with stakeholders, and workforce development. To deploy smart infrastructure enablers for intelligent mobility strategies, such as automated and electric vehicles, all stakeholders must be fully engaged in an open process. For example, intelligent transportation systems and broadband/fiber roadmaps can be developed with stakeholder input by the traffic operations division in coordination with the information technology division (responsible for computerized information resources) and transportation consultants. The Transportation Systems Management and Operations Program Plan development is currently underway at TDOT, which outlines the vision and strategies for intelligent

mobility. Furthermore, TDOT and TDEC are collaborating to develop the Tennessee Electric Vehicle Infrastructure Deployment Plan. Such activities can be expanded to achieve the broader impact of intelligent mobility technologies. Such activities can be expanded to the other areas mentioned above.

2) **Benchmarking.** Efforts can be undertaken to understand the current state-of-the-practice for statewide intelligent mobility readiness plans in other states, lessons learned, and recommendations while tracking emerging technology advances.

3) **Intelligent Transportation Systems.** Improvements in roadway, digital, and electric vehicle infrastructure technologies through ITS architecture service packages can be envisioned. A wide range of CAV service applications can be considered for implementation in Tennessee, including emergency vehicle preemption, broadcast traveler information, queue warning, work zone management, personalized traveler information, road weather motorist and warning, pedestrian and cyclist safety, and electric charging stations management.

4) **Multimodal transportation.** TDOT can identify opportunities in terms of connected, automated, and electric transportation systems that are multimodal, i.e., including freight, transit, pedestrians, and bicycles. For example, the TDOT traffic operations division staff can work with the multimodal transportation resources division staff to conceive and implement projects that deal with transit systems detecting pedestrians to increase safety or coordinate with private sector logistics companies to improve freight movement and delivery.

5) **Planning.** Intelligent mobility strategies can be integrated into long-term planning and programming processes. This activity can involve coordination between the traffic operations division and long-range planning division staff for the various plans created at TDOT, e.g., the TSMO Program Plan and the TEVI plan.

6) **Data collection.** TDOT can develop data collection and harnessing capability from new sensors, e.g., OBUs and RSUs that transmit basic safety messages and alerts or warnings. However, this will require investments of significant resources to handle CAV-related activities, including equipment deployment and data collection. Notably, CAV data collection, processing, and use are particularly challenging, given the uncertainties associated with communication technologies (i.e., Dedicated Short-Range Communication V2X technology), CAV data storage and analysis, data sharing, the requirement to have a sufficient number of OBUs on vehicles, and most importantly TDOT not owning or operating traffic signals in Tennessee.

7) **Conduct Interviews and Surveys.** Technology readiness surveys were designed and conducted for members of the TennSMART consortium by the research team. TDOT can further conduct interviews and surveys of various stakeholders, including TDOT Division Directors and staff, regarding their readiness for CAV and synergistic technologies, including electric vehicles.

8) **Workforce.** TDOT can consider creating positions for TDOT-based program managers to test and deploy CAVs (their responsibilities can be similar to ITS managers). This activity is clearly resource-intensive, requiring higher-level administrative approvals.

9) **Coordination.** Develop an external stakeholder coordination strategy, especially with IOOs, vehicle manufacturers, information technology companies, and the TennSMART consortium.

10) **Research Development and Deployment.** TDOT can further research, develop, pilot-test, and deploy intelligent mobility technologies. TDOT demonstrates the capabilities and benefits of CAVs through testbeds, e.g., I-24 smart corridor. Additionally, the Chattanooga MLK Smart City Corridor testbed and other statewide initiatives are exemplars. More comprehensive pilot testing and deployment of these technologies will help achieve transportation system improvement goals.

- ***Future research on intelligent mobility strategies.*** TDOT can conduct research on specific issues related to CAV data, harnessing the data, and investing in modeling/simulation capabilities that can directly deal with the 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. Currently, TDOT has invested resources in the I-24 Mobility Technology Interstate Observation Network (I-24 MOTION) to understand how different types of vehicles interact with each other and infrastructure to advance congestion management across Tennessee. Also, TDOT's Research Program can address the agency's research needs. However, more investments in research activities to synergize various aspects of intelligent mobility strategies are needed. TDOT should continue to invest in several aspects of intelligent mobility strategies. These would include research on the efficacy and broader impacts of intelligent mobility strategies and the potential for disruption in terms of job losses in Tennessee due to vehicle automation, e.g., losses in taxi driver and large-truck driver jobs. Further, there is a need to explore 1) how rural areas will be impacted by access to CAV and broadband technologies; 2) how transit agencies can use CAV technologies to address first mile/last mile issues; 3) how to address equity and inclusion of disadvantaged and under-represented groups in the accessibility of emerging technologies; and 4) what are the impacts of intelligent mobility strategies on land use in the long term.

The report features details about use-cases that can support the deployment of smart infrastructure in Tennessee. For instance, these include 1) installing RSUs and OBUs on personal and State Vehicles, 2) funding opportunities in IIJA, 3) options for installing communications equipment when TDOT does not own or operate traffic signals, 4) communications considerations associated with connected vehicle equipment, 5) use cases showing CAV data storage/transmission considerations, and 6) staffing needs associated with smart infrastructure deployments.

Overall, this report highlights investments needed in intelligent mobility strategies from a statewide perspective. In this regard, it is critical to nurture partnerships between stakeholders, i.e., government agencies, industry, and academic institutions, as is workforce development. Specifically, investments are needed in innovative solutions encompassing physical infrastructure, digital and smart infrastructure, electric vehicles, and charging infrastructure. Furthermore, state policies and regulations are needed to guide the safe development, deployment, and adoption of new technologies, considering federal policy guidance. The application of new tools, large-scale data, modeling, simulation, visualization, and artificial intelligence can help Tennessee plan for the future of intelligent mobility.

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Glossary of Key Terms and Acronyms

ACC - Adaptive Cruise Control
AWARE - Advanced Warning and Risk Evasion
CACC - Cooperative Adaptive Cruise Control
CAV – Connected and Automated Vehicle
CDA - Cooperative Driving Automation
CTP - California Transportation Plan
C-V2X - Cellular Vehicle-to-Everything
DCFC - Direct Current Fast Chargers
DET - Drive Electric Tennessee
DMS - Dynamic Message Sign
DSRC - Dedicated Short-Range Communication
EV – Electric Vehicle
FHWA - Federal Highway Administration
HAR – Highway Advisory Radio
HIP - Highway Infrastructure Program
HOV - High-Occupancy Vehicle
ICM - Integrated Corridor Management
ISSE - Institute for a Secure and Sustainable Environment
I2V – Infrastructure-to-Vehicle
ITS JPO - Intelligent Transportation Systems Joint Program Office
LED - Light-Emitting Diode
LPC - Local Power Companies
LTE – Long-Term Evolution
MPO - Metropolitan Planning Organization
OBU – On-Board Unit
ODD - Operational Design Domain
ORNL - Oak Ridge National Laboratory
OVDS - Over Height Vehicle Detection Sensor
PBA - Public Building Authority
PVMS - Portable Variable Message Sign
RD&D - Research, Develop and Deploy
RDS - Radar Detection System
RSU – Road-Side Unit
SAE - Society of Automotive Engineers
SAV - Shared Automated Vehicles
SCMS - Security Credential Management System
SPaT - Signal Phasing and Timing
TDEC - Tennessee Department of Environment and Conservation
TIM - Traveler Information Message
TMC - Traffic Management Center
TVA - Tennessee Valley Authority
US DOE - U.S. Department of Energy
US DOT - U.S. Department of Transportation

V2V – Vehicle-to-Vehicle
VDS - Video Detection System/ Video Detection Sensors
WAS - Worker Alert System
WWPS - Wrong-Way Driving Prevention Systems
WZIA - Work Zone Intrusion Alert
ZEV - Zero-Emission Vehicle

Introduction

The Tennessee Department of Transportation and the TennSMART consortium consisting of academic institutions, government agencies, and private sector companies, has led the development of a vision covering CAV technologies and solutions encompassing electrification and multimodal personal and freight movements while ensuring cybersecurity. Transportation innovations captured through these intelligent mobility strategies are critical to achieving economic competitiveness, safety, smoother movement of people and goods, and energy and environmental improvements. To reiterate, intelligent mobility encompasses connected and automated vehicles, electric vehicles, and multi-modal personal and freight movements, all done safely and securely. It is enabled by large-scale (big) data, tools for transportation modeling and artificial intelligence, simulation and visualization, multi-scale connectivity, and high-performance computing. To assess intelligent mobility strategies in Tennessee, this report first provides a framework by exploring focus areas, including physical infrastructure, digital infrastructure, electric vehicle infrastructure, policies, regulations, and associated public knowledge and acceptance. A key focus is on developing supporting information for readiness to enhance intelligent mobility in Tennessee. Readiness or preparedness in this context applies to emerging solutions that include physical infrastructure, digital infrastructure (e.g., connectivity and automation), electric vehicle infrastructure, policy and regulations, and public acceptance. To develop and implement actionable and innovative strategies for new technology solutions, stakeholders should be willing to invest in research, development, pilot testing, and deployment. Also, they should be willing to invest in proactive strategies to improve the transportation system rather than responding to problems after they occur.

The focus is on developing supporting information for readiness to enhance intelligent mobility in Tennessee. Readiness or preparedness in this context applies to emerging solutions that include physical infrastructure, digital infrastructure, electric vehicle infrastructure, policy and regulations, and public acceptance.

As mentioned in previous reports, the key resources that can be leveraged in Tennessee 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. To prepare for intelligent mobility in Tennessee, strategies to consider are provided in this report. TDOT can consider these intelligent mobility strategies in coordination with TennSMART and other partners.

1.1 Research objectives and purpose

The overall goal of this project is to get a baseline for intelligent mobility readiness in Tennessee. The research objectives are as follows:

- Present a comprehensive review of intelligent mobility in Tennessee.
- Develop a business case for intelligent mobility strategies by exploring their expected benefits and impacts.
- Provide a framework for Tennessee's intelligent mobility readiness assessment and perform a readiness assessment based on an extensive internet-based survey of TennSMART consortium members.
- Benchmark and review aspirational states in the US regarding intelligent mobility strategies.

The report recommends intelligent mobility strategies to provide valuable insights into what actions would need to be taken in the future to enhance the planning and performance of the transportation system in Tennessee.

1.2 Methodological approach

The methodological approach entails the review of relevant publications, text mining, use of data, development of conceptual frameworks, and implementation of surveys.

- Regional Tennessee Intelligent Transportation Systems (ITS) architecture reports were collected to provide an overview of intelligent mobility in Tennessee. A text mining analysis was conducted to analyze the content. Manual extraction of data from the reports is visualized. Additionally, data on electric vehicle infrastructure was collected from the Tennessee Department of Environment and Conservation (TDEC) and a gap analysis of roadways needing coverage of fast-charging stations is presented in this report.
- Tennessee and national data were collected and analyzed to develop a business case for intelligent mobility strategies and estimate their potential benefits and impacts.
- A readiness survey was developed and conducted to assess intelligent mobility based on the focus areas of physical, digital, and electric vehicle infrastructure and public knowledge and acceptance.
- To benchmark aspirational states regarding intelligent mobility strategies, identification, and collection of the information were done by reviewing and collecting publications from the state department of transportation websites for California, Florida, Michigan, and Minnesota.

1.3 Expected outcomes

This project will have numerous expected benefits for TDOT, including:

- Investment opportunities for intelligent mobility strategies are identified.
- Estimates of the potential benefits that intelligent mobility strategies can provide in Tennessee are quantified.
- The readiness survey reveals the strength and areas needing improvement for various infrastructures and public acceptance of intelligent mobility strategies

- Consideration of innovative strategies for consideration in Tennessee is enabled through benchmarking.

Given their impacts, integrating automation, vehicles' connectivity, and electrification is a key societal goal. This is enabled by growing computational power, the ubiquity of ambient sensors, large-scale (big) data, and emerging modeling/Artificial Intelligence techniques. The report points to the choice that states, regions, and cities have in becoming more accessible, safer, energy-efficient, cleaner, and supportive of diverse travel needs through multimodal cyber-physical systems or becoming sprawled out metropolises with heavy dependence on single-occupant vehicles, fossil fuels and associated costs of congestion, pollution, and degraded air quality.

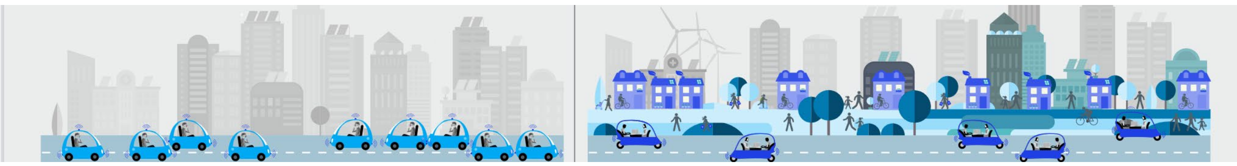


Figure 1-1 Sprawl versus compact, mixed-use, multimodal development with emerging technologies. (Source: McKinsey. https://www.mckinsey.com/. What steps must cities take to realize the full benefits of autonomous vehicles?)

1.4 Report structure

The report is organized into the following sections:

Chapter 1 – Introduction.

Chapter 2 – Overview of Intelligent Mobility in Tennessee. This chapter discusses an overview of intelligent mobility in Tennessee.

Chapter 3 – Business Case-Expected Benefits of Intelligent Mobility. This chapter highlights the impacts and benefits of intelligent mobility strategies.

Chapter 4 – Readiness Assessment for Tennessee. This chapter discusses the intelligent mobility readiness assessment for Tennessee.

Chapter 5 – Benchmarking Peer and Aspirational States. This chapter provides initial information about benchmarks for Tennessee's readiness and strategies from aspirational agencies in other states.

Chapter 6 – Conclusions and Recommendations. The findings are summarized along with the contributions of the reported work. A discussion of recommendations and lessons learned is provided.

Overview of Intelligent Mobility in Tennessee

2.1 Background and framework

This chapter summarizes intelligent mobility in Tennessee, with a state-wide review focusing on available digital infrastructure. While Tennessee faces physical infrastructure challenges regarding roads needing repair and improving structurally deficient bridges (4.4%), innovative solutions are also needed for growth-related congestion in major cities, implementing safety countermeasures, and environmentally friendly technologies. Relevant information on innovative intelligent transportation system inventories across Tennessee comes from several sources that include 1) ITS architecture reports for 11 cities in Tennessee (from Bristol to Memphis), the statewide ITS architecture report, other TDOT sources (such as integrated ITS SmartWay systems). Additionally, summaries of national-level inventories for transportation infrastructure technologies are provided, and TDEC sources are used for electric vehicle charging infrastructure.

Starting with digital infrastructure, Traffic Management Centers (TMCs) are the backbone of intelligent transportation systems in Tennessee. They operate in different regions of Tennessee to monitor traffic operations and communications. The TMCs in Tennessee have sufficient equipment and resources to enable the diffusion of emerging technologies. These resources include TMC operators, HELP vehicles and operators, information technology (IT) technicians, closed-circuit television (CCTV) cameras, speed detectors, dynamic message signs (DMS), highway advisory radio (HAR) transmitters, and portable variable message signs (PVMS). However, inventories are either low or non-existent for 1) changeable speed limit signs, 2) dynamic message signs and over lane signs for active lane management, 3) roadside and onboard devices for connected vehicles and new sensors, 4) software for context-relevant applications/user services, 5) fiber for fast communication of data, and 6) latest traffic control devices (e.g., traffic signal upgrades to cabinets, communication devices that can perform edge computing, and new signal controllers that can communicate with roadside units, radar detection sensors, and 360-degree cameras for detection and traffic surveillance).

Notably, establishing the appropriate cyber-physical eco-system is critical, which also entails the collection, processing, management/storage, and harnessing of CAV (Vehicle-to-Everything) communications data. Providing web-based platforms for vehicle location and geo-referencing, Signal Phasing and Timing (SPaT), MAP data, Traveler Information Message (TIM), and message authentication are important considerations for readiness. Additionally, software applications from the ITS architecture can be beneficial in different contexts. There is a need to identify connected vehicle mobility and safety applications/user services, e.g., lane management and control system or work zone alerts, in different regions of Tennessee.

2.2 A conceptual framework

According to the TennSMART consortium, intelligent mobility is defined as "the application of innovative, efficient, and environmentally friendly solutions for moving people and goods." It envisions an automated, connected, electric, and shared transportation system that is multimodal, secure, and efficient. As shown in Figure 2-1, it consists of five focus areas: (1) CAVs, (2) EVs, (3) Cybersecurity, (4) Freight Efficiency, and (5) Multimodal Commuting.

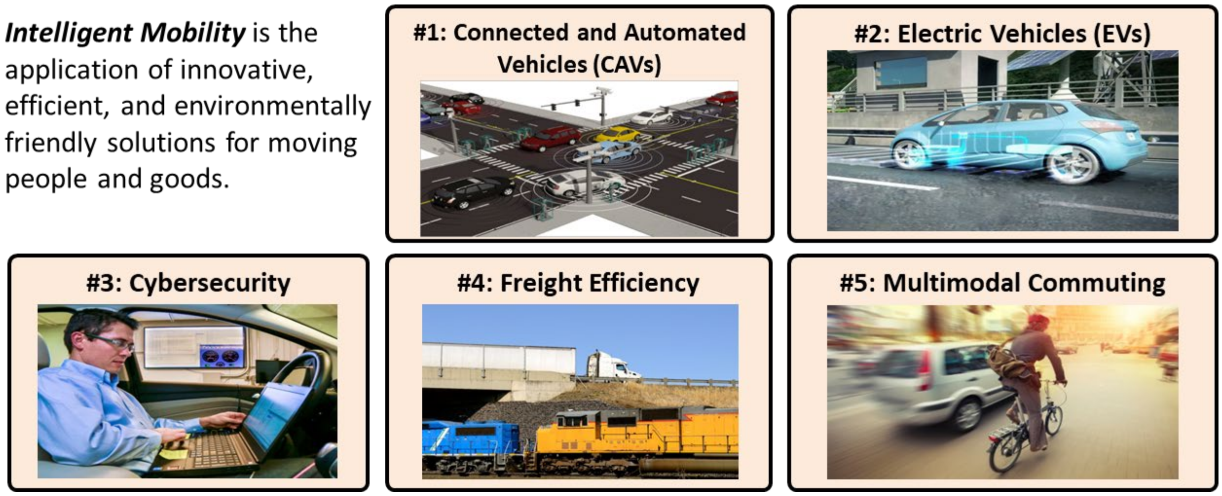


Figure 2-1 Definition of Intelligent Mobility

Connected and Automated Vehicles: Connected and automated vehicles use sensors computation, data science, algorithms, and communications for vehicle-to-everything interactions. The continued growth of CAV technologies is expected to significantly change the way vehicles move and how travelers achieve mobility. CAVs will significantly impact mobility and many other facets of transportation at scales ranging from the individual vehicle level to the transportation system level. Transportation networks must be readied for the large-scale deployment of CAV technologies in the near future.

Electric Vehicles: Electric vehicles use a fossil fuel alternative for propulsion, and they need charging infrastructure to obtain energy. Electric vehicles are environmentally friendly. Transportation networks are preparing for EVs by enhancing charging infrastructure, accelerating their diffusion.

Cybersecurity: As digital and physical infrastructure converges, vehicles and smart infrastructure become more vulnerable to cyber-attacks. Therefore, it is important to develop systems that can transmit trustworthy messages from vehicles and the infrastructure and address individuals' identity and privacy needs. It is critical to address cybersecurity and privacy risks associated with emerging technologies.

Freight Efficiency: Transportation of freight is an increasingly important aspect of an increasingly connected society dependent on e-commerce. Freight efficiency can be enhanced by developing hybrid electric heavy-duty vehicles, truck platooning technologies, and automating freight delivery. Freight efficiency is a crucial intelligent mobility strategy. There is a need to understand how emerging technologies can improve the delivery of goods to consumers.

Multimodal Commuting: Multimodal transportation refers to the way people travel by multiple and diverse means of transportation such as bus, subway, light rail, electric scooter, walking, and bicycling. A key aspect of multimodal commuting is to facilitate mode shifts that enhance mobility and convenience for travelers.

The framework of the intelligent mobility provided above may be restrictive, e.g., CAVs are part of intelligent transportation systems, which offer a broader set of transportation improvement strategies. Therefore, to broaden and operationalize the framework, five areas can be considered: (1) physical infrastructure, (2) digital infrastructure, (3) electric vehicle infrastructure, (4) public knowledge and acceptance, and (5) policy and regulation. A brief description of these areas is as follows.

Physical Infrastructure: Physical infrastructure includes all physical assets associated with roads (i.e., the roadway itself, markings, signage, safety barriers, earthworks, drainage, and structures). Also included are public transit systems as well as pedestrian and bicycle facilities.

Digital Infrastructure: Digital infrastructure provides the information technology foundation for operating the transportation system. It includes transportation sensors (e.g., cameras, loops, and radars), cable, information dissemination equipment (e.g., radio transmitters and message signs), communication devices, traffic signal controllers, and transportation management centers with associated data centers and equipment. Digital infrastructure also includes cloud-hosted services, data centers, security credentialing, and in-vehicle devices/systems (onboard units and sensing systems).

Electric Vehicle Infrastructure: Electric vehicle infrastructure includes structures, machinery, and equipment needed to support electric vehicle charging, as well as electricity generation and distribution.

Public Knowledge and Acceptance: Public knowledge and acceptance signify communicating and disseminating scientifically based knowledge to the public to educate them about transportation issues (e.g., safe mobility). This is often done through media (e.g., smart devices and the internet).

Policy and Regulation: Policy and regulation comprise transportation system goals (e.g., mobility and safety), mechanisms for transportation investments, and relevant regulations (e.g., safety standards of CAVs on public roads).

Broadly speaking, intelligent mobility provides efficient use of facility resources using existing and emerging technology as well as coordination among agencies and stakeholders. Based on the literature, the application of connected and automated vehicles, electrification, and shared mobility services provide opportunities to move the needle on existing and emerging technologies in Tennessee. Concomitantly, the collection of big data, archival, and analytics, including artificial intelligence techniques, provides unprecedented opportunities. Examples of strategies in smart mobility include opportunities to:

- Enable vehicle and infrastructure communication for improved mobility and safety. This will entail deploying roadside units that can communicate with in-vehicle units and the collection as well as analysis of system performance using trajectories constructed from basic safety message data (5G cellular vehicle-to-everything (C-V2X) communication data) and high-resolution traffic surveillance camera data.
- Identifying hotspots along smart corridors in terms of congestion, safety, energy, and emissions.
- Designing experiments to test and deploy cutting-edge technologies such as adaptive cruise control (ACC) and cooperative adaptive cruise control (CACC).
- Using simulations or digital twins to anticipate edge cases that can detract from the safe movement of vehicles.

The I-24 Smart Corridor in Tennessee is an example of using new technologies to improve transportation performance. Specifically, the I-24 Smart Corridor Study has envisioned and evaluated multiple capacity and operational improvements to manage congestion and improve safety along the I-24 corridor. In this context, TDOT is forming partnerships with local authorities to implement the I-24 Smart Corridor initiative. The objectives include increasing travel time reliability and reducing crashes on the I-24 Smart Corridor. The proposed technological improvements deployed on I-24 Smart Corridor include emergency pull-offs, ramp extensions, and connected vehicle infrastructure. Additionally, dynamic lane use control, variable speed limits, and queue warning applications are anticipated, along with ramp metering. Notably, these strategies are consistent with the reviewed literature and reflect leadership in bringing together the emerging technologies at the core of intelligent transportation systems, especially automation and connectivity. Implementing these strategies requires a detailed evaluation and better understanding of the impacts of these improvements to replicate intelligent mobility strategies widely and inform future smart corridor transportation projects.

2.3 Outline of Tennessee statewide ITS architecture

According to TDOT, an ITS architecture is defined as a high-level plan for how ITS can address transportation needs in a state or region. The Federal Highway Administration (FHWA) requires that those projects or programs to use federal funds for ITS are identified in the ITS architecture. In 2019, the Tennessee Statewide Intelligent Transportation Systems Architecture was released by TDOT. This document provides updates to the previous ITS architecture document developed in 2006 by taking the national-level framework, Architecture References for Cooperative and Intelligent Transportation, into account. Focusing on the application of technology to deal with challenges in transportation, it aims to offer the framework for planning, defining, and integrating technological advancements in transportation in the state of Tennessee. Notably, it covers important issues regarding future vehicle connectivity and automation.

2.4 ITS system inventory (existing assets)

Currently, in Tennessee, four TMCs are operated 24 hours a day, 7 days a week in Knoxville, Chattanooga, Nashville, and Memphis to cover Regions 1, 2, 3, and 4, respectively. The TMCs monitor traffic operations and communications to detect and manage incidents on the road by harnessing different types of ITS devices. According to TDOT, the TMCs are operated with 551 cameras, 183 message signs, 1107 roadway detection systems, and 49 video detection systems. Camera Video Surveillance monitors congested freeways and provides improved incident management capabilities, while Radar Detection System (RDS) and Video Detection System (VDS) monitor traffic flow helping calculate travel times for routes. Roadway traffic sensors report traffic counts, speed, and travel time, while DMSs are mounted over interstate travel lanes providing traffic and construction information to motorists and other key messages about driving. The ITS equipment and resources of each TDOT region are presented in TABLE 2-1 (Source: TDOT Website [2]).

Table 2-1 NUMBER OF INTEGRATED ITS EQUIPMENT AND RESOURCES IN TENNESSEE REGIONS

ITS EQUIPMENT AND RESOURCES	*Region 1 (Knoxville)*	*Region 2 (Chattanooga)*	*Region 3 (Nashville)*	*Region 4 (Memphis)*
TMC Operators	20	17	22	17
HELP Operators	17	16	35	25
HELP Vehicles (Updated TDOT's TMO, 2022)	21	24	41	28
IT Technicians	N/A	2	3	2
Interstate Miles (SmartWay)	86	73	183	95
Interstate Miles (HELP Routes)	52	47.5	146	13
CCTV Cameras	112	110	178	126
Speed Detectors	241	217	234	306
Dynamic Message Signs (DMS)	35	37	70	48
Highway Advisory Radio (HAR) Transmitters	20	7	14	16
HAR Signs w/ Beacons	33	20	47	40
Portable Variable Message Signs (PVMS)	5	N/A	3	N/A
Fog Zone Swing Gates	N/A	6	N/A	N/A
ESS Fog Sensors	N/A	9	N/A	N/A
Warning Beacons (Fog Zone)	N/A	6	N/A	N/A
Changeable Speed Limit Signs	N/A	10	N/A	N/A
Secure Control Center HUB (Fog Zone)	N/A	1	N/A	N/A
Video Detection Sensors (VDS)	N/A	N/A	N/A	20
Overheight Vehicle Detection Sensor (OVDS)	N/A	N/A	N/A	5

2.5 ITS needs and services defined: Connected Automated Vehicles

The architecture defines a variety of ITS needs in the state of Tennessee. Importantly, it suggests CAVs as one of the 16 key items for ITS needs. Concerning connected vehicle applications, Tennessee has plans to deploy communication devices in the I-24 corridor to enhance traffic safety and efficiency. C-V2X technology will be deployed for different types of operations and services that rely on basic safety messages, SPaT, and TIMs. As noted in a previous report, the transition from Dedicated Short-Range Communication (DSRC) vehicle-to-everything (V2X) to C-V2X is underway. DSRC V2X technology has been planned at traffic signals in Tennessee, e.g., 152 roadside units (RSUs) were planned by TDOT using DSRC V2X and Bluetooth combination units in the I-24 Smart Corridor. Similarly, many pilot programs and testbeds around the nation have deployed DSRC V2X technology and are now impacted by the Federal Communication Commission's ruling on opening the safety band. The implication is that existing DSRC V2X deployments (and future deployments) should migrate to C-V2X. Notably, dual-mode RSUs are available along with LTE C-V2X. The transition is being carried out by working with vendors.

However, this involves more than swapping DSRC V2X devices with LTE C-V2X devices. Complicating the migration to C-V2X is TDOT's role in traffic signal operations and maintenance, which is limited to funding and designing/construction of traffic signals, but local agencies operate and maintain signals. Hence local agencies can work with TDOT to operate and maintain C-V2X technology. Moreover, C-V2X technologies are not widely tested and interference from unlicensed devices and channel congestion can adversely affect safety-critical applications. Given the substantial uncertainties in transitioning to these technologies, TDOT's discussions with infrastructure owners and operators IOOs about the operation and maintenance of C-V2X may have to wait for the resolution of issues, while TDOT can invest in experimentation with dual-mode devices. Recommendations are provided about dual-mode devices, CAV data, and needed research and testing. Regarding automated vehicle applications, the ITS architecture suggests several automated vehicles (e.g., passenger vehicles, shuttles) to support transit and personal motor vehicle use. Additionally, shared automated vehicles can be encouraged to take full advantage of resources.

2.6 Key relevant ITS service packages in Tennessee

The architecture also suggests service packages, and key service packages relevant to intelligent mobility are summarized in TABLE 2-2. Most of the service packages relevant to intelligent mobility are related to CAVs, while some are related to cybersecurity, freight efficiency, and multimodal commuting. For instance, the existing service package Broadcast Traveler Information (TI01) provides a digital broadcast service disseminating traveler information to all equipped travelers within range. The planned service package Privacy Protection (SU07) provides the privacy protection essential to the operation of connected vehicle applications by obscuring the network identifiers of mobile devices. More detailed descriptions of service packages are available at TDOT website [3].

2.7 Text analysis of regional ITS Architectures in Tennessee

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 in reports. Using text analysis software allows for an unbiased, systematic review of a large body of literature, with valuable outputs such as word clouds and extracted topics combined with statistical information about the collected corpus. Text analysis outputs include keyword frequency clouds, key phrase frequency clouds, and a list of detected topics. The data used in the text analysis was completed on 11 reports of regional ITS architectures in Tennessee using QDA Miner 8 in combination with WordStat 5.

To show the results, visualization tools such as "word cloud" and "phrase cloud" are used to display the results obtained from statistical analysis. Word cloud plots are used to demonstrate the frequency statistics of the word lists. In the word cloud, frequencies are converted to words of different sizes. The more frequently the word appears in the studies, the larger the word would be in the plot. Figure 2-2 demonstrates the word and phrase cloud plot based on the frequency statistics of the word list and phrase list regarding the Tennessee regional ITS architecture reports. The word cloud emphasizes the words "Information," "Transit," "Management," and

“Emergency” are some of the most frequent words listed. Likewise, the phrase "Service Package," "Travel Information," "Traffic Management," “Traffic Signal,” and “Incident Management” are the most frequent phrases listed. It can be inferred that the focus of the Tennessee regional ITS architectures is on improving travel time and traffic management as well as emergency vehicles.

TABLE 2-2 KEY RELEVANT ITS SERVICE PACKAGES FROM TENNESSEE STATEWIDE ITS ARCHITECTURE

Service Package	***Service Package Name***	***Status***	***Relevance to Intelligent Mobility***
CVO01	Carrier Operations and Fleet Management	Existing	Freight Efficiency
CVO02	Freight Administration	Existing	Freight Efficiency
CVO12	HAZMAT Management	Existing	Freight Efficiency
PM04	Regional Parking Management	Existing	Multimodal Commuting
PT18	Integrated Multi-Modal Electronic Payment	Planned	Multimodal Commuting
ST09	Connected Eco-Driving	Planned	CAVs
SU01	Connected Vehicle System Monitoring and Management	Planned	CAVs
SU07	Privacy Protection	Planned	Cybersecurity
TI01	Broadcast Traveler Information	Existing	CAVs
TI04	Infrastructure-Provided Planning and Route Guidance	Existing	Multimodal Commuting
TM04	Connected Vehicle Traffic Signal System	Planned	CAVs
TM21	Speed Harmonization	Planned	CAVs
VS01	Autonomous Vehicle Safety Systems	Planned	CAVs
VS02	V2V Basic Safety	Planned	CAVs
VS03	Situational Awareness	Planned	CAVs
VS05	Curve Speed Warning	Planned	CAVs
VS06	Stop Sign Gap Assist	Planned	CAVs
VS07	Road Weather Motorist Alert and Warning	Planned	CAVs
VS08	Queue Warning	Planned	CAVs
VS09	Reduced Speed Zone Warning / Lane Closure	Planned	CAVs
VS10	Restricted Lane Warnings	Planned	CAVs
VS13	Intersection Safety Warning and Collision Avoidance	Planned	CAVs
VS14	Cooperative Adaptive Cruise Control	Planned	CAVs
VS17	Traffic Code Dissemination	Planned	CAVs

Figure 2-2 Word cloud of high frequency words (left) and phrase cloud of high frequency phrases (right) among regional Tennessee ITS architectures

TABLE 2-3 shows the results of topic extraction. Higher coherence indicates higher variability explained by the topic. Having the highest coherence, the topics of "Workforce," "Safety," "Fiber Optic," and "Emergency Vehicles" are the most important topics discussed among the Tennessee regional ITS architectures.

TABLE 2-3 RESULTS OF TOPICS EXTRACTION

Topics	*Keywords*	*Coherence*	*Freq.*	*% Cases*
Workforce	Agents; employees; omission; hold; legal; designated; agrees; damages; reputation; injury; property damage; user agrees; act or omission; damages to TDOT; personal injury; dissemination of information	0.616	346	90.00%
Safety	Death; property damage; reputation; injury; privacy; termination; damages; legal; personal injury; damages to TDOT; dissemination of information; act or omission; including but not limited; CCTV system	0.579	251	90.00%
Fiber Optic	Optic; fiber; dark; licensed; Comcast; fiber optic; dark fibers; network routes; fiber-optic network; license agreement	0.549	322	70.00%
Emergency Vehicles	Quickest; safest; incident; emergency vehicles; facilitate the safest quickest arrival; routing of emergency vehicles; emergency services; emergency operations; emergency vehicles to incidents; traffic signal preemption; emergency dispatch; emergency management; area alerts; incident management; incident response; disaster or other emergency situation; emergency dispatch requests; emergency management agencies; emergency plan; emergency traffic control; manage evacuation and reentry; tactical decision support;	0.382	2205	100.00%

2.6 Intelligent transportation systems and electrification deployment cases in Tennessee

The following case studies are provided to complete the picture of intelligent mobility activities in Tennessee [4].

Freight Efficiency-SmartPark Technology Demonstration Project, Phase II: A Truck Parking Information System pilot led by the Federal Motor Carrier Safety Administration was tested in a public rest area near Athens, Tennessee, in 2016 with several system components including detectors, CCTV cameras, on-site processor, off-site server, DMSs, and Interactive Voice Response system. The main goal of this pilot testing was to analyze the system's efficacy in disseminating real-time parking availability information to truck drivers on the road. The pilot reveals that detectors should be oriented appropriately to the roadway and calibrated daily.

Multimodal Commuting-FHWA Bicycle-Pedestrian Count Technology Pilot Project: In 2015, FHWA initiated a one-year Bicycle-Pedestrian Count Technology Pilot Project. The goal of this project was to increase the capacity of Metropolitan Planning Organizations (MPOs) to establish and operate effective bicycle and pedestrian count programs. Memphis, Tennessee, was one of the 10 MPOs that participated in this pilot project. This project demonstrates that automated bicycle-pedestrian counters can save time and provide the ability to track continuous data in the long term while suggesting that data collected with automated counters can be validated with manual spot checks.

Safety-Wrong-Way Driving Prevention Systems: An evaluation of commercially available Wrong-Way Driving Prevention Systems was conducted at off-ramps in Nashville, Tennessee. The evaluation was first performed in a closed environment without external traffic, followed by one-month field testing based on five criteria: accuracy, responsiveness, live tracking, cost, and other factors. The evaluation results reveal that the flashing light-emitting diode (LED) equipped wrong-way sign requires a short response time to ensure it is activated and seen before vehicles pass the sign.

Safety-Work Zone Alert Systems: In 2019 and 2020, an evaluation was performed to assess three existing Work Zone Intrusion Alert (WZIA) technologies in Tennessee: Intellicone, Advanced Warning and Risk Evasion (AWARE), and the Worker Alert System (WAS). All three WZIA technologies were user-friendly, easy to deploy, and durable. Especially, AWARE, which is a radar-based warning system, is perceived by workers to be more effective and beneficial (100% of workers) than WAS (89%) and Intellicone (88%). AWARE was also the most durable and the least likely to raise false alarms.

Electrification-EV fast-charging infrastructure: TDEC and the Tennessee Valley Authority (TVA) are partnering to develop a statewide EV fast-charging network to power the growth of EVs across Tennessee and reduce barriers to transportation electrification. As of August 2021, only 23 fast-charging locations are currently operating in Tennessee that are open to all consumers and support both charging standards common to EVs.

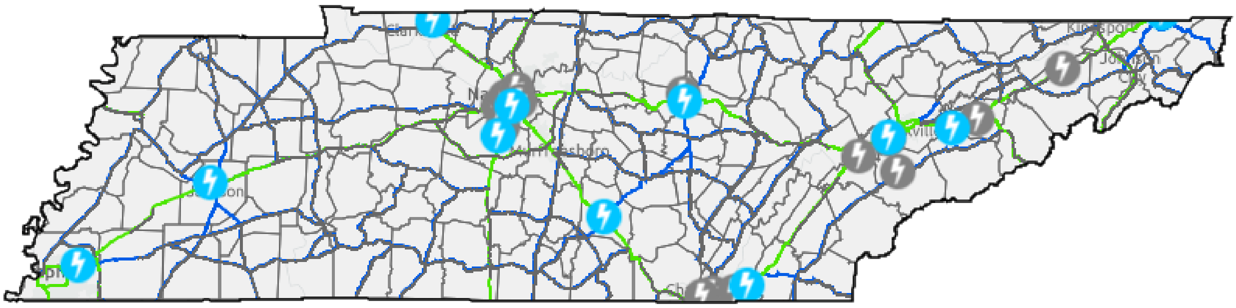


Figure 2-3 The DC fast-charging network in Tennessee

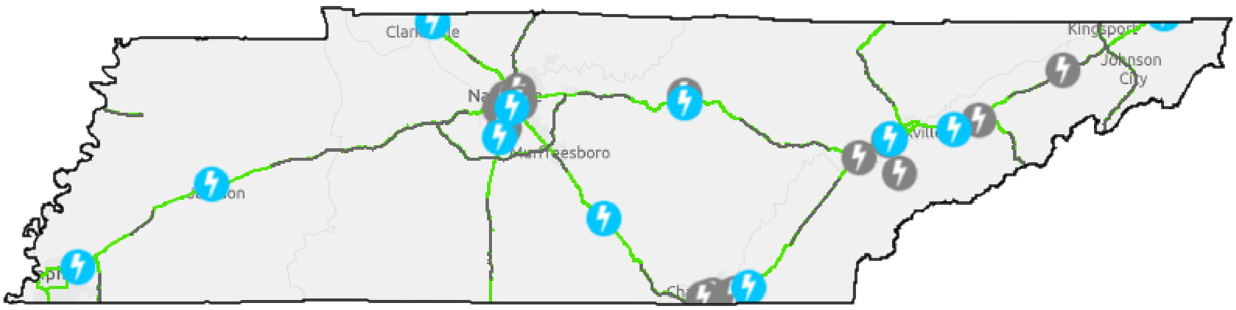


Figure 2-4 The DC fast-charging network of major highways in Tennessee

Note: Green demonstrates primary corridors covered by DC fast chargers, gray demonstrates incomplete primary corridors.

Business Case-Expected Benefits of Intelligent Mobility

3.1 Transportation costs and impacts in Tennessee

The business case for intelligent mobility readiness and expected benefits from intelligent mobility solutions are discussed in this chapter. The review of ongoing research on the impact of intelligent mobility strategies is a composite of research done at the national and state levels. TABLE 3-1 below provides information about the extent of problems and impacts of innovative transportation solutions in terms of economic competitiveness, safety, mobility, energy, and environment. These costs are based on data collected from TDOT (e.g., safety and national sources).

Intelligent mobility is expected to provide substantial benefits in terms of safety, mobility, energy, and environment.

TABLE 3-1 TRANSPORTATION COSTS AND IMPACTS IN TENNESSEE

Economic Costs	*Safety*	*Traffic flow & congestion*	*Energy and Efficiency*	*Health and Environment*
• *Congestion costs the economy $4.2 billion in 2020* • *$25 billion annual economic cost and societal harm from crashes*	• 1,325 lives were lost in 2021 on TN roadways • Estimated 66,000 people were injured in crashes in 2021 • Vulnerable road user/bike and ped crashes (177 pedestrian deaths in 2021)	• 225 Million hours spent in delays annually	• 83 million gallons of fuel are wasted annually • $0.6 trillion in goods shipped by truck each year	• Greenhouse gases • Public health impacts

Safety is used to demonstrate the costs. Specifically, to quantify the economic costs of crashes, the first step is to visualize the total deaths and pedestrian deaths in Tennessee. Figure 3-1 shows the total roadway deaths in Tennessee from 2011 to 2021 and Figure 3-2 shows the equivalent pedestrian deaths. Both show an increasing trend, with total fatalities going from 937 people to 1326 in 10 years and pedestrian fatalities from 83 to 177 (with a dip further to 68). The relative increase in total fatalities is 41.5%, whereas the increase in pedestrian fatalities is substantially larger at 113.3%. Thus, fatalities for pedestrians have increased at a higher rate than total fatalities in Tennessee.

There is a notable increase in the total and pedestrian deaths during 2020 and 2021, despite the reduction in travel due to COVID in 2020 and 2021. Compared to 2019, when there were 1136 total deaths, the deaths in 2020 and 2021 were 1217 and 1326, respectively. This represents 7.1% and 16.7% increases. Pedestrian deaths seem to increase at a larger rate, perhaps due to more walking during the pandemic. Specifically compared to 2019, when there were 148 pedestrian deaths, 2020 and 2021 saw substantial increases at 172 and 177 fatalities. This is a 16% and 20% increase compared to 2019, based on the data presented in Figure 2 below [5].

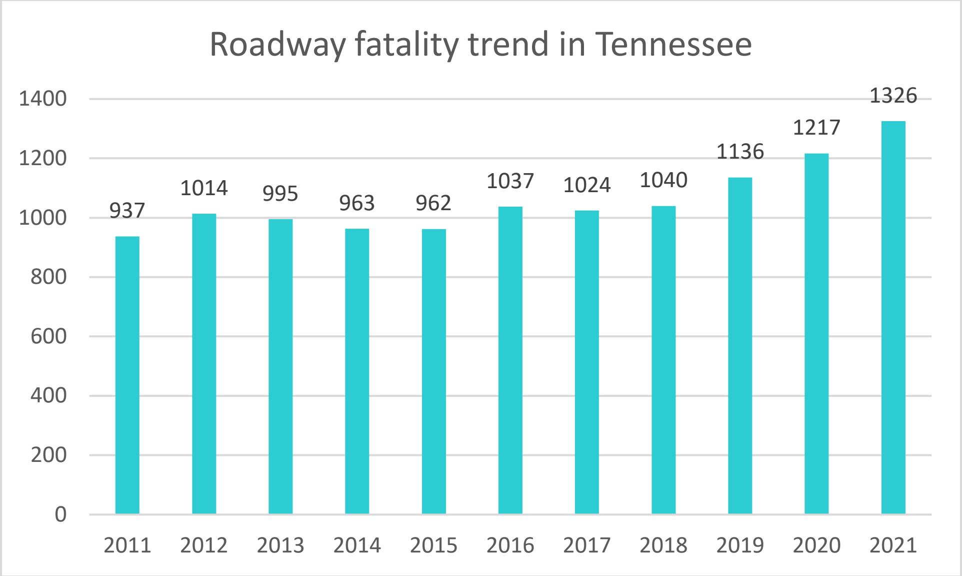


Figure 3-1 Yearly Total Roadway Fatalities in TN (2011-2021)

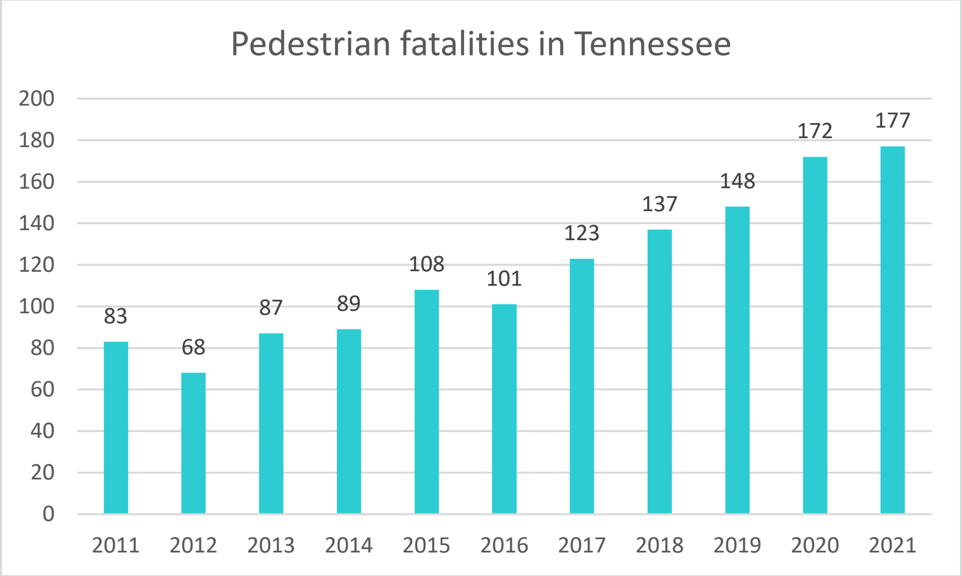


Figure 3-2 Yearly Pedestrian Roadway Fatalities in TN (2011-2021)

The descriptive analysis of means and standard deviation shows that, on average, 1059 deaths occur every year, which is about three deaths every day. The standard deviation in the data is substantial at 119.9. The minimum number of deaths in any year is 937 and the maximum is 1326 (in 2021), representing a wide range. Similarly, there is one pedestrian death every three days, and the mean is 117.5 deaths per year, with a standard deviation of 36.8. The minimum yearly number of deaths is 68 and the maximum number of deaths is 177. Notably, the costs of roadway deaths alone are staggering at $11.96 billion per year when using $11,295,400 as the social and economic cost of a fatality [6]. The costs of pedestrian deaths are high and increasing at a higher rate. Specifically, the cost of pedestrian deaths averages at $1.33 Billion per year.

3.2 Estimated reductions in costs and economic benefits of intelligent mobility

A framework developed for conceptualization consists of policies, goals, actions, and context, which are explained below. Specifically, policies articulate goals, e.g., economic competitiveness, public health and safety, mobility and reduction in congestion, clean environment, and reduction of dependence on fossil fuels. Polices such as the infrastructure investment and jobs act provide transportation funding to achieve the articulated goals. The actions funded by policies can include supporting telecommunications and connectivity, advancing automation, applying modeling and simulation, applying artificial intelligence techniques to monitor and improve system performance, enhancing electric vehicle infrastructure, supporting connected devices, and other smart city strategies. The actions must be implemented in diverse contexts, characterized by land use, social and economic factors, and transportation networks, for which the relevance of specific actions must be determined. The actions associated with intelligent mobility are defined broadly, as mentioned before. For example, solutions to air pollution through emissions reductions can range from using catalytic converters to better planning strategies shown in Figure 3-3, with alternative fuel vehicle technologies as one option. Similarly, many intelligent transportation system technologies can be viewed as options. The Intelligent Transportation Systems architecture provides a resource for deploying emerging CAV and more conventional ITS technologies.

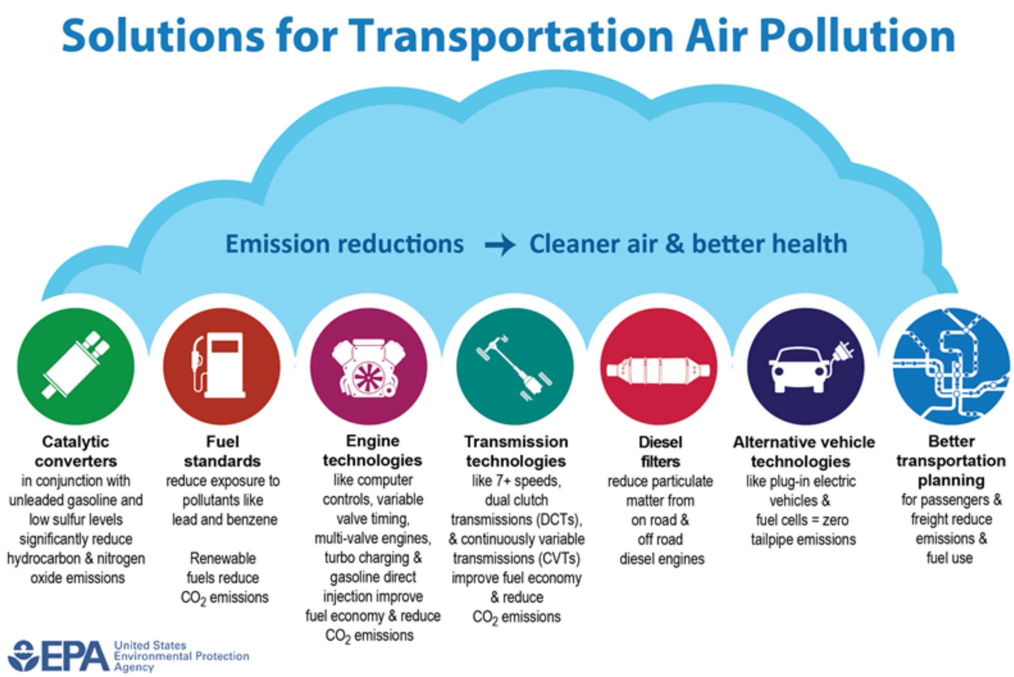


Figure 3-3 Solutions for transportation air pollution reduction. Source: EPA

Estimating the reductions in costs due to intelligent mobility strategies is based on research conducted by the team, reports from reputable companies (McKinsey and Co.) and organizations (Insurance Institute for Highway Safety), and data collected from TDOT and national sources such as https://www.fueleconomy.gov. The estimated economic benefits (e.g., from the redevelopment of parking lots) and reductions in costs of crashes and emissions due to intelligent mobility strategies of automation and electrification are summarized in TABLE 3-2. The business case for why intelligent mobility strategies of automation and electrification are important to Tennessee. The safety situation in Tennessee and traffic congestion have worsened and are projected to increase even further in the future. Such trends and future projections underscore the business case for emerging and innovative solutions and point to the importance of improved planning and operations of the transportation system.

TABLE 3-1 ESTIMATED BENEFITS IN TENNESSEE WITH FULL AUTOMATION AND ELECTRIFICATION ADOPTION

Economic Costs	*Safety*	*Traffic flow & congestion*	*Energy and Efficiency*	*Health and Environment*
• Savings in congestion $2 billion • Reduction of $8 billion annual economic cost and societal harm from crashes • Savings in environmental cost of damage by $70 million • Higher GDP due to redevelopment of real estate by about $4.3 billion	• 430 lives can be saved per year on TN roadways • Estimated 21,500 reductions in people injured in crashes annually • 20% reduction in vulnerable road user/bike and ped crashes	• About 48% reduction in hours spent in delays annually	• Increase in energy efficiency due to adoption of hybrid vehicles by about 50% more MPG* • 83 million gallons of fuel are wasted annually • $0.6 trillion in goods shipped by truck each year	• Reduction in greenhouse gases due to electrification by about 33%* • Public health impacts

Source: https://www.fueleconomy.gov/

Examples of benefits according to the Intelligent Transportation Systems Joint Program Office (ITS JPO) are discussed. The benefits of intelligent transportation systems can be measured based on the six goals identified by the U.S. Department of Transportation (US DOT): safety, mobility, efficiency, productivity, energy and environmental impacts, and customer satisfaction. The ITS JPO (https://www.itskrs.its.dot.gov/benefits) provides an overview of highlighted ITS benefits from ten key applications, four of which are directly relevant to intelligent mobility strategies, including CAVs, EVs, freight efficiency, and multimodal commuting. Those ITS benefits are summarized as follows.

Large Truck Platooning

According to ITS JPO, truck platooning uses connected vehicle technologies such as vehicle-to-vehicle (V2V) wireless communication to have trucks follow each other safely and more closely than in typical driving to reduce air resistance and create fuel savings. The first vehicle in the truck platoon acts as the leader, while following vehicles adapt to the first vehicle's movements. The US DOT is researching the impacts of truck platooning to ensure that it is mature enough to be widely applied. The implementation with three trucks by California DOT revealed that truck platooning could provide the second truck with 6-7 percent fuel savings and the third truck with 9% - 11% fuel savings without compromising the fuel efficiency of the first truck [7].

EV Charging Stations

As drivers of plug-in EVs need sufficient access to charging stations, installing EV charging stations in public spaces or workplaces can help accelerate EV adoption. There are three main types of charging: Level 1 (120V), Level 2 (240V), and DC Fast charging. According to the US Department of Energy (US DOE), intelligent vehicle charging infrastructure would enable drivers to save $420 annually per electric vehicle [8].

Electric Bus Fleets

Since battery-electric buses can remove emissions and reduce operational costs compared to conventional buses with combustion engines, transit agencies, especially in big cities such as New York and Los Angeles, have started adopting electric bus fleets since 2017, according to ITS JPO. According to the National Renewable Energy Lab, a pilot testing in Seattle has shown that battery-electric buses could reduce maintenance costs per mile by 44 percent compared to diesel buses. Moreover, the American Lung Association reported that nationwide fleet electrification could save $72 billion in healthcare costs by reducing emissions [9, 10].

Integrated Corridor Management

According to ITS JPO, Integrated Corridor Management (ICM) aims to improve the movement of people and goods by integrating existing infrastructure along major corridors and taking different travel modes into account. ICM can consist of ramp metering, robust data collection, and multimodal operational strategies. US DOT reported that the ICM on I-15 in San Diego, California, can save commuters more than 14,000 person-hours each day during peak commute periods [11].

Another source of early evidence from the Society of Automotive Engineers (SAE) Levels 1 and 2 automation is shown in the graphic below (Figure 3-4). AV technologies already provide substantial reductions (ranging from 7% to 78%) in police-reported crashes, injuries, and insurance claims. Also, evidence from in-vehicle pedestrian avoidance technologies shows substantial benefits. Automatic braking systems that recognize pedestrians can reduce pedestrian crashes by 27 percent.

Studies by the research team using federally available CARMA data have indicated that compared with adaptive cruise control, cooperative adaptive cruise control provided the following benefits:

Lower following vehicles' speed volatility (variations); mean reduction of 20% range from 14% to 29%, smoother speed adjustment for cooperative systems, Lower following vehicle fuel consumption with a mean reduction of 4%, ranging from 0.5% to 6.7%, and lower following vehicle emissions, with a mean reduction of 4%, ranging from 3.06% to 4.94% [12]. Thus, substantial additional benefits are expected from cooperation and communication between platooned vehicles. Simulations have confirmed the presence of substantial additional mobility and safety benefits from cooperation among vehicles [13].

Real-world benefits of crash avoidance technologies

HLDI and IIHS study the effects of crash avoidance features by comparing rates of police-reported crashes and insurance claims for vehicles with and without the technologies. Results below are for passenger vehicles unless otherwise noted.

December 2020

Forward collision warning

- ↓ 27% Front-to-rear crashes
- ↓ 20% Front-to-rear crashes with injuries
- ↓ 9% Claim rates for damage to other vehicles
- ↓ 17% Claim rates for injuries to people in other vehicles
- ↓ 44% Large truck front-to-rear crashes

Forward collision warning plus autobrake

- ↓ 50% Front-to-rear crashes
- ↓ 56% Front-to-rear crashes with injuries
- ↓ 14% Claim rates for damage to other vehicles
- ↓ 24% Claim rates for injuries to people in other vehicles
- ↓ 41% Large truck front-to-rear crashes

Lane departure warning

- ↓ 11% Single-vehicle, sideswipe and head-on crashes
- ↓ 21% Injury crashes of the same types

Blind spot detection

- ↓ 14% Lane-change crashes
- ↓ 23% Lane-change crashes with injuries
- ↓ 7% Claim rates for damage to other vehicles
- ↓ 9% Claim rates for injuries to people in other vehicles

Rear automatic braking

- ↓ 78% Backing crashes (when combined with rearview camera and parking sensors)
- ↓ 10% Claim rates for damage to the insured vehicle
- ↓ 28% Claim rates for damage to other vehicles

Rearview cameras

- ↓ 17% Backing crashes

Rear cross-traffic alert

- ↓ 22% Backing crashes

Added costs

Lower crash rates are a clear benefit of these technologies, but some features can lead to higher repair costs in the crashes that do happen. That's because sensors and other components are often located on the vehicle's exterior. For example, in the case of forward collision warning without autobrake, the average payment per claim for damage to the insured vehicle goes up $117 for vehicles equipped with the feature.

iihs.org

Figure 3-4 Real-world benefits of crash avoidance technologies. Source: https://www.iihs.org

3.3 Intelligent mobility funding

Tennessee is poised to receive $6.2 billion (2021 to 2026) through the Infrastructure Investment and Jobs Act (IIJA), a critical source of funds for intelligent mobility projects. Specifically, investments in intelligent mobility projects can come from sources with the IIJA legislation for "Building a Better America." Among other objectives, the act encourages investments in new and emerging technologies such as connected and automated vehicles and associated broadband deployment, electric vehicle infrastructures such as charging stations; safety for all road users, particularly vulnerable road users; addressing environmental impacts of transportation, especially emissions; and equity and inclusion of disadvantaged and under-represented groups in CAV accessibility, planning and project selection. Notably, IIJA prioritizes projects that advance choices across all modes and are sustainable. The sources of funds for intelligent mobility can include core programs (NHPP-National Highway Performance Program, STBG-Surface Transportation Block Grant, HSIP-Highway Safety Improvement Program, RR-Refuge Roads, CMAQ-Congestion Mitigation and Air Quality, Metropolitan Planning, and Freight), as well as new programs related to electric vehicle infrastructure, carbon and green initiatives, protection and resiliency of infrastructure, bridge rehabilitation, and ferry transportation. For Tennessee, there is new funding of $139 million for carbon reduction, $88 million for electric vehicle infrastructure, $302 million for bridge rehabilitation, and $158 million for Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT). Notably, some of the IIJA funds are grants that need resources to prepare proposals and plans. TDOT can adopt the broader zero-emissions vehicles mandate and envision electric vehicle infrastructure in smart corridors to increase the chances of success in competitive grants.

3.4 Unintended consequences

Emerging transportation technologies will automate some tasks and make some of the workforces (e.g., delivery workers, ambulance drivers, and plumbers) more productive, lowering the cost of providing the services. Also, automation technologies can lower crash costs, which are their clear benefits. However, the repair costs may be higher if such vehicles with more sensors and technologies are involved in crashes. The sensors and other technology components that enable automation may be damaged during collisions and they are typically more expensive to repair. On a broader scale, automation may be disruptive to manufacturing employment in Tennessee, with potential job losses in car manufacturing. While factory automation itself can reduce the number of tasks performed by workers [1], vehicle support industries may be affected directly as demand for many support services can be significantly reduced, e.g., fewer crashes can eliminate much of the need for repair. Vehicle intensive-use occupations can see substantial impacts, e.g., AVs 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. Thus, anticipating some of the unintended consequences, especially negative social impacts on labor, the insurance industry, and equity in access to automated vehicles, is crucial as they may disproportionately and negatively affect different strata of the society, creating equity issues. The business case should also consider collaborative approaches and strategies for mitigating the disruptive consequences of innovation adoption.

Readiness Assessment for Tennessee

> *Readiness for emerging technologies is high in electric vehicle infrastructure, followed by digital infrastructure, roadway infrastructure, and modest levels in public knowledge and acceptance.*

Intelligent mobility strategies are critical to achieving economic development, safety, smoother movement of people and goods, and energy and environmental improvements. To reiterate, intelligent mobility encompasses connected and automated vehicles, electric vehicles, and multi-modal personal and freight movements, all done safely and securely. To assess CAV citywide readiness and intelligent mobility strategies in Tennessee, this chapter first develops a CAV readiness assessment index and quantifies the index based on Tennessee regional ITS architectures. The index can help rank cities for CAV readiness. Then, this section provides a framework by exploring focus areas that include physical infrastructure, digital infrastructure, electric vehicle infrastructure, policies and regulations, and associated public knowledge and acceptance. A key focus is on developing supporting information for readiness to enhance intelligent mobility in Tennessee.

4.1 CAV Readiness assessment of cities in Tennessee based on ITS Architecture

Connected Automated Vehicles (CAVs) are about to be deployed on roads, but one question is still unanswered how ready stakeholders are to accommodate CAVs concerning required policies and infrastructure elements. With the arrival of CAVs, transportation systems are expected to be revolutionized as CAVs may increase daily trips, change individuals' day-to-day routines, and reduce on-road emissions.

Through a literature review, the research team found a previous attempt to assess the CAV readiness of cities in the United States [14, 15]. As summarized below, they defined 32 CAV readiness elements grouped into four main categories: (1) physical infrastructure, (2) digital infrastructure, (3) policy and regulations, and (4) other factors. They assessed 98 cities' readiness for CAV deployment by combining those 32 readiness elements into a single index [15]. The results indicate that the major cities in the United States are far from completely ready to embrace CAV technology. Notably, the assessment results show that Memphis, TN, and Nashville, TN are less prepared cities for CAV deployment in terms of physical infrastructure, digital infrastructure, policy and regulation, and other factors.

Researchers used these variables to develop a holistic readiness index that can be used to evaluate CAV readiness [14, 15]. Using the index for evaluating readiness for CAVs, indicates that large cities are currently more prepared than small- and medium-sized cities. However, smaller cities can be ready even sooner than some of the large cities if appropriate infrastructure investments are made.

Through quantifying the above indicators based on the Tennessee Regional ITS Architectures (Shown in Table A-1 in Appendix A) and aggregating them into a CAV readiness index, as shown in Figure 4-1, the studied cities are ranked from a high to less readiness order. Memphis, Chattanooga, and Nashville are ranked with the highest CAV readiness index, respectively. On the other hand, Knoxville, Clarksville, and Johnson City are ranked with the lowest index.

Physical infrastructure

- High-quality road signage and marking
- CAV-compatible parking facilities
- Sensor-equipped cones and beacons
- CAV-only pick-up and drop-off areas
- CAV-compatible tolling facilities

Digital infrastructure

- Roadside information communication
- Vehicle to vehicle communication devices
- Infrastructure to vehicle communication devices
- High-resolution maps of the road network
- Infrastructure-based pedestrian detection devices

Policy and regulations

- Driving regulations
- Testing regulations
- Tax incentives for consumers
- Tax incentives for organizations
- Reduced fees for consumers
- Reduced fees for organizations
- HOV lane permission
- Parking privileges
- Tolling privileges
- Preventing misuse of safety harbors
- Maintenance of the existing signs and markings
- Designation of CAV-compatible areas
- Guidelines for lowering inconsistency in design
- Autonomous truck permits

Other factors

- Land use pattern
- Re-evaluation of bridge structures
- Transit control center
- Autonomous PRT services
- US DOT Smart City Challenge
- Research on CAV requirements
- Inappropriate weather
- Auto tax rate

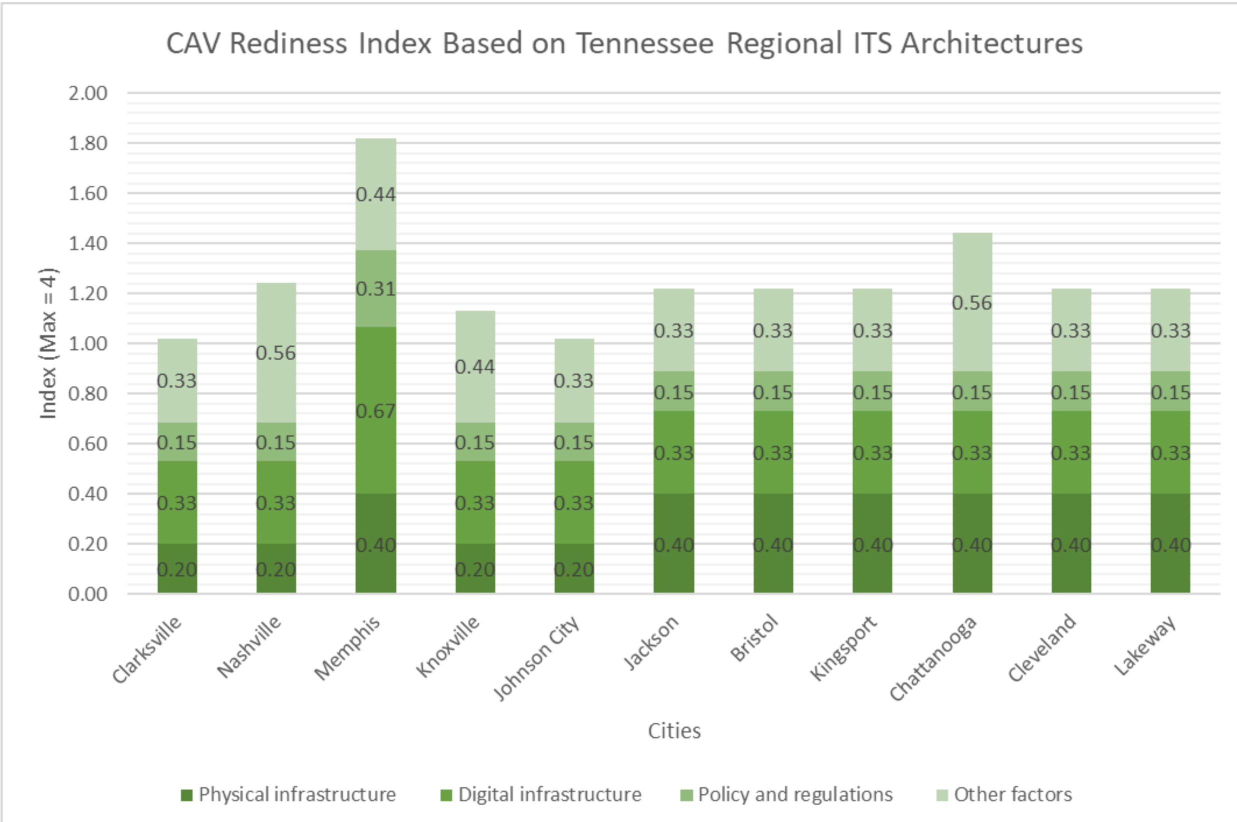


Figure 4-1 CAV Readiness Index Based on TN Regional ITS Architectures

4.2 Intelligent mobility readiness assessment

Tennessee's Intelligent mobility readiness assessment is performed by conducting an extensive web survey. The survey aims to identify intelligent mobility practices and Tennessee's readiness as viewed by TennSMART, a Tennessee-based consortium including research institutions, vehicle manufacturers and suppliers, fleet operators, software developers, utilities, and government officials and regulators. The list of TennSMART members is illustrated in TABLE 4-1.

4.2.1 Readiness assessment framework

As mentioned, the framework of the intelligent mobility readiness assessment consists of five areas: (1) physical infrastructure, (2) digital infrastructure, (3) electric vehicle infrastructure, (4) public knowledge and acceptance, and (5) policy and regulation. The survey of TennSMART members covers those areas except for (5) policy and Regulation.

TABLE 4-1 TENNSMART CONSORTIUM MEMBERS

Category	*Organization*
Public Sector	City of Knoxville
	Tennessee Department of Environment and Conservation
	Tennessee Department of Transportation
	Tennessee Valley Authority
	EPB of Chattanooga
Private Sector	AAA
	Bridgestone Americas
	DENSO Manufacturing Tennessee
	FedEx Corporation
	Google LLC
	Gresham Smith
	HDR, Inc.
	HNTB Corporation
	Local Motors
	Lyft
	Miovision Technologies
	Nissan North America
	Softchoice
	Stansell Electric Company Inc.
Research Institution	Oak Ridge National Laboratory
University	Tennessee Tech University
	University of Memphis
	The University of Tennessee, Knoxville
	The University of Tennessee, Chattanooga
	Vanderbilt University

4.2.2 Survey methodology

The survey process consisted of two stages: the pre-survey and the main survey. Both surveys were developed using a web-based survey tool, Qualtrics, so that respondents could easily access the questionnaires and answer the questions online. By conducting the pre-survey, TennSMART members were informed of the main survey coming soon so that they could prepare for the main survey in advance. Through the pre-survey, areas relevant to each organization were identified while obtaining the names and contact information of those who would participate in the main survey. The survey ended up obtaining 93 email addresses from 26 organizations in total. The full version of the pre-survey is attached in Appendix B.1.

The responses made by TennSMART members from the main survey are used to develop a baseline inventory for current intelligent mobility activities and help identify options for future activities that will enhance mobility in Tennessee. On Qualtrics, a set of questions has been developed for each area of interest. In this survey, respondents can choose which areas they will address depending on the relevance of each area to their organization's focus. The questionnaire structure was organized by referring to a survey of TDOT directors previously conducted to explore sustainability practices in Tennessee. The items for survey questions are based on a report published by AASHTO regarding the national strategy for transportation automation and the 2019 Connected Vehicle and Automated Vehicle Survey conducted by the US DOT that surveyed freeway, arterial, and transit agencies to track the deployment of ITS. The items covered by the survey of TennSMART members in this project are as follows.

Area 1. Physical Infrastructure

- Roadway improvements and technologies for CAVs' adaptation to roadways
- Pavement markings improvements and technologies for CAVs to detect pavement markings
- Road sign improvements and technologies for CAVs to detect road signs
- Operational Design Domains (ODDs) for CAVs
- Technologies and regulations for truck platooning
- Roadway infrastructure improvements and technologies for multimodal travel
- Workforce education and training for enhancing intelligent mobility

Area 2. Digital Infrastructure

- Infrastructure-to-Vehicle technology applications
- Plans for onboard units and cellular-vehicle-to-everything (C-V2X) units
- Plans to harness data from C-V2X units
- Processing and managing large scale data
- Technologies for collecting, managing, and using real-time traffic data
- Enhancing cybersecurity in the transportation system

Area 3. Electric Vehicle Infrastructure

- EV infrastructure (e.g., charging stations, electricity generation, and distribution)
- Assessments of future demand for EVs or charging infrastructure
- Expanding the number of EV charging stations

Area 4. Public Knowledge and Acceptance

- Public perception regarding CAVs in terms of knowledge and perceived barriers
- Public perception regarding EVs in terms of knowledge and perceived barriers
- Informing the public about automation in the freight industry
- Informing the public about existing and emerging intelligent mobility options

For every question in the main survey, as shown in Figure 4-2, background information with relevant figures is provided to help respondents understand the question. Every question has multiple choices, some of which are followed by a designated box for respondents to specify some relevant information. For instance, a question about pavement markings is shown in Figure

4-2. Respondents should select one of the five choices given. Depending on their answers, they can also provide some relevant information in the corresponding box. The full version of the main survey is available in Appendix B.2.

To safely operate on roadways, it is necessary for CAVs' vision systems to clearly detect pavement markings. **Has your organization researched, developed, or deployed pavement markings improvements or any technologies for CAVs to clearly detect pavement markings?**

CAV detecting road markings (source: reflective-systems.com)

- Yes (Please specify)
- No, but we have a specific plan for it. (Please specify)
- No, but we expect to have a specific plan for it in the future. (Please specify)
- No, and we have no plan for it.
- Don't know/ Not sure/ Not applicable

Figure 4-2 An Example Question of the Intelligent Mobility Readiness Survey

4.2.3 Readiness assessment methodology

According to the survey results, the readiness assessment is performed to identify how much Tennessee is ready for Intelligent Mobility. As shown in Figure 4-3, the readiness assessment methodology was developed by referring to the "Community Smart Mobility Readiness Profile Tool" developed by Stantec and Vanderbilt University. TennSMART members receive a readiness score for each area of interest based on their responses to the questions, which derives the readiness percentage (%) calculated by dividing the received readiness score by the maximum score available. Based on the readiness percentage (%), the readiness level is identified for each area of interest. By comparing the identified readiness level to the target level, the status of Tennessee concerning Intelligent Mobility by area can be assessed. For example, analysis can highlight the areas requiring more action and progress. In Figure 4-3, an example readiness assessment with five readiness levels from 1 to 5 is displayed.

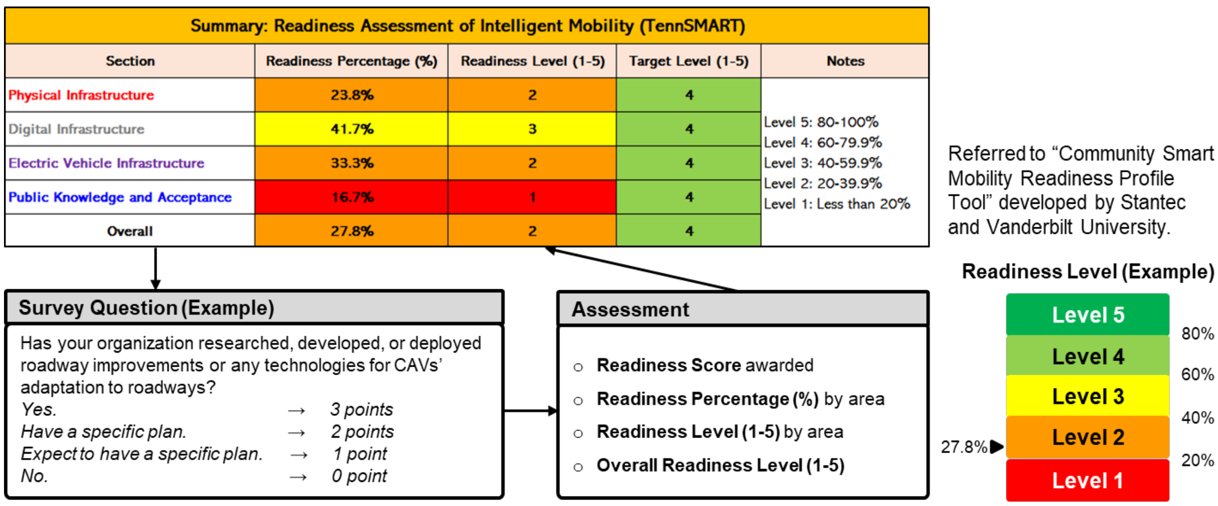


Figure 4-3 Methodology of Intelligent Mobility Readiness Assessment in Tennessee (The numbers are examples)

4.2.4 Readiness assessment results

As mentioned, a framework to study intelligent mobility across Tennessee was developed. The framework focuses on physical roadway infrastructure, electric vehicle infrastructure, digital infrastructure, policy/regulation, and public knowledge/acceptance. Each area contains a series of subcategories to broadly explore intelligent mobility readiness across TennSMART members, including representatives from cities, agencies, a national lab, the private sector, and academia. A questionnaire was designed and developed to assess intelligent mobility readiness and score it. After its distribution to TennSMART members, 22 responses are analyzed. The framework assesses readiness on a scale of 0 (no activity – 0% Readiness) to 3 (strong activity – 100% Readiness) in terms of physical infrastructure, digital infrastructure, electric vehicle infrastructure, public knowledge and acceptance, and policy/regulation awareness. The survey asked respondents whether their organization had researched, developed, or deployed roadway improvements or emerging technologies. The answers were Yes (coded as 3), No, but we have a specific plan for it (coded as 2), No, but we expect to have a specific plan for it in the future (coded as 1), No, and we have no plan for it (coded as 0), and don't know/ not sure/ not applicable is excluded from the readiness index calculation. As a demonstration, the distribution of responses to some of the key questions concerning the options available for each question is illustrated in TABLE 4-2. For each area of interest, a set of questions were developed and administered through a structured survey. For example, physical roadway infrastructure was divided into roadway structures, signage and markings, and design standards.

TABLE 4-2 DISTRIBUTION OF RESPONSES TO SOME OF THE KEY QUESTIONS

Question (N=22 respondents)		No. of respondents
Physical Infrastructure		
Detecting pavement markings for CAV	Yes	5
	No, but we have a specific plan for it	1
	No, but we expect to have a specific plan for it in the future	2
	No, and we have no plan for it	7
	Don't know/ Not sure/ Not applicable	7
Road infrastructure improvements for supporting multimodal travel	Yes	11
	No, but we have a specific plan for it	2
	No, but we expect to have a specific plan for it in the future	1
	No, and we have no plan for it	2
	Don't know/ Not sure/ Not applicable	6
Electric Vehicle Infrastructure		
Actions toward EV infrastructure in terms of charging stations, electricity generation, and distribution	Yes	15
	No, but we have a specific plan for it	1
	No, but we expect to have a specific plan for it in the future	2
	No, and we have no plan for it	0
	Don't know/ Not sure/ Not applicable	4
Assessments of future demand for EVs or charging infrastructure	Yes	10
	No, but we have a specific plan for it	1
	No, but we expect to have a specific plan for it in the future	2
	No, and we have no plan for it	1
	Don't know/ Not sure/ Not applicable	8
Digital Infrastructure		
C-V2X communication	Yes	4
	No, but we have a specific plan for it	1
	No, but we expect to have a specific plan for it in the future	2
	No, and we have no plan for it	5
	Don't know/ Not sure/ Not applicable	10
Actions toward enhancing cybersecurity	Yes	9
	No, but we have a specific plan for it	0
	No, but we expect to have a specific plan for it in the future	2
	No, and we have no plan for it	4
	Don't know/ Not sure/ Not applicable	7
Public Knowledge and Acceptance		
Efforts toward showing barriers to CAV adoption to the public	Yes	9
	No, but we have a specific plan for it	0
	No, but we expect to have a specific plan for it in the future	0
	No, and we have no plan for it	4
	Don't know/ Not sure/ Not applicable	9
Efforts toward showing barriers to EV adoption to the public	Yes	6
	No, but we have a specific plan for it	1
	No, but we expect to have a specific plan for it in the future	0
	No, and we have no plan for it	4

	Don't know/ Not sure/ Not applicable	*11*

As shown in Figure 4-4, the results range from the high activity and readiness in electric vehicle infrastructure, followed by digital infrastructure, roadway infrastructure, and modest levels of public knowledge and acceptance.

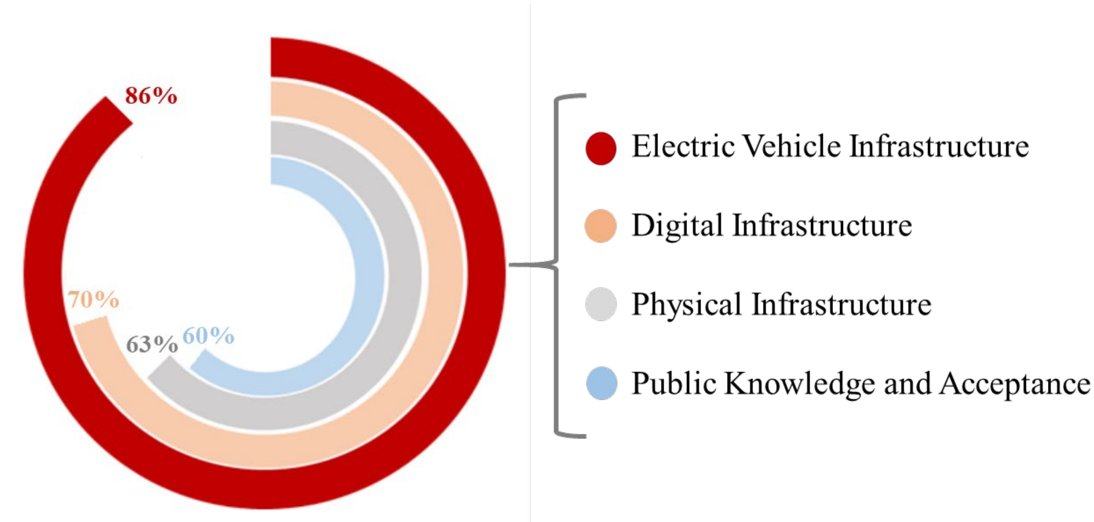


Figure 4-4 Readiness index for each area

The level of readiness for each question within each area is demonstrated in the tables below. TABLE 4-3 illustrates some of the responders' comments and readiness concerning each question within a physical infrastructure. The overall readiness index for this area shows 63% readiness, which is moderate, and it is better to focus on the areas that need more attention to enhance readiness in this area. The least readiness is for the ability of CAVs to detect pavement markings, which has 42% readiness, followed by road sign improvements (49%), truck platooning readiness (56%), and operational design domain (ODD), which is 69%. Clearly focusing on improving pavement markings and road signs for CAVs, expanding ODDs, and facilitating truck platooning can improve physical infrastructure readiness. There are multiple recommendations for each of these subcategories based on what respondents have done or are doing right now. Such as developing simple line detection algorithms for better detection of pavement markings, designing increased width of pavement markings for CAV deployment to enhance their visibility, and conducting detailed vehicle modeling for truck platooning to assess the energy efficiency of such technology.

TABLE 4-4 explains the results for the area of electric vehicle infrastructure. This is the area with the highest readiness index among all areas, which shows that this area has received substantial attention, owing to the presence of electricity generation in Tennessee and the proactive efforts of TDOT and TDEC. To support electrification, the transportation system needs "a network of EV charging stations" with different charging levels (e.g., Level 1, Level 2, and DC Fast charging). The results show high readiness levels in installing charging stations and electricity generation and distribution, assessing future demand for charging infrastructure and expanding charging stations. Although the overall readiness in this area is higher than the others, there are still some recommendations that can help in achieving even higher readiness, such as developing analytic models for predicting the market share of different types of vehicles for better assessment of the future demand or constructing electric vehicle parking as an action toward EV infrastructure.

Similarly, TABLE 4-5 shows selected comments by respondents and the level of readiness concerning each question within the digital infrastructure. Although this area has a high readiness index, it lacks in the subcategory of C-V2X communication and needs attention in this regard. Notably, CAV technologies can exchange information with digital infrastructure, e.g., C-V2X capable roadside units can warn drivers of red-light running or high speeds on curves. The low readiness in C-V2X communication is quite apparent, showing 44% on the readiness scale, which is a low score (this may also be because this question applies more to agencies than the entire spectrum of TennSMART members). The next category with readiness improvement potential is harnessing the C-V2X data to improve mobility and safety. Cybersecurity also ranked low on readiness, and this shows that more attention is needed on C-V2X communication and securely collecting/harnessing CAV data. Some of the valuable suggestions based on the comments of the respondents are working in conjunction with academic institutions on deploying a field solution for C-V2X communications and asking for providing research projects in this regard, such as using OBUs and RSUs in both in-lab and on-road testing or cooperating with data science and data analytics experts from different organizations to harness the C-V2X data to improve mobility, safety, energy consumption, and environment.

Finally, TABLE 4-6 represents responders' comments and the level of readiness concerning each question within the public knowledge and acceptance area. This area ranked the lowest in terms of readiness and needs the most consideration. Informing the public about automation in passenger vehicles and the freight industry (e.g., truck platooning) has the lowest index among all subcategories, which can receive attention in the future. Another area that shows potential for improvement in public knowledge and acceptance is informing about existing and emerging intelligent mobility options, which are automation and electrification in passenger travel by personal vehicles, transit, and freight. There are some insightful comments from the respondents that can help in achieving a higher readiness index for Public Knowledge and Acceptance, such as conducting research projects to understand how the public perceives intelligent mobility strategies and what it would take for the public to adopt CAVs and EVs, and then educate and engage the public and policymakers about CAVs and intelligent mobility benefits or cooperating with other private or public organizations to study EV adoption based on their specific models. One example of a model for consideration is the Oak Ridge National Laboratory's Market Acceptance of Advanced Automotive Technologies (MA3T).

TABLE 4-3 PHYSICAL INFRASTRUCTURE METER FOR EACH QUESTION

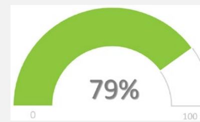
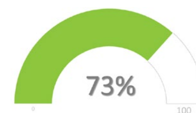
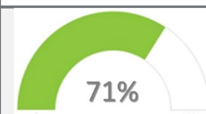
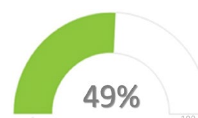
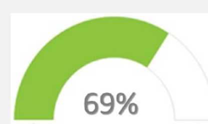
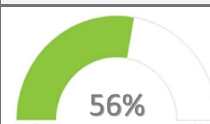
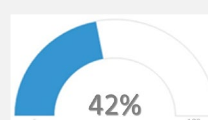
Question	*Responders' comments*	*Readiness Meter*
Road infrastructure improvements for supporting multimodal travel	• Installation of Miovision cameras to detect different object types on the roadway • Deployment detection and/or roadside communication to pedestrians • Developing a National Bikeway Network for FHWA in the hope to provide information for researchers and public sectors to use with other datasets (e.g., crash data) to improve non-motorized transportation safety and accessibility • Adoption of the multimodal access policy	
CAVs' adaption to roadways	• Deploying Roadside Units (RSUs), requiring RSUs as part of CMAQ projects, improved signing, and striping. Monitoring LED flash rate issues • Working with the cities of Knoxville and Franklin to deploy DSRC V2X to communicate SPaT and MAP information; and working with TDOT/Vanderbilt on the Circles/I-24 Test Bed. Additionally, research and develop SOPs and conceptual designs for MAS facilities operated by first-tier automotive manufacturers (under NDAs) • Protecting the users in a safer manner which leads to infrastructure that is less complicated and safer to navigate, which should help with infrastructure issues • There is the I-24 MOTION project, which will enable live highway experimentation of autonomous and human driver mixed traffic by collecting anonymized trajectory data of all roadway vehicles	
Enhancing intelligent mobility	• CTR delivers multiple workshops addressing many individual aspects of intelligent mobility • Partnering with TTAP to offer courses in intelligent mobility	
Road sign improvement for CAVs	• Developing simple sign detection algorithms and focusing on comparing the algorithm's performance in a real-world setting versus in a virtual digital twin of the real-world data • Conducting training that addresses the design and maintenance of all traffic control devices, including traffic signs	
ODD for CAVs	• Research on merging at on-ramps for CAVs and intersection safety improvements with CAVs • Monitoring the intersections to detect and identify all users • Research on cooperative driving automation (CDA) and scenario generation	
Truck platooning for safety and efficiency	• Conducting detailed vehicle modeling for truck platooning to assess the energy efficiency of such technology • Researching regulations for truck platooning • Assisting State DOTs in developing guidance documents	
Detecting pavement marking for CAV	• Developing simple line detection algorithms • Stansell's sister company, C&D Safety, stands ready for innovation and deployment of pavement marking improvements to support CAV • Designing increased width of pavement markings for CAV deployment to enhance their visibility	

TABLE 4-4 ELECTRIC VEHICLE INFRASTRUCTURE METER FOR EACH QUESTION

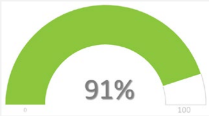
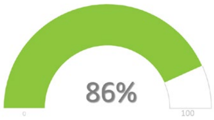
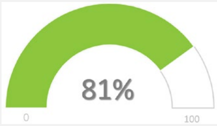
Question	*Responders' comments*	*Readiness Meter*
Action toward EV infrastructure in terms of charging stations, electricity generation, and distribution	• Constructing electric vehicle parking through our partnership with the Public Building Authority (PBA) • Researching and developing charging infrastructures in areas such as charging/power transfer technologies, grid, and location optimization/planning • Assisting LPCs, public and private businesses, and others on their options for installing Level 2 and DCFC equipment and services	
Expanding the number of EV charging stations	• There is an ongoing project funded by TDOT to evaluate EV charging station sites along the I-40 corridor • The DEUSA project is helping 14 states develop their own statewide "drive electric" initiatives (and the number of states is growing), and the EMPOWER project will be a nationwide workplace charging education and outreach initiative reaching into 32 states • TVA and TDEC signed an MOU in 2021 to establish a partnership to install public DC Fast EV chargers • Stansell Electric has experience with the deployment of electricity generation and distribution and stands ready for EV infrastructure planning, design, installation, and ongoing maintenance	
Assessments of future demand for EVs or charging infrastructure	• Developing analytic models for predicting the market share of different types of vehicles • Developing an infrastructure location planning tool based on future demands • Directly survey employees and the vehicle mix parked on campus to evaluate this need • Developing partnerships and teams that can help prepare communities for locating DCFC and L2 (and L1 where it is the right fit) EVSE	

TABLE 4-5 DIGITAL INFRASTRUCTURE METER FOR EACH QUESTION

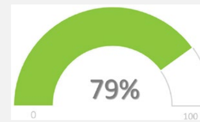
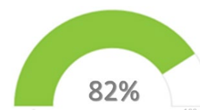
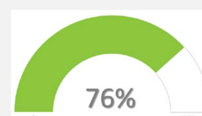
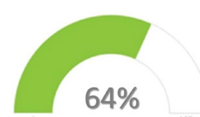
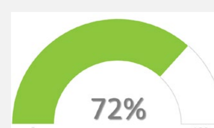
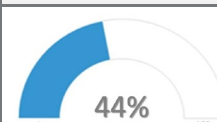
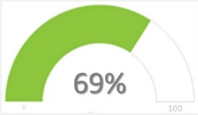
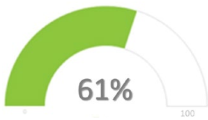
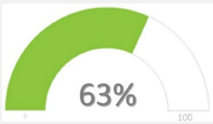
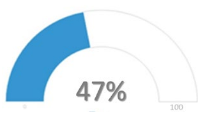
Question	*Responders' comments*	*Readiness Meter*
Collecting, managing, and using real-time traffic data	• several projects at ORNL are collecting/using real-time data (e.g., TomTom, Wejo, GridSmart, and high-resolution data from signal controllers) for developing energy-efficient smart mobility solutions • Conducting research related to real-time traffic data and the development of traffic management algorithms • Using Automated Traffic Signal Performance Measures • Conducting academic research projects that leverage real-time traffic data such as working with TDOT to deploy an AI-driven decision support system (AI-DSS) to help TMC operators with the I-24 SMART Corridor • RITIS/INRIX cell probe data and radar RSUs on interstates • Developing dashboards for clients that make use of real-time traffic data from both sensors as well as commercially available streams to improve the ability of a TMC/TOC operator to make use of the data	
Processing or managing large scale data	• ORNL's Chattanooga Twin (CTwin) project is processing large amounts of data from at least dozens of sources • Working on data from traffic signals, various types of cameras, and large data sets • Building custom software and deploying software packages • Processing video/Lidar images, CAV Basic Safety Messages, Probe data from cellular, WAZE, and STREETLIGHT	
Infrastructure-vehicle communication technology application	• ORNL has about 4 projects funded by DOE researching V2V and V2I communications. They will be testing C-V2X & DSRC V2X • Stansell has installed and now maintains DSCR, Radar, and 360° Video Detection Systems on multiple corridors and has a close working relationship with multiple manufacturers • Developing grant applications for CAV V2X communication applications, and developing specifications and RFPs for implementation of these applications including Queue Warning, Work Zone warning, Speed Advisory, etc.	
Actions toward enhancing cybersecurity	• Evaluating and acting on cybersecurity-related to the electric grid, including EV charging • Monitoring credentialing/certificate requirements • Providing access through firewalls to the system for over the air updates	
Plan to receive and harness the C-V2X data to improve mobility and Safety	• There is a 5G lab with help from AT&T that will be able to receive and harness the data • Deploying some BlueToad devices that track Bluetooth signatures for travel time estimation • The department of Industrial and Systems Engineering at UTK is interested in receiving and harnessing data by using our data science and data analytics expertise	
C-V2X communication	• Working in conjunction with UTK and ETSU on deploying a field solution • Using OBU and RSU in both in-lab and on-road testing • Providing research projects in this regard	

TABLE 4-6 PUBLIC KNOWLEDGE AND ACCEPTANCE METER FOR EACH QUESTION

Question	*Responders' comments*	*Readiness Meter*
Efforts toward showing barriers to CAV adoption to the public	• conducting research projects to understand how CAVs are perceived by the public and what it would take for the public to adopt CAVs • involving in conferences that focus on this as well as having discussions within the DOE and DOE Clean Cities communities about CAVs • The Institute for a Secure and Sustainable Environment (ISSE) at UTK focuses on the public awareness of alternative fuel vehicles (including EVs) through East TN Clean Fuel Coalition, which is a DOE Clean City program housed within ISSE	
Efforts toward showing barriers to EV adoption to the public	• Working with ORNL to study EV adoptions based on their MA3T (Market Acceptance of Advanced Automotive Technologies) model • TVA has conducted studies of consumer attitudes and behaviors around EVs. The results of these studies inform the strategy to address EV barriers, which are identified by Drive Electric TN: 1) EV infrastructure, 2) EV awareness and education, 3) EV availability, and 4) supportive policies • Creation of 10+ DET Chapters across the state to develop local teams that can work locally to hold Ride & Drives and address the misperceptions directly	
Efforts toward informing the public about existing and emerging intelligent mobility options	• ATSPM's and Counts can actively measure additional CO2 Emissions as a result of delay due to accidents, poor timing, and even infrastructure failures; And they can calculate lost wages and additional fuel consumed as a result of a delay • There is a statewide TDM program and provides funding for many, more local, TDM programs to inform users of shared mobility options • Numerous researchers are regularly engaged in the public dissemination of their specific CAV and intelligent mobility projects	
Informing the public about automation in the freight industry	• TDOT helped deploy platooning efforts in the state a few years ago and a lot of effort was put into educating the public on truck platooning • Informing through Freight Advisory Committee meeting • Inclusion of platooning article in the DET email system as well as on the Fuels Fix website	

Benchmarking Peer and Aspirational States

Tennessee has an opportunity to boost intelligent mobility by benchmarking aspirational states including California, Florida, Michigan, and Minnesota.

The Tennessee DOT seeks to boost readiness for intelligent mobility solutions, encompassing physical infrastructure, digital infrastructure, electric vehicle infrastructure, policies, and public acceptance. This report provides initial information about benchmarks for Tennessee's readiness relative to aspirational agencies in other states. Notably, TDOT has not previously conducted such a readiness benchmarking project. The research team provides information that a TDOT benchmarking team can use to enhance readiness further. The performance measures relevant to the goals include safety, mobility, energy, and environment, intending to reduce the costs associated with these goals, e.g., reducing the costs of crashes, injuries, and deaths. With input from TDOT, the aspirational agencies selected include California, Florida, Michigan, and Minnesota Departments of Transportation. They were selected owing to their leadership in research, development, testing, and deployment of emerging technologies in transportation.

The research team collected and analyzed information from the four states to identify innovative strategies, approaches, and best practices adopted in Tennessee to boost readiness. The results of these case studies are discussed below.

California Department of Transportation

The California Department of Transportation has implemented projects and taken initiatives to enhance physical infrastructure readiness.

- Caltrans plans to deploy more than 100,000 freight vehicles and equipment capable of zero-emission operation and maximize renewable energy-powered near-zero emission freight vehicles and equipment [16].
- Plans to continue implementing alternative fuel infrastructure and clean fuels for jets, ships, and freight-related equipment [17].
- Caltrans plans to improve truck parking facilities by locating them away from neighborhoods and equipping them with electric charging infrastructure [17].
- Plans to have the entire fleet of intercity Passenger Rail on renewable energy by 2023; upgrade them to an energy-efficient system by 2025; complete hydrogen pilots (testing of hydrogen fuel cells in passenger rail) by 2025, and transition the fleet to zero emissions by 2035 [18].
- Caltrans entered a multi-state coalition with Arizona, New Mexico, and Texas to develop the I-10 corridor as a connected vehicle corridor [16]. I-10 corridor project extends from the Ports of Long Beach and Los Angeles in California to the Port of Beaumont in Texas [19]. The state DOTs have plans to deploy connected vehicle technologies to more than 1,000 commercial vehicles in this study area to improve traveler information, asset condition management, and system performances [20].

California has implemented projects and taken initiatives that can enhance readiness for digital infrastructure and cybersecurity:

- California Department of Technology strategizes to develop a world-class cyber security workforce by developing job roles, expanding cybersecurity training opportunities, increasing opportunities to source cybersecurity talent, and establishing a federated cybersecurity oversight system and effective cybersecurity defense technologies [21].
- The automated vehicle policy mentioned in the draft California State Transportation Agency framework includes strategies to ensure seamless booking and payment between AVs and multimodal systems. The strategies include open-loop payment systems, prepay cash options or mobile payments, online and telephone booking, and smartphone app-based multi-lingual booking. Strategies for data collection across agencies include establishing a data clearinghouse to store, manage, and share big data from AVs [22].

Implemented projects and initiatives that can enhance readiness for EV infrastructure:

- Programs to help bridge the gap between the up-front cost of zero-emission vehicles (ZEV) and conventional vehicles. Some of the programs are Clean Cars 4 All, the statewide Clean Vehicle Rebate Project (CVRP), the statewide Financing Assistance for Lower-Income Consumers Pilot Project, and Increased Public Fleet Incentives for CVRP-Eligible Vehicles. ZEVs include battery-electric, plug-in hybrid electric, and fuel cell electric vehicles [23].
- Incentives can be provided to ZEV drivers by permitting access to the high-occupancy vehicle (HOV) lane if they have a Clean Air Vehicle decal from the Department of Motor Vehicles [23].
- Caltrans has installed 699 ZEV infrastructure (electric charging stations and hydrogen stations) and 326 electric vehicle charging ports at Caltrans facilities [18].
- Caltrans plans to add 15 plug-in batteries, and electric street sweepers, to the Caltrans fleet at the beginning of 2022. Caltrans is establishing a zero-emission working group to develop strategies to transition all rail to zero-emissions. To increase the visibility of ZEV infrastructure, the ZEV installation guide was updated in 2021 [18].

Implemented projects and initiatives that can enhance user/consumer acceptance and awareness:

- Campaigns to inspire, educate and empower Californians to drive electric [23].

Comprehensive plans and policies to enhance the readiness of intelligent mobility strategies:

- The California Transportation Plan (CTP) 2050 lays out the roadmap to achieve safety, resiliency, and accessible transportation systems by providing relevant policies and strategies [17].
- Caltrans has planned to publish CTP Implementation Progress Report every year to describe the progress of CTP implementations at the state, regional and local levels [18].
- The Zero-Emission Vehicle Action Plan (2018) contains policies to advance transportation electrification [23].
- The Zero-Emission Vehicle Installation Guide contains strategies to increase the visibility of ZEV infrastructures [18].
- The California Sustainable Freight Action Plan plans to improve California's Freight Transportation System by 2030 and beyond [16].

- Cal-Secure is a multi-year cyber security roadmap to manage existing and future cybersecurity threats [21].

Overall, California provides expanded opportunities to address ZEVs and associated infrastructure. Specifically, Caltrans has expanded opportunities to address ZEVs, CAVs, and their associated infrastructure throughout the state. Caltrans has also formed coalitions with three more states to support truck platooning and connectivity from California to those states.

Florida Department of Transportation

The Florida Department of Transportation (FDOT) has implemented projects and taken initiatives that can enhance readiness for physical infrastructure:

- Created CAV-only pick-up and drop-off areas, especially in CAV Park-and-Ride facilities [24].
- Implemented CAV-compatible tolling facilities to ensure that driverless vehicles can conveniently use toll roads and electronic toll collection. In fact, FDOT, Florida's Turnpike Enterprise dedicated to the research, development, and testing of tolling and emerging transportation technologies in safe and controlled environments [25].
- Enhanced CAV operations through improved pavement markings and adequate signal systems, which are critical infrastructure components of CAV operations. To prepare for AV implementation on roadways, most agencies in Florida indicated their pavement markings should be more than suitable for AV deployments in terms of lane control and automated steering due to FDOT design guidelines being comprehensive and state-of-the-practice. Additionally, FDOT has a plan to improve maintenance programs for pavement markings that should be implemented to maintain visibility [26].

Implemented projects and initiatives that can enhance readiness for digital infrastructure and cybersecurity:

- Driver-Assisted Truck Platooning Pilot based on V2V communication will enable trucking companies to platoon multiple trucks in Florida [27].
- The Orlando Greenway project included the installation of CCTV cameras for a Parking Availability System and a Transit User Verification System to be utilized at the University of Central Florida (UCF). The parking availability system will provide real-time information on parking availability for UCF student parking lots, and the transit user verification system will determine the presence of students waiting for buses [28].
- From research conducted by Florida State University, in collaboration with FDOT, a Security Credential Management System (SCMS) was deployed to protect the system by verifying the legitimacy of V2V and infrastructure-to-vehicle (I2V) messages. The deployment of the SCMS resulted in a significant step in Florida's CV Initiative [28].

Implemented projects and initiatives that can enhance readiness for EV infrastructure:

- A Comprehensive Solar Energy Power System for Service Plazas along the Florida Turnpike envisions potentially using solar energy to supply energy needs for its service plazas. This project aims to examine how solar energy could be utilized to use solar technologies for charging EVs and using solar energy in charging stations [29].

- There are currently 3,907 Level 2 charging plugs and 844 direct current fast charge plugs in Florida. Figure 5-1 provides locations for all of Florida's current direct current fast charger locations as of June 2020, including the Tesla charging network that serves one-half of the EVs in Florida [30].

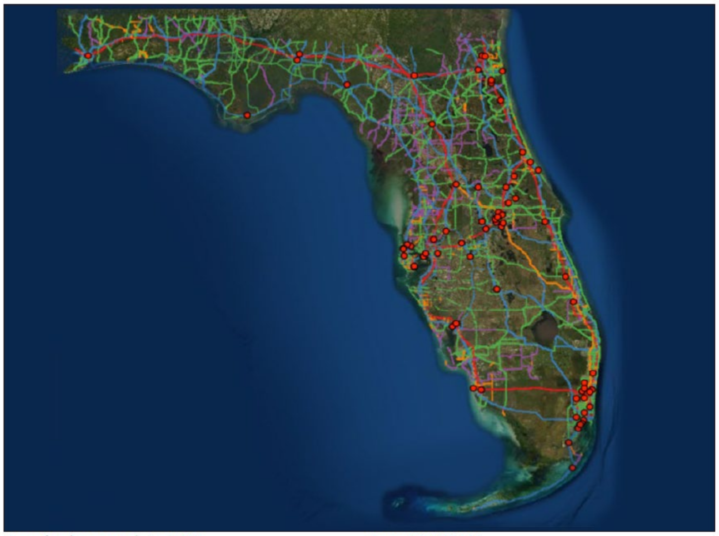


Figure 5-1 Locations for all Florida's current DCFC locations as of June 2020

Implemented projects and initiatives that can enhance user/consumer acceptance and awareness:

- Tax incentives, such as rebates and state tax credits, to the buyers of electric vehicles. For instance, when a person gets one of the electric vehicles, he/she can also get some money from both the US and local Florida governments [30].
- Allowing companies to test CAVs in real-world conditions seems the first step to developing a smart transportation system. The Central Florida region is also home to SUNTRAX Test Facility, a soon-to-be-operational 475-acre state-of-the-art facility dedicated to researching, developing, and testing emerging transportation technologies in a safe and controlled environment, owned and operated by Florida's Turnpike Enterprise. When fully operational, SUNTRAX will provide numerous testing spaces to study tolling technology, lane marking, intelligent transportation systems, and CAVs [26].
- Many hotels and vacation destinations now offer some level of EV charging for their guest, typically Level 2. FDOT plans to provide direct current fast chargers in the urban core and at convention and hotel clusters to support business and vacation travel. Furthermore, additional Level 2 charging in parking garages and lots will be required to support multi-day business and vacation travel, which has been included in EV adoption policies in Florida [30].

Michigan Department of Transportation

The Michigan Department of Transportation (MDOT) has implemented projects and taken initiatives that can enhance readiness for physical infrastructure:

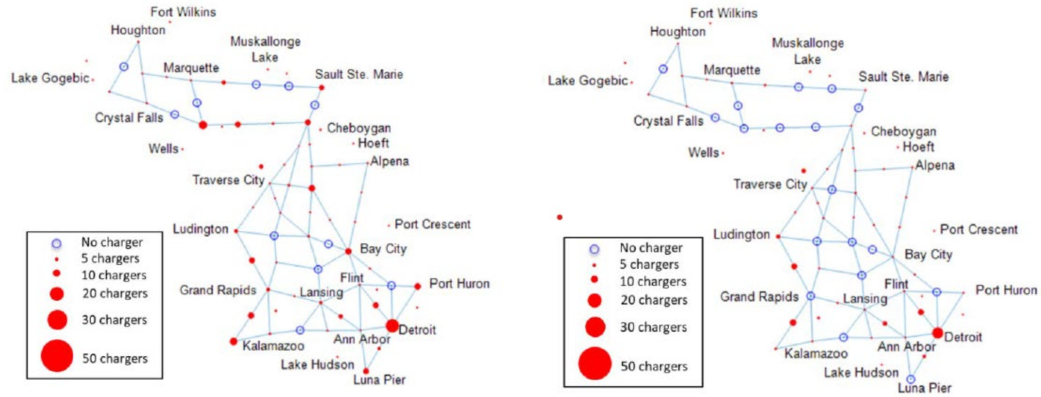
- MDOT has implemented some facilities formerly known as the Mobility Transformation Facilities, dedicated to testing and developing CAV technologies. The testing was performed at Mcity, the world's first purpose-built facility for testing CAVs and technologies under controlled and realistic conditions [31].
- A range of different pavement marking materials was applied to road surfaces to determine if certain materials were more readily detectable by image processing on CAVs [31].
- Three types of parking spots are included in Mcity: parallel, diagonal, and stall parking. Each presents its challenges for automated parking systems. In addition, an accessible parking spot and signage were installed in one location to assess if AVs can differentiate between them and non-accessible spots [31].
- Mcity has implemented a wide range of lighting sources throughout the testing space designed to reflect various real-world lighting conditions. This test helps MDOT realize which lighting can have the most prominent impact on the good performance of CAVs [31].

Implemented projects and initiatives that can enhance readiness for digital infrastructure/cybersecurity:

- Mcity has focused on new I2V/V2V communication protocols such as C-V2X and 5G. There is also increased emphasis on I2V equipment and communications as part of the roadway infrastructure. This includes adding sensors to the roadway infrastructure to provide information to vehicles when basic I2V, V2V, and vehicle-based sensing technology are not enough to provide a complete understanding of the roadway and all its users. The additional infrastructure-based sensing capability in image processing, LiDAR, and radar is largely being focused on different types of intersections, where sensing and communication provide CAVs with additional information regarding pedestrians, cyclists, and other vehicles [31].
- Roadside cameras equipped with state-of-the-art pedestrian detection technologies could be critical for the penetration of CAVs. Hence, the construction of the Mcity Test Facility at the University of Michigan and associated testing and development in the Ann Arbor Connected Environment was expanded to include equipping four midblock crosswalks along Plymouth Road. Each crosswalk was equipped with a camera system to detect pedestrians, a Lear DSRC V2X RSU, an Econolite cobalt controller, and a connected vehicle co-processor card [31].

Implemented projects and initiatives that can enhance readiness for EV infrastructure:

- MDOT plans to implement the required infrastructure for electric vehicles until 2030. This plan uses high technology with 100kWh batteries and 150kW chargers (high-tech). Figure 5-2 portrays charging stations' required locations and capacities across Michigan under the considered technological scenario [32].



(c) High-tech, 2030 EV demand, Bare-Bone and Tourism (d) High-tech, 2030 EV demand, Tourism only

Figure 5-2 Visualized Location of Charging Stations and Number of Charging Outlets under high technology [32]

Implemented projects and initiatives that can enhance user/consumer acceptance and awareness:

- One of the most critical policies and regulations that can be considered for enhancing EV penetration is Tax incentives for organizations. On November 17, 2021, MDOT distributed more than $6 million to six transit agencies for zero-emission battery-electric buses, and the project expanded transit benefits in rural and urban communities. Additionally, MDOT has decided to design and install new charging infrastructures to support the new electric vehicles [33].
- Electric vehicles' prices play an important role in their adoption of CAVs, and cities can impact the prices by providing some incentives. In Michigan, the $2,000 rebate for a new electric vehicle and the $500 rebate for at-home charging infrastructure can be paired with the $7,500 federal tax credit, reducing nearly $10,000 off a new electric vehicle [34].

Minnesota Department of Transportation

The Minnesota Department of Transportation (MnDOT) has implemented projects and initiatives that can enhance readiness for physical infrastructure:

- Ramp Queue Detection project utilized in-pavement magnetic sensors, detectors, and side-fire sensors to improve the queue length estimates [35].
- Under the highway 52 Rural Corridor project, fiber optics and other CAV technologies are being installed between Rochester and St. Paul to test move-over alerts, work zone safety, and traveler information.
- Under the I-94 project, easy to see that advanced pavement markings are being tested for drivers and automated vehicles.
- MnRoad is a testbed in Minnesota that contains a 2.5-mile closed track and a 3.5-mile closed segment of the freeway where MnDOT has tested pavement impacts, smart signs, lane-keeping, and winter-weather impacts of CAVs, and autonomous commercial trucking.
- MnDOT is testing Autonomous Truck Mounted Attenuator to improve work zone safety.

- MnDOT is testing LiDAR technology to study the reliability and durability of the system in snow, rain, and dusty environment.
- The Rochester Automated Shuttle Pilot project is testing a level 4 automated shuttle to examine automated vehicle operations.

Implemented projects and initiatives that can enhance digital infrastructure/cybersecurity:

- Vehicle Infrastructure Integration for safety, mobility, and user fees project will use OBUs, RSUs, and DSRC V2X. MnDOT envisions several applications namely mileage-based user fee, work zone alert, school zone alert, speed zone alert, curve warning, intersection collision warning, and enhanced traveler information [36].
- Safe Corridor Enhancement Backbone Extension project uses and extends the existing connect Minnesota conduit along the I-94 corridor to allow low-cost extension of the communications and data fiber optic [37].
- Cell Phone Traffic Data project demonstrates the capability of traffic data systems of cell phones and compares the capability with the requirement of state and county ITS management system [38].
- MnDOT has developed a map that shows routes where truck platooning is allowed (24 hours), restricted (peak hour restrictions), and under consideration.

Implemented projects and initiatives that can enhance readiness for EV infrastructure [39]:

- MnDOT has its EV Dashboard which shows the distribution of plug-in EVs and the network of charging stations across Minnesota counties [40].
- Minnesota plans to have 20% of the light-duty cars be EV and hybrid electric vehicles by 2030.

Implemented projects and initiatives that can enhance user/consumer acceptance/awareness:

- MnDOT has plans to implement effective tactics and messaging options to inform and engage the people of Minnesota in CAV preparedness programs [39].
- MnDOT has conducted public meetings [41], online surveys [42], and scenario planning workshops [43] to engage stakeholders and the public in CAV policymaking.
- MnDOT reviews and approves the plan of interested parties who want to do truck platooning. The state law permits up to three trucks in a platoon and allows them on freeways and expressways.

Minnesota Department of Transportation has developed comprehensive plans/reports/policies to enhance the readiness of intelligent mobility:

- MnDOT has published a plan document called "Minnesota Go" which contains Minnesota's 50-year-long vision for its transportation. MNDOT has listed automation and Energy shifts as the opportunities that will impact the future of transportation [44].
- Based on "Minnesota GO," a 20-year based Statewide Multimodal Transportation Plan is developed (last adopted in 2017). Other system plans are Highway Investment Plan, Bicycle Plan, Aviation Plan, Freight Plan, Rail Plan, Ports and Waterways Plan, Pedestrian Plan, and Greater Minnesota Transit Plan [45].
- "Accelerating Electric Vehicle Adoption: A Vision for Minnesota" to increase EV use, build charging infrastructure, and prioritize renewable energy to charge EVs [46].

Ultimately, TDOT division managers and staff should select the relevant best practices from these aspirational states that can be adopted in Tennessee. Over time, the performance of the transportation system should be monitored to assess the effectiveness of the new practices and processes, realizing that improvements can take multiple years to show results.

Conclusions and Recommendations

This report delivers an overview of intelligent mobility in Tennessee; a business case for intelligent mobility strategies by predicting their benefits and impacts; results of a readiness survey and assessment based on the focus areas defined in the framework; and benchmarking of aspirational states in the US with regards to intelligent mobility strategies. The readiness assessment results are based on an extensive internet-based survey of TennSMART consortium members that included government agencies, private sector companies, and universities. Through input from these stakeholders, including TDOT's management and staff, this study contributes to pushing the boundaries on research, testing, and deployment of innovative solutions to position the entire state of Tennessee for ingesting emerging technologies in transportation. The responses provide baseline inventory for current intelligent mobility activities and help identify options for future activities that will enhance mobility in Tennessee. The results of the readiness assessment in Tennessee reveal a high activity and readiness in electric vehicle infrastructure, followed by digital infrastructure, roadway infrastructure, and modest levels of public knowledge and acceptance.

Furthermore, the analysis of ITS architecture plans for cities in Tennessee shows Tennessee's focus on a set of strategies. These include 1) installing digital infrastructure, especially fiber optic networks and field sensors, 2) responding to emergencies—planning, operation, and routing of emergency vehicles when responding to incidents, traffic signal preemption and emergency traffic control, area alerts, evacuation if needed, and traffic incident management, 3) enhancing safety, especially reducing deaths and injuries and damages to TDOT property—through the collection of information (e.g., CCTV cameras) and dissemination of information through dynamic message signs and radio transmitters, and 4) workforce development.

The team has identified the leading states in emerging technologies (CAV and EV) research and development and summarized their progress and success stories. These include Michigan, Florida, California, and Minnesota. A key aspect of this research is that the holistic approach developed in this study gives insights into how to plan for the future of emerging technologies. Ultimately, TDOT division managers and staff should select the relevant best practices from these aspirational states that can be adopted in Tennessee. Over time, the performance of the transportation system should be monitored to assess the effectiveness of the new practices and processes, realizing that improvements can take multiple years to show results.

The application of new tools, large-scale data, modeling, simulation, visualization, and artificial intelligence can help Tennessee plan for the future of intelligent mobility.

Successful implementation of intelligent mobility strategies requires that TDOT and partners rely on the diverse resources available in Tennessee. To prepare for intelligent mobility in Tennessee, recommendations are partly based on rankings received in the readiness survey of TennSMART consortium members. The recommendations are based on physical, digital, and electric vehicle charging infrastructure and public knowledge and acceptance.

- ***Enhancing readiness in physical roadway infrastructure.*** Several aspects of roadway infrastructure can be considered by TDOT. These include 1) designing and increasing the width of pavement markings and improving signs, where needed, to enhance their visibility for CAVs throughout Tennessee. Notably, TDOT is enhancing pavement markings and signs, with appropriate staffing and funding devoted to this endeavor. Also, TDOT can consider creating CAV park-and-ride facilities in the long term to make the CAV deployment in Tennessee smoother. 2) Partnering with organizations, e.g., TennSMART and academic institutions, to hold workshops addressing many individual aspects of intelligent mobility, especially roadway design changes, pavement performance changes (e.g., due to reduced wheel wander), improving pavement condition, and other physical infrastructure issues.
- ***Enhancing readiness in digital infrastructure.*** TDOT can allocate more resources to 1) using sensing technologies such as smart cameras to detect different object types and road users, e.g., identifying trending volatile behaviors among all road users and implementing mitigation measures for stable flow. 2) In partnership with IOOs, ensure that traffic signals are upgraded and their operation is smooth. 3) Developing and training a technology-savvy workforce, e.g., by arranging to offer courses in emerging technology and their safe, secure, and effective operation. 4) Establishing strong cooperation with data science experts from different organizations such as universities to harness connected vehicle data. Real-time traffic and CAV data dashboards can be developed to improve the ability of TMC operators to access and harness the data. TDOT can work with universities and the private sector to deploy a field solution for V2X communications and conduct pilot testing of new dual-mode OBUs and RSUs in laboratory settings and on-road. Furthermore, research can be conducted on cooperative driving automation and scenario generation to expand operational design domains for highly automated vehicles.
- ***Enhancing readiness in electric vehicle infrastructure.*** Regarding support for transportation electrification, TDOT, TDEC, and diverse stakeholders such as TVA and private sector companies can partner to 1) Deploy EV charging stations along interstates and critical routes in Tennessee (efforts are underway in this regard through Tennessee Electric Vehicle Infrastructure, or TEVI). 2) Develop and use an infrastructure location planning tool for creating a network of charging stations based on the future demand for EVs in Tennessee and undertake other supportive actions related to EV charging. A plan can guide the efficient deployment of charging stations by considering the development of partnerships that can help prepare communities for locating DC fast charging. Also, constructing electric vehicle parking facilities through partnerships with public building authorities can be pursued. 3) TDOT can also consider adopting the zero-emission vehicle program and mandate, which includes several types of alternative fuel vehicles.
- ***Strategies for readiness in public knowledge and acceptance.*** TDOT can improve public knowledge and acceptance using either internal resources or through the participation of universities, especially centers or institutes that focus on technology transfer activities and public awareness. Strategies to consider can include educating travelers about CAV capabilities, re-engaging AVs in complex situations when driver attention is needed, and communicating the intent of CAVs to conventional vehicle drivers. Also, knowledge about alternative fuel vehicles (including EVs) can be disseminated through the Tennessee Clean Fuel Coalition, a DOE Clean City program (an initiative that TDOT's Long-Range Planning can

coordinate and pursue). TDOT can seek and incorporate public feedback into intelligent mobility policies and programs. TDOT can cooperate with other private or public organizations to study EV/CAV adoption based on their specific models. One example is the Oak Ridge National Laboratory Market Acceptance of Advanced Automotive Technologies model.

To deploy smart infrastructure enablers for intelligent mobility strategies, such as automated and electric vehicles, all stakeholders need to be fully engaged in an open process.

- ***General strategies for enhancing intelligent mobility.*** The strategies mentioned below can be adopted by TDOT, with some of them supporting TDOT's Transportation System Management and Operations Program Plan. The strategies include several action items that can be easily implemented to show demonstrable progress.

1) **Creating Roadmaps.** TDOT can develop roadmaps for physical and digital infrastructure, electric vehicle infrastructure, regulation and policy, user acceptance, partnerships with stakeholders, and workforce development. To deploy smart infrastructure enablers for intelligent mobility strategies, such as automated and electric vehicles, all stakeholders must be fully engaged in an open process. For example, intelligent transportation systems and broadband/fiber roadmaps can be developed with stakeholder input by the traffic operations division in coordination with the information technology division (responsible for computerized information resources) and transportation consultants. The Transportation Systems Management and Operations Program Plan development is currently underway at TDOT, which outlines the vision and strategies for intelligent mobility. Furthermore, TDOT and TDEC are collaborating to develop the Tennessee Electric Vehicle Infrastructure Deployment Plan. Such activities can be expanded to achieve the broader impact of intelligent mobility technologies. Such activities can be expanded to the other areas mentioned above.

2) **Benchmarking.** Efforts can be undertaken to understand the current state-of-the-practice for statewide intelligent mobility readiness plans in other states, lessons learned, and recommendations while tracking emerging technology advances.

3) **Intelligent Transportation Systems.** Improvements in roadway, digital, and electric vehicle infrastructure technologies through ITS architecture service packages can be envisioned. A wide range of CAV service applications can be considered for implementation in Tennessee, including emergency vehicle preemption, broadcast traveler information, queue warning, work zone management, personalized traveler information, road weather motorist and warning, pedestrian and cyclist safety, and electric charging stations management.

4) **Multimodal transportation.** TDOT can identify opportunities in terms of connected, automated, and electric transportation systems that are multimodal, i.e., including freight, transit, pedestrians, and bicycles. For example, the TDOT traffic operations division staff can work with the multimodal transportation resources division staff to conceive and implement projects that deal with transit systems detecting pedestrians to

increase safety or coordinate with private sector logistics companies to improve freight movement and delivery.

5) **Planning.** Intelligent mobility strategies can be integrated into long-term planning and programming processes. This activity can involve coordination between the traffic operations division and long-range planning division staff for the various plans created at TDOT, e.g., the TSMO Program Plan and the TEVI plan.

6) **Data collection.** TDOT can develop data collection and harnessing capability from new sensors, e.g., OBUs and RSUs that transmit basic safety messages and alerts or warnings. However, this will require investments of significant resources to handle CAV-related activities, including equipment deployment and data collection. Notably, CAV data collection, processing, and use are particularly challenging, given the uncertainties associated with communication technologies (i.e., DSRC V2X technology), CAV data storage and analysis, data sharing, the requirement to have a sufficient number of OBUs on vehicles, and most importantly TDOT not owning or operating traffic signals in Tennessee.

7) **Conduct Interviews and Surveys.** Technology readiness surveys were designed and conducted for members of the TennSMART consortium by the research team. TDOT can further conduct interviews and surveys of various stakeholders, including TDOT Division Directors and staff, regarding their readiness for CAV and synergistic technologies, including electric vehicles.

8) **Workforce.** TDOT can consider creating positions for TDOT-based program managers to test and deploy CAVs (their responsibilities can be similar to ITS managers). This activity is clearly resource-intensive, requiring higher-level administrative approvals.

9) **Coordination.** Develop an external stakeholder coordination strategy, especially with IOOs, vehicle manufacturers, information technology companies, and the TennSMART consortium.

10) **Research Development and Deployment.** TDOT can further research, develop, pilot-test, and deploy intelligent mobility technologies. TDOT demonstrates the capabilities and benefits of CAVs through testbeds, e.g., I-24 smart corridor. Additionally, the Chattanooga MLK Smart City Corridor testbed and other statewide initiatives are exemplars. More comprehensive pilot testing and deployment of these technologies will help achieve transportation system improvement goals.

- ***Future research on intelligent mobility strategies.*** TDOT can conduct research on specific issues related to CAV data, harnessing the data, and investing in modeling/simulation capabilities that can directly deal with the 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. Currently, TDOT has invested resources in the I-24 Mobility Technology Interstate Observation Network (I-24 MOTION) to understand how different types of vehicles interact with each other and infrastructure to advance congestion management across Tennessee. Also, TDOT's Research Program addresses the agency's research needs. However, more investments in research activities to synergize various aspects of intelligent mobility strategies are needed. TDOT should continue to invest in several aspects of intelligent mobility strategies. These would include research on the efficacy and broader impacts of intelligent mobility strategies and the potential for disruption in terms of job losses in Tennessee due to vehicle automation, e.g., losses in taxi driver and large-truck driver jobs. Further, there is a need to explore 1) how rural areas will be impacted by access to CAV and broadband technologies; 2) how transit agencies can use CAV technologies to address first mile/last mile issues; 3) how to address equity and inclusion of disadvantaged and under-represented groups in the accessibility of emerging technologies; and 4) what are the impacts of intelligent mobility strategies on land use in the long term.

The report features details about use-cases that can support the deployment of smart infrastructure in Tennessee. For instance, these include 1) installing RSUs and OBUs on personal and state vehicles, 2) funding opportunities in IIJA, 3) options for installing communications equipment when TDOT does not own or operate traffic signals, 4) communications considerations associated with connected vehicle equipment, 5) use cases showing CAV data storage/transmission considerations, and 6) staffing needs associated with smart infrastructure deployments.

Overall, this report highlights investments needed in intelligent mobility strategies from a statewide perspective. In this regard, it is critical to nurture partnerships between stakeholders, i.e., government agencies, industry, and academic institutions, as is workforce development. Specifically, investments are needed in innovative solutions encompassing physical infrastructure, digital and smart infrastructure, electric vehicles, and charging infrastructure. Furthermore, state policies and regulations are needed to guide the safe development, deployment, and adoption of new technologies, considering federal policy guidance. The application of new tools, large-scale data, modeling, simulation, visualization, and artificial intelligence can help Tennessee plan for the future of intelligent mobility.

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Appendices

Appendix A: CAV Readiness Index Data

TABLE A- 1 CAV READINESS INDEX DATA FROM THE TENNESSEE REGIONAL ITS ARCHITECTURES

Indicator	*Clarksville*	*Nashville*	*Memphis*	*Knoxville*	*Johnson City*	*Jackson*	*Bristol*	*Kingsport*	*Chattanooga*	*Cleveland*	*Lakeway*
Policy and Regulations	0.15	0.15	0.31	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Driving regulations	0	0	0	0	0	0	0	0	0	0	0
Testing regulations	0	0	0	0	0	0	0	0	0	0	0
Tax incentives for consumers	0	0	0	0	0	0	0	0	0	0	0
Tax incentives for organizations	0	0	0	0	0	0	0	0	0	0	0
Reduced fees for consumers	0	0	0	0	0	0	0	0	0	0	0
Reduced fees for organizations	0	0	0	0	0	0	0	0	0	0	0
HOV lane permission	0	0	0	0	0	0	0	0	0	0	0
Parking privileges	0	0	0	0	0	0	0	0	0	0	0
Tolling privilege	0	0	0	0	0	0	0	0	0	0	0
Preventing misuse of safety harbors	0	0	1	0	0	0	0	0	0	0	0
Maintenance of the existing signs and markings	1	1	1	1	1	1	1	1	1	1	1
Designation of CAV-compatible areas	1	1	1	1	1	1	1	1	1	1	1
Guidelines to lowering inconsistency in design and use of signage	0	0	1	0	0	0	0	0	0	0	0

Continued Table A-1

Indicator	Clarksville	Nashville	Memphis	Knoxville	Johnson City	Jackson	Bristol	Kingsport	Chattanooga	Cleveland	Lakeway
Physical Infrastructure	0.2	0.2	0.4	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4
High-quality road signage and marking	1	1	1	1	1	1	1	1	1	1	1
CAV-compatible parking facilities	0	0	0	0	0	0	0	0	0	0	0
Sensor-equipped cones and beacons	0	0	1	0	0	1	1	1	1	1	1
CAV-only pick-up and drop-off areas	0	0	0	0	0	0	0	0	0	0	0
CAV-compatible tolling facilities	0	0	0	0	0	0	0	0	0	0	0
Digital Infrastructure	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Infrastructure to vehicle communication devices	0	0	0	0	0	0	0	0	0	0	0
High-resolution maps of the road network	1	1	1	1	1	1	1	1	1	1	1
Infrastructure-based pedestrian detection technologies	0	0	1	0	0	0	0	0	0	0	0
Other Indicators	0.33	0.56	0.44	0.44	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Autonomous truck permits	0	0	0	0	0	0	0	0	0	0	0
Land use pattern	0	1	1	1	0	0	0	0	1	0	0
Re-evaluation of the bridge structure	0	0	0	0	0	0	0	0	0	0	0
Transit control center	1	1	1	1	1	1	1	1	1	1	1
Autonomous DRT services	0	0	0	0	0	0	0	0	0	0	0
US DOT Smart City Challenge	0	1	0	0	0	0	0	0	1	0	0
Research on CAV requirements	1	1	1	1	1	1	1	1	1	1	1
Inappropriate weather	0	0	0	0	0	0	0	0	0	0	0
Auto tax rate higher than Nation	1	1	1	1	1	1	1	1	1	1	1

Appendix B: Intelligent Mobility Readiness Survey

B.1 Pre-Survey

Introduction

Preparatory Survey on Intelligent Mobility for TennSMART Members

We are conducting an assessment of readiness for intelligent mobility in Tennessee and are interested in your organization's experiences as a member of TennSMART consortium. As the primary contact for TennSMART, we hope you will respond to this survey and the main survey coming soon. **We are requesting you to identify areas that are relevant to your organization's focus. We are also requesting you to provide the names and contact information of 5 or more members in your organization who would be best able to cover the areas.** **Your identity or personal information will not be disclosed.**

Is your organization a member of TennSMART consortium?

- ◯ Yes
- ◯ No

As a TennSMART member, please identify your organization.

- ◯ AAA
- ◯ Bridgestone Americas
- ◯ City of Knoxville
- ◯ DENSO Manufacturing Tennessee, Inc.
- ◯ EPB
- ◯ FedEx Corporation
- ◯ Google LLC
- ◯ Gresham Smith
- ◯ Oak Ridge National Laboratory
- ◯ Softchoice
- ◯ Stansell Electric Company Inc.
- ◯ Stantec Consulting Services Inc.
- ◯ Tennessee Department of Environment and Conservation (TDEC)
- ◯ Tennessee Department of Transportation (TDOT)
- ◯ Tennessee Tech University
- ◯ Tennessee Valley Authority (TVA)

- HDR, Inc.
- HNTB Corporation
- Local Motors
- Lyft
- Miovision Technologies
- Nissan North America
- University of Memphis
- The University of Tennessee, Knoxville
- The University of Tennessee, Chattanooga
- Vanderbilt University
- Other (Please Specify)

Please Identify your organization.

Respondent Information

What is your main role in your organization (e.g., Planner or Engineer)?

Relevant Areas

Intelligent Mobility covers the following areas. Please read the brief description, and answer the question.

The Areas of Intelligent Mobility

Physical Infrastructure

Physical infrastructure includes all physical assets associated with roads (i.e., the roadway itself, markings, signage, safety barriers, earthworks, drainage, and structures). Also included are public transit systems as well as pedestrian and bicycle facilities.

Digital Infrastructure

Digital infrastructure provides the information technology foundation for operating the transportation system. It includes transportation sensors (e.g., cameras, loops, and radars), cable, information dissemination equipment (e.g., radio transmitters and message signs), communication devices, traffic signal controllers, and transportation management centers with associated data centers and equipment. Digital infrastructure also includes cloud hosted services, data centers, security credentialing, and in-vehicle devices/systems (Onboard units and sensing systems).

Electric Vehicle Infrastructure

Electric Vehicle infrastructure includes structures, machinery and equipment needed to support electric vehicle charging, as well as electricity generation and distribution.

Public Knowledge and Acceptance

Public knowledge and acceptance signify communication and dissemination of scientifically-based knowledge to the public for educating them in terms of transportation issues (e.g., safe mobility). This is often done through media (e.g., smart devices and the internet).

For EACH of the areas, please rate its relevance to your organization's focus.

	Not relevant	Moderately relevant	Highly relevant
Physical Infrastructure	○	○	○
Digital Infrastructure	○	○	○
Electric Vehicle Infrastructure	○	○	○
Public Knowledge and Acceptance	○	○	○

Names and Contact Information

Our goal is to learn more about work underway in your organization related to the areas you identified. **Please provide the names and contact information of 5 or more individuals working in the area(s) you have identified.**
(If convenient, you can upload a document or spreadsheet by clicking on "choose file" below. Your document or spreadsheet should contain at a minimum the names and email contact information for potential survey respondents.)

Person 1

Name (First and Last)

Email Address

Telephone Number (Optional)

Area of relevance for Person 1 (Please select all that apply.)

- ☐ Physical Infrastructure
- ☐ Digital Infrastructure
- ☐ Electric Vehicle Infrastructure
- ☐ Public Knowledge and Acceptance
- ☐ Do not know / Not sure

Do you have another contact you would like to enter?

- ○ Yes
- ○ No

Person 2

Name (First and Last)

Email Address

Telephone Number (Optional)

Area of relevance for Person 2 (Please select all that apply.)

- ☐ Physical Infrastructure
- ☐ Digital Infrastructure
- ☐ Electric Vehicle Infrastructure
- ☐ Public Knowledge and Acceptance
- ☐ Do not know / Not sure

Do you have another contact you would like to enter?

- ○ Yes
- ○ No

Person 3

Name (First and Last) ____

Email Address ____

Telephone Number (Optional) ____

Area of relevance for Person 3 (Please select all that apply.)

- ☐ Physical Infrastructure
- ☐ Digital Infrastructure
- ☐ Electric Vehicle Infrastructure
- ☐ Public Knowledge and Acceptance
- ☐ Do not know / Not sure

Do you have another contact you would like to enter?

- ○ Yes
- ○ No

Person 4

Name (First and Last) ____

Email Address ____

Telephone Number (Optional) ____

Area of relevance for Person 4 (Please select all that apply.)

- ☐ Physical Infrastructure
- ☐ Digital Infrastructure
- ☐ Electric Vehicle Infrastructure
- ☐ Public Knowledge and Acceptance
- ☐ Do not know / Not sure

Do you have another contact you would like to enter?

- ○ Yes
- ○ No

Person 5

Name (First and Last) [ ]

Email Address [ ]

Telephone Number (Optional) [ ]

Area of relevance for Person 5 (Please select all that apply.)

- ☐ Physical Infrastructure
- ☐ Digital Infrastructure
- ☐ Electric Vehicle Infrastructure
- ☐ Public Knowledge and Acceptance
- ☐ Do not know / Not sure

Do you have another contact you would like to enter?

- ◯ Yes
- ◯ No

Person 6

Name (First and Last) [ ]

Email Address [ ]

Telephone Number (Optional) [ ]

Area of relevance for Person 6 (Please select all that apply.)

- ☐ Physical Infrastructure
- ☐ Digital Infrastructure
- ☐ Electric Vehicle Infrastructure
- ☐ Public Knowledge and Acceptance
- ☐ Do not know / Not sure

Do you have another contact you would like to enter?

- ◯ Yes
- ◯ No

Person 7

Name (First and Last) | |
Email Address | |
Telephone Number (Optional) | |

Area of relevance for Person 7 (Please select all that apply.)

- ☐ Physical Infrastructure
- ☐ Digital Infrastructure
- ☐ Electric Vehicle Infrastructure
- ☐ Public Knowledge and Acceptance
- ☐ Do not know / Not sure

Do you have another contact you would like to enter?

- ○ Yes
- ○ No

Person 8

Name (First and Last) | |
Email Address | |
Telephone Number (Optional) | |

Area of relevance for Person 8 (Please select all that apply.)

- ☐ Physical Infrastructure
- ☐ Digital Infrastructure
- ☐ Electric Vehicle Infrastructure
- ☐ Public Knowledge and Acceptance
- ☐ Do not know / Not sure

Do you have another contact you would like to enter?

- ○ Yes
- ○ No

Person 9

Name (First and Last)

Email Address

Telephone Number (Optional)

Area of relevance for Person 9 (Please select all that apply.)

- ☐ Physical Infrastructure
- ☐ Digital Infrastructure
- ☐ Electric Vehicle Infrastructure
- ☐ Public Knowledge and Acceptance
- ☐ Do not know / Not sure

Do you have another contact you would like to enter?

- ○ Yes
- ○ No

Person 10

Name (First and Last)

Email Address

Telephone Number (Optional)

Area of relevance for Person 10 (Please select all that apply.)

- ☐ Physical Infrastructure
- ☐ Digital Infrastructure
- ☐ Electric Vehicle Infrastructure
- ☐ Public Knowledge and Acceptance
- ☐ Do not know / Not sure

Additional Comments

Any additional comments that you would like to share with us?

B.2 Main Survey

Introduction

Intelligent Mobility Survey for TennSMART Members

Purpose of the Survey. The purpose of this survey is to identify current intelligent mobility practices and Tennessee's readiness in terms of physical, digital, and electric vehicle infrastructure and user acceptance as viewed by TennSMART members. The responses will be used to develop a baseline inventory for current intelligent mobility activities and help identify options for future activities that will enhance mobility in Tennessee.

Background. We are conducting an assessment of readiness for intelligent mobility in Tennessee and are interested in your experiences as a representative of your organization (in TennSMART). Your participation will involve answering questions about readiness for intelligent mobility.

Confidentiality. Please know that your identity or personal information will not be disclosed in any publication. Survey data will be stored securely and will be made available only to persons conducting the study. There are no foreseeable risks in answering the questions other than those encountered in everyday life.

Participation. Your participation in this study is voluntary. You may decline to participate without any penalty. If you decide to participate, you may withdraw from the survey at anytime. If you withdraw from the study before data collection is completed your data will be deleted.

Questions? If you have questions at any time about the study or the procedures, you may contact Professor Asad Khattak, at akhattak@utk.edu and (865) 974-7792.

TennSMART aims. TennSMART members aim to accelerate the development and deployment of new intelligent mobility innovations. Using connectivity, automation, and electrification, TennSMART members are leveraging emerging transportation technologies that improve safety, accessibility, and system operations while reducing energy consumption and emissions. TennSMART stakeholders include automotive and trucking industries, municipalities, universities, and research institutions to address intelligent mobility opportunities together that no one organization could attain alone.

Terms and abbreviations

Intelligent Mobility: This term means the application of innovative, efficient, and environmentally friendly solutions for moving people and goods. Intelligent Mobility envisions an automated, connected, electric, and shared transportation system that is multimodal, secure, and efficient.

Abbreviations

Connected and Automated Vehicles (CAVs): CAVs include Automated Vehicles (AVs) operating at higher levels of automation, that is, Society of Automotive Engineers (SAE) levels 3, 4 and 5. They also include Connected Vehicles (CVs) that communicate with other vehicles and transportation infrastructure. Please see Figures 1 and 2 for an explanation.

Automated Vehicles (AVs): At least some aspect of a safety-critical control function (e.g., steering, throttle, or braking) in AVs occurs without direct driver input (US DOT).

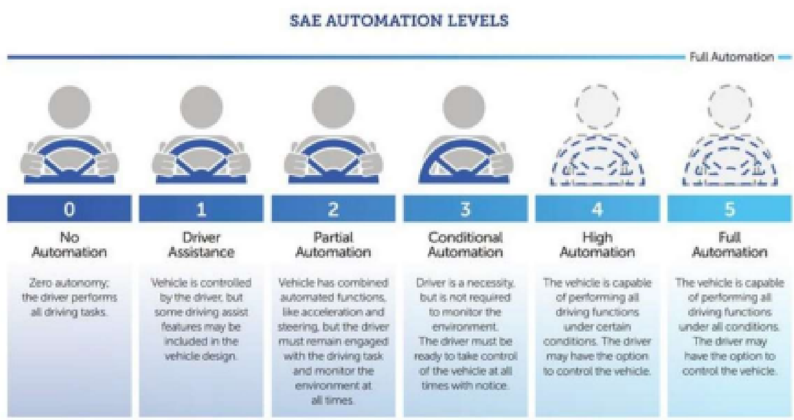


Figure 1: Levels of Automation. (Source: NHTSA)

Connected Vehicles (CVs): CVs broadcast and receive a diverse range of messages around mobility and safety using C-V2X technology. These messages share information on vehicles' speed, heading, location, and other variables. This information is used for mobility and safety applications that provide drivers with warnings about imminent collisions (USDOT).

Figure 2: Connected Vehicles. (Source: USDOT)

Electric Vehicles (EVs): These vehicles are propelled by electric power and they include all-electric/plug-in hybrid. They have different charging options, as shown in Figure 3, which can facilitate long-distance travel and provide convenient charging where people live, work, and shop. Their accelerated adoption can reduce dependence on fossil fuels, reduce emissions and improve air quality.

Mobility as a Service (MaaS): Travelers can now use different ride-hailing mobility services, e.g., Uber and Lyft.

Figure 3: Levels of Electric Vehicle Charging. (Source: ConEdison)

Participant Questions

Answering the questions below will constitute your consent to participate in the study.

Would you like to participate in this study?

- Yes
- No

Is your organization a member of TennSMART consortium?

- Yes IF YES, next question displays
- No IF NO, skip to "Please identify your organization."

As a member of TennSMART, please identify your organization.

- AAA
- Bridgestone Americas
- City of Knoxville
- DENSO Manufacturing Tennessee, Inc.
- EPB
- FedEx Corporation
- Google LLC
- Gresham Smith
- HDR, Inc.
- HNTB Corporation
- Local Motors
- Lyft
- Miovision Technologies
- Nissan North America
- Oak Ridge National Laboratory
- Softchoice
- Stansell Electric Company Inc.
- Stantec Consulting Services Inc.
- Tennessee Department of Environment and Conservation (TDEC)
- Tennessee Department of Transportation (TDOT)
- Tennessee Tech University
- Tennessee Valley Authority (TVA)
- University of Memphis
- The University of Tennessee, Knoxville
- The University of Tennessee, Chattanooga
- Vanderbilt University
- Other (Please Specify)

Please identify your organization.

Relevant Areas

Intelligent Mobility covers the following areas. Please read the brief description, and answer the question.

The Areas of Intelligent Mobility

Physical Infrastructure

Physical infrastructure includes all physical assets associated with roads (i.e., the roadway itself, markings, signage, safety barriers, earthworks, drainage, and structures). Also included are public transit systems as well as pedestrian and bicycle facilities.

Digital Infrastructure

Digital infrastructure provides the information technology foundation for operating the transportation system. It includes transportation sensors (e.g., cameras, loops, and radars), cable, information dissemination equipment (e.g., radio transmitters and message signs), communication devices, traffic signal controllers, and transportation management centers with associated data centers and equipment. Digital infrastructure also includes cloud hosted services, data centers, security credentialing, and in-vehicle devices/systems (Onboard units and sensing systems).

Electric Vehicle Infrastructure

Electric Vehicle infrastructure includes structures, machinery and equipment needed to support electric vehicle charging, as well as electricity generation and distribution.

Public Knowledge and Acceptance

Public knowledge and acceptance signify communication and dissemination of scientifically-based knowledge to the public for educating them in terms of transportation issues (e.g., safe mobility). This is often done through media (e.g., smart devices and the internet).

For EACH of the areas, please rate its relevance to your organization's focus.

FOR EACH CATEGORY BELOW, RESPECITIVE SECTIONS ARE DISPLAYED IF "MODERATELY RELEVANT' OR 'HIGHLY RELEVANT' ARE SELECTED

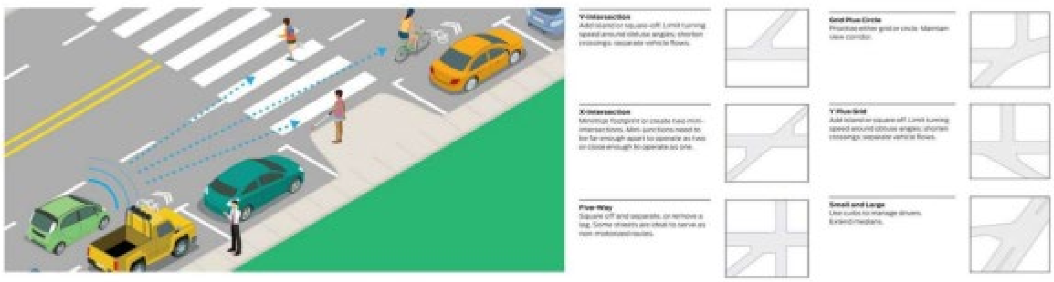
	Not relevant	Moderately relevant	Highly relevant
Physical Infrastructure	○	○	○
Digital Infrastructure	○	○	○
Electric Vehicle Infrastructure	○	○	○

	Not relevant	Moderately relevant	Highly relevant
Public Knowledge and Acceptance	○	○	○

Physical Infrastructure

Physical Infrastructure

Existing roadways may need improvements to adapt to CAVs (e.g., curb redesign), while CAVs should also adapt to complex roadway designs (e.g., irregular intersections).



Left side: Curb redesign. (Source: pedbikeinfo.org)

Right side: Intersection Types. (Source: NACTO Urban Street Design Guide (pp.100-101))

Has your organization researched, developed, or deployed roadway improvements or any technologies for CAVs' adaptation to roadways?

- ○ [ ] Yes (Please specify)
- ○ [ ] No, but we have a specific plan for it (Please specify)
- ○ No, but we expect to have a specific plan for it in the future (Please specify) [ ]
- ○ No, and we have no plan for it
- ○ Don't know/ Not sure/ Not applicable

To safely operate on roadways, it is necessary for CAVs' vision systems to clearly detect pavement markings.

CAV detecting road markings (source: reflective-systems.com)

Has your organization researched, developed, or deployed pavement markings improvements or any technologies for CAVs to clearly detect pavement markings?

- ◯ Yes (Please specify) ______
- ◯ No, but we have a specific plan for it (Please specify) ______
- ◯ No, but we expect to have a specific plan for it in the future (Please specify) ______
- ◯ No, and we have no plan for it
- ◯ Don't know/ Not sure/ Not applicable

CAVs require high readability of road signs.

Road signs. (Source: FHWA)

Has your organization researched, developed, or deployed road sign improvements or any technologies for CAVs to correctly detect road signs?

- ○ [ ] Yes (Please specify)
- ○ [ ] No, but we have a specific plan for it (Please specify)
- ○ No, but we expect to have a specific plan for it in the future (Please specify) [ ]
- ○ No, and we have no plan for it
- ○ Don't know/ Not sure/ Not applicable

The Operational Design Domain (ODD) describes "conditions in which CAVs function" (e.g., CAV-dedicated lanes, time-of-day restrictions, and weather conditions). The following figure shows an example of ODD for CAVs.

Operational Design Domains (Source: PAS1883, bsigroup.com)

Has your organization considered or worked on issues related to ODD for CAVs?

- ○ [ ] Yes (Please specify)
- ○ [ ] No, but we have a specific plan for it (Please specify)

- No, but we expect to have a specific plan for it in the future (Please specify)
- No, and we have no plan for it
- Don't know/ Not sure/ Not applicable

Truck platoons on highways can improve commercial vehicle efficiency, but also can impede other traffic and impact safety (e.g., crash severity).

Truck platooning (Source: Peloton)

Has your organization researched, developed, or deployed any technologies or regulations for truck platooning to be safer or more efficient?

- Yes (Please specify)
- No, but we have a specific plan for it (Please specify)
- No, but we expect to have a specific plan for it in the future (Please specify)
- No, and we have no plan for it
- Don't know/ Not sure/ Not applicable

Multimodal travel by individuals can involve different types of modes (e.g., smart bus, scooter, bicycle, and public transit), which requires well-designed road infrastructure including bus stops, bicycle lanes, crosswalks, and sidewalks.

Multimodal travel (Source: roadtraffic-technology)

Has your organization researched, developed, or deployed road infrastructure improvements or technology to support multimodal travel?

- ○ [ ] Yes (Please specify)
- ○ [ ] No, but we have a specific plan for it (Please specify)
- ○ No, but we expect to have a specific plan for it in the future (Please specify) [ ]
- ○ No, and we have no plan for it
- ○ Don't know/ Not sure/ Not applicable

A well-trained and technology-savvy workforce is needed to address Intelligent Mobility issues in the future including transportation system connectivity and automation, transportation electrification, cybersecurity, freight efficiency, and multimodal travel.

Workforce education (Source: Connecticut Center for Advanced Technology)

Has your organization implemented workforce education and training for enhancing intelligent mobility?

- ☐ Yes (Please specify)
- ☐ No, but we have a specific plan for it (Please specify)
- No, but we expect to have a specific plan for it in the future (Please specify) ☐
- No, and we have no plan for it
- Don't know/ Not sure/ Not applicable

Digital Infrastructure

Digital Infrastructure

CAV technologies can exchange information with digital infrastructure, e.g., C-V2X capable roadside units can give warnings to drivers for red light running, or for high speeds on curves. The following figure shows the concept of infrastructure-vehicle communication.

Vehicle-Infrastructure Communication. (Source: USDOT)

Has your organization worked on any infrastructure-vehicle communication technology applications?

- ○ Yes (Please specify) ____________
- ○ No, but we have a specific plan for it (Please specify) ____________
- ○ No, but we expect to have a specific plan for it in the future (Please specify) ____________
- ○ No, and we have no plan for it
- ○ Don't know/ Not sure/ Not applicable

Does your organization have plans for onboard units in vehicles to read and communicate with roadside cellular-vehicle-to-everything (C-V2X) units?

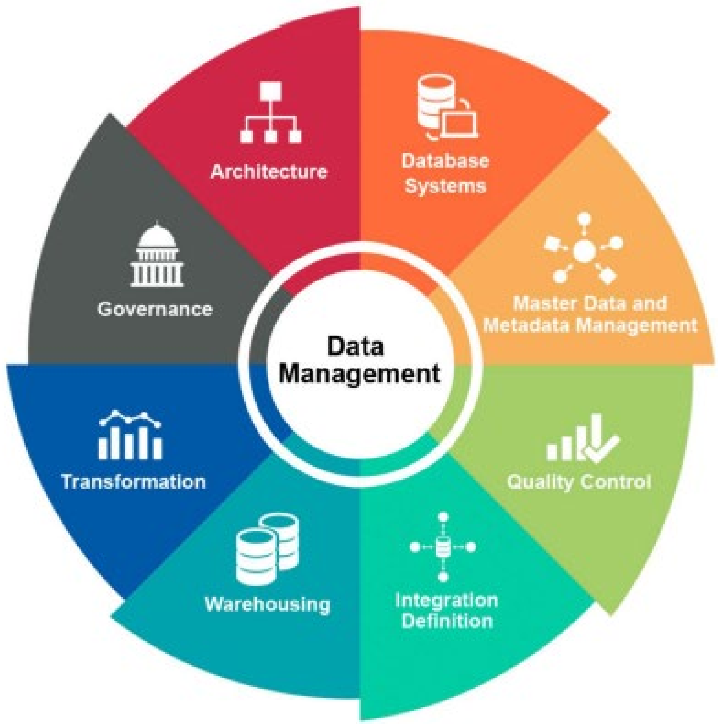
- ○ Yes (Please specify) ____________
- ○ No, but we have a specific plan for it (Please specify) ____________

- No, but we expect to have a specific plan for it in the future (Please specify) ____
- No, and we have no plan for it
- Don't know/ Not sure/ Not applicable

Assuming that cellular-vehicle-to-everything (C-V2X) units were widely deployed, would your organization have a plan to receive and harness the data i.e., use it to improve mobility and safety?

- ____ Yes (Please specify)
- ____ No, but we have a specific plan for it (Please specify)
- No, but we expect to have a specific plan for it in the future (Please specify) ____
- No, and we have no plan for it
- Don't know/ Not sure/ Not applicable

Digital Infrastructure (e.g., sensors, communication devices, and traffic signal controllers) generates data that can be used for many purposes such as incident management and traffic safety assessment.

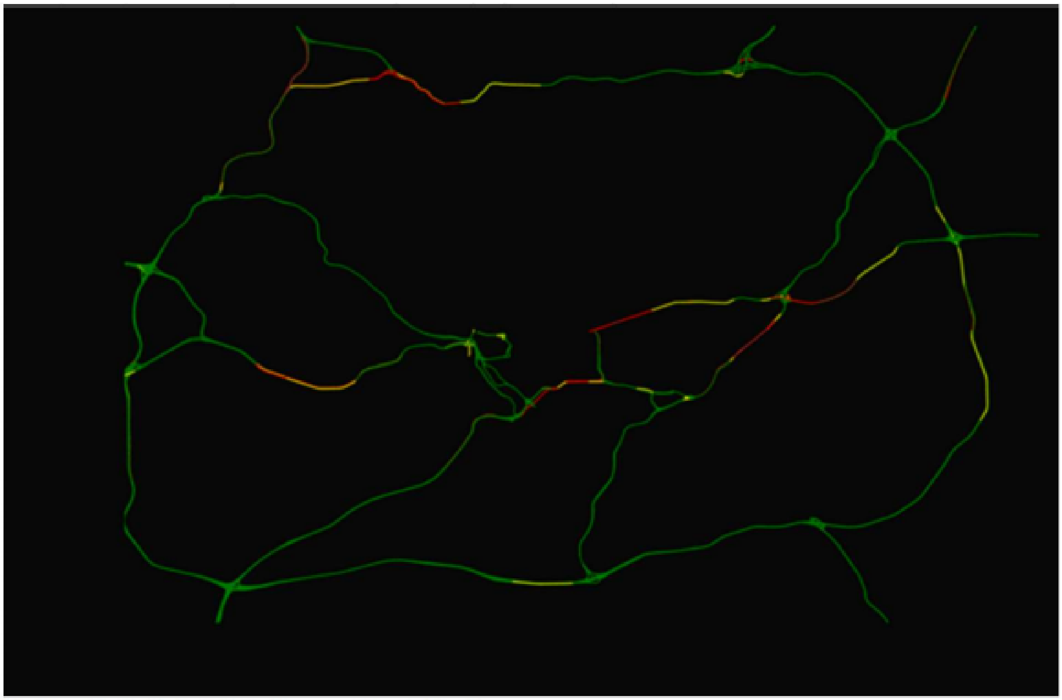


Data Management (Source: Oceangliders)

Has your organization worked on processing or managing large scale data?

- ○ [ ] Yes (Please specify)
- ○ [ ] No, but we have a specific plan for it (Please specify)
- ○ No, but we expect to have a specific plan for it in the future (Please specify) [ ]
- ○ No, and we have no plan for it
- ○ Don't know/ Not sure/ Not applicable

Monitoring traffic flow in real-time is essential for quick responses to a variety of situations (e.g., crashes or vehicle breakdowns). For instance, as shown in the following figure, the "HERE Traffic API" provides traffic flow and incident information allowing users to request traffic map tiles.



Highway Traffic Data in D.C. (Source: Skanda Vivek)

Has your organization researched, developed, or deployed any technologies for collecting, managing, and using real-time traffic data?

- ○ [ ] Yes (Please specify)
- ○ [ ] No, but we have a specific plan for it (Please specify)
- ○ No, but we expect to have a specific plan for it in the future (Please specify) [ ]
- ○ No, and we have no plan for it
- ○ Don't know/ Not sure/ Not applicable

The vulnerability of the increasingly connected transportation system to cyber-attacks is a key concern.

Cybersecurity. (Source: Information Age)

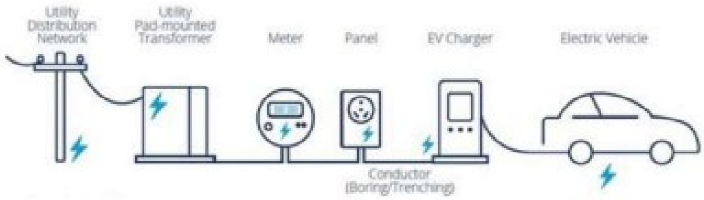
Has your organization considered actions that will enhance cybersecurity in the transportation system?

- ○ ☐ Yes (Please specify)
- ○ ☐ No, but we have a specific plan for it (Please specify)
- ○ No, but we expect to have a specific plan for it in the future (Please specify) ☐
- ○ No, and we have no plan for it
- ○ Don't know/ Not sure/ Not applicable

Electric Vehicle Infrastructure

Electric Vehicle Infrastructure

To support electrification, the transportation system needs "a network of EV charging stations" with different levels of charging (e.g., Level 1, Level 2, and DC Fast charging).

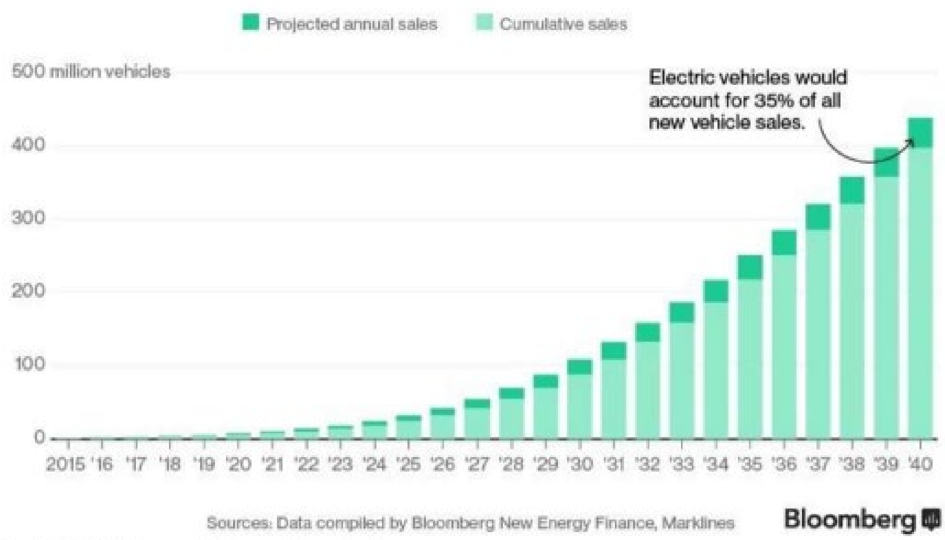


Electric Vehicle Charging Infrastructure (Source: Central Hudson)

Has your organization researched, developed, or deployed EV infrastructure (e.g., charging stations, electricity generation and distribution)?

- ○ [ ] Yes (Please specify)
- ○ [ ] No, but we have a specific plan for it (Please specify)
- ○ No, but we expect to have a specific plan for it in the future (Please specify) [ ]
- ○ No, and we have no plan for it
- ○ Don't know/ Not sure/ Not applicable

Shortage of EV charging stations might be a critical barrier to the future adoption of EVs by consumers.

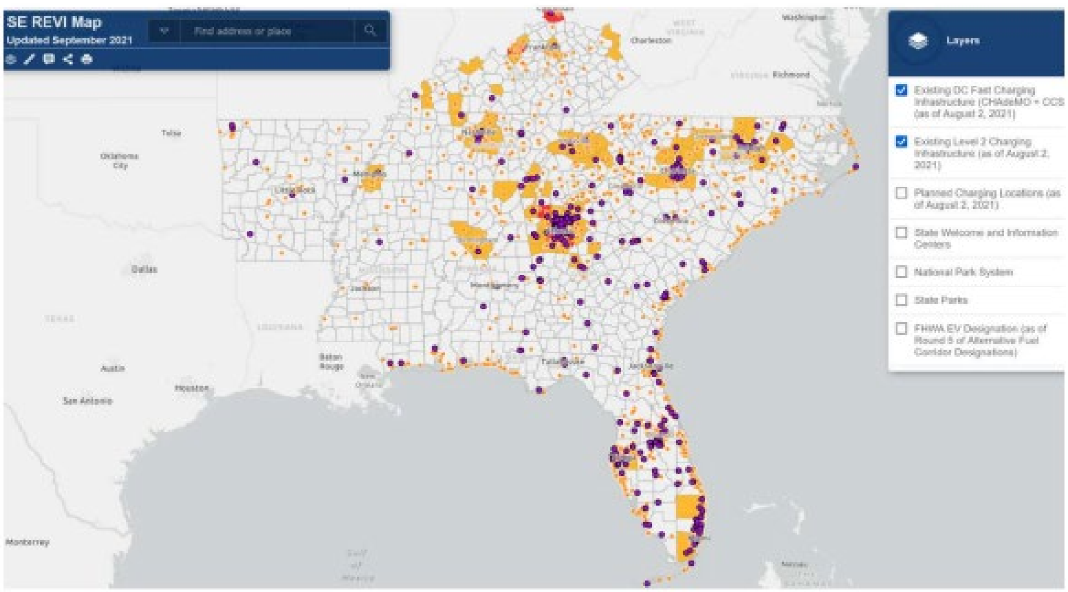


Electric Vehicle Demand (Source: Bloomberg)

Has your organization conducted assessments of future demand for EVs or charging infrastructure?

- ○ [ ] Yes (Please specify)
- ○ [ ] No, but we have a specific plan for it (Please specify)
- ○ No, but we expect to have a specific plan for it in the future (Please specify) [ ]
- ○ No, and we have no plan for it
- ○ Don't know/ Not sure/ Not applicable

To keep EVs charged up for longer trips, charging stations can be expanded along major highways.



Electric Vehicle Charging Stations Sign (Source: TDEC)

Has your organization worked on expanding the number of EV charging stations?

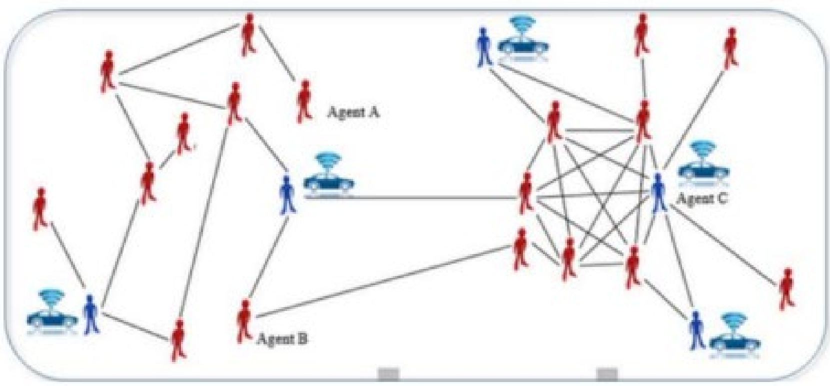
- ○ [ ] Yes (Please specify)
- ○ [ ] No, but we have a specific plan for it (Please specify)

- No, but we expect to have a specific plan for it in the future (Please specify) [ ]
- No, and we have no plan for it
- Don't know/ Not sure/ Not applicable

Public Knowledge and Acceptance

Public Knowledge and Acceptance

Adoption of CAVs depends on perceived benefits (e.g., expanded options to manage time more efficiently) and risks (e.g., unexpected failures of the automated driving system).

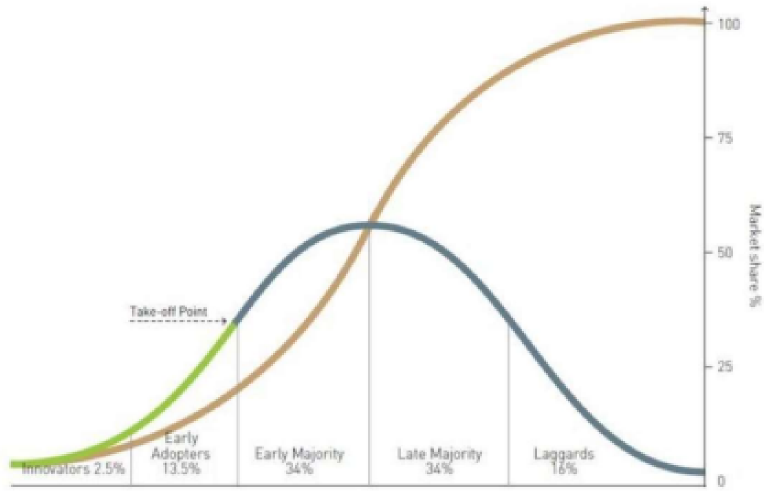


CAV adoption (Source: Mishra)

Has your organization made any efforts to understand public perception regarding CAVs in terms of their knowledge and perceived barriers to adoption?

- [ ] Yes (Please specify)
- [ ] No, but we have a specific plan for it (Please specify)
- No, but we expect to have a specific plan for it in the future (Please specify) [ ]
- No, and we have no plan for it
- Don't know/ Not sure/ Not applicable

Adoption of EVs depends on perceived benefits (e.g., energy and environmental) and risks (e.g., concerns about limited range).



Electric Vehicle adoption (Source: The Conversation)

Has your organization made any efforts to understand public perception of EVs in terms of their knowledge and perceived barriers to adoption?

- ○ [ ] Yes (Please specify)
- ○ [ ] No, but we have a specific plan for it (Please specify)
- ○ No, but we expect to have a specific plan for it in the future (Please specify) [ ]
- ○ No, and we have no plan for it
- ○ Don't know/ Not sure/ Not applicable

The emergence of CAVs enables truck platooning, which could have numerous benefits as well as potential concerns.

Truck platooning (Source: Dreamstime.com)

Has your organization made any efforts to inform the public about automation in the freight industry (e.g., implications of truck platooning)?

- ○ [ ] Yes (Please specify)
- ○ [ ] No, but we have a specific plan for it (Please specify)
- ○ No, but we expect to have a specific plan for it in the future (Please specify) [ ]
- ○ No, and we have no plan for it
- ○ Don't know/ Not sure/ Not applicable

Integration of automated, connected, electric, and shared vehicles (ACES) can enhance mobility and safety. This can be done through connectivity between vehicles and infrastructure, reducing human errors while driving, reducing fuel consumption and emissions, and reducing congestion by sharing travel modes.

ACES concept (Source: IEEE Young Professionals)

Has your organization made any efforts to inform the public about existing and emerging intelligent mobility options (e.g., shared automated vehicles)?

- ○ [ ] Yes (Please specify)
- ○ [ ] No, but we have a specific plan for it (Please specify)
- ○ No, but we expect to have a specific plan for it in the future (Please specify) [ ]
- ○ No, and we have no plan for it
- ○ Don't know/ Not sure/ Not applicable

TennSMART Event Attendance

Smart cities (Source: SmartCitiesWorld)

As a forum for stakeholder engagement, have you attended any events sponsored by TennSMART?

- ○ [ ] Yes (Please specify)
- ○ No
- ○ Don't know/ Not sure

Barriers to Intelligent Mobility

Does your organization face barriers surrounding intelligent mobility (e.g., lack of knowledge or resources, and not enough staff)?

- ○ [ ] Yes (Please specify)
- ○ No
- ○ Don't know/ Not sure

Intelligent mobility encompasses technologies that aim for safe, accessible, and efficient roadways, while reducing congestion, fuel consumption, pollution, and economic burdens.

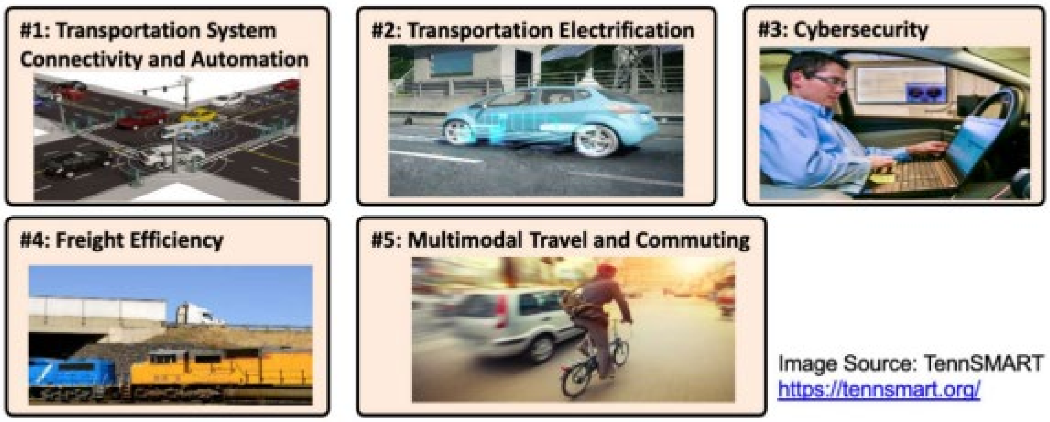


Image Source: TennSMART https://tennsmart.org/

In the context of the new Infrastructure investment and Jobs Act, does your organization have plans to work on projects that would accelerate readiness in the following areas?

	Yes	No	Not applicable
Transportation System Connectivity and Automation	○	○	○
Transportation Electrification	○	○	○
Cybersecurity	○	○	○
Freight Efficiency	○	○	○
Multimodal Travel and Commuting	○	○	○

How familiar are you with the following legislation in Tennessee?

	Highly familiar	Moderately familiar	Not familiar
Automated Vehicles Act (TCA 55-30)	○	○	○
Incentives, laws, and regulations for alternative fuels	○	○	○
Vehicle emissions testing requirements	○	○	○

Additional Questions

You can share a file related to this survey by clicking on "Choose File" below, as appropriate.

Any comments or information that you would like to share with us?

Intelligent Mobility Readiness Survey

Powered by Qualtrics

Appendix C: Example of responses to the readiness survey

Q10. Has your organization worked on expanding the number of EV charging stations?

(1) We already have roadmaps for vehicle electrification.

Please specify:

TDOT Managed:

- I-40 Alternative Fuels Deployment Plan
  - FHWA awarded a competitive grant for the development of deployment plans. The Plan analyzed existing electric vehicle charging stations and compressed natural gas stations along I-40 in Arkansas, Tennessee, and North Carolina, as well as existing funding and partners. Infrastructure gaps were identified. Stakeholders from these three states participated, but TDOT was the lead. The grant was awarded in Fall 2019 and was completed in November 2020.
- I-40 Alternative Fuels Implementation Plan
  - This Plan builds upon the Deployment Plan to bridge the gap between assessment and implementation. This Plan will include a more detailed analysis of infrastructure gaps and site selection along I-40 while assisting in developing a framework to expand to other corridors. This Plan began in August 2021 and is scheduled for completion in October 2022.

TDOT and Collaborative Partners:

- Drive Electric Tennessee (DET), a core group of stakeholders, including State agencies, electric utilities, cities, universities, electric vehicle manufacturers, businesses, and advocacy groups, began efforts in 2018 to develop a shared vision to increase electric vehicle (EV) adoption in Tennessee over the next 5-10 years. DET aims to increase the number of light-duty plug-in EVs on Tennessee roads to at least 200,000 by 2028. DET identifies four Opportunity Areas, which contain the action steps for the roadmap. These areas include: 1) Driving Charging Infrastructure Availability, 2) Driving Awareness, 3) Driving Innovative & Supportive Policies, and 4) Driving EV Availability, Offerings, & Innovation.

(2) We expect to have roadmaps in 1-2 years.

Please specify:

If the Infrastructure Bill passes with the EV Formula Grant, a funding plan and formal structure will need to be developed. All details are pending the Bill's approval.

(3) We expect to have roadmaps in 3-4 years.

Please specify:

(4) We expect to have roadmaps in more than 5 years.

Please specify:

(5) We have no roadmaps (yet) for vehicle electrification.

(6) Don't know / Not sure / Not applicable or relevant to my industry

Q11. To support electrification, the transportation network needs "EV charging stations" that can support EVs with different levels of charging, e.g., Level 1, Level 2, and DC Fast charging. Has your organization researched, developed, or deployed EV infrastructure i.e., charging stations?

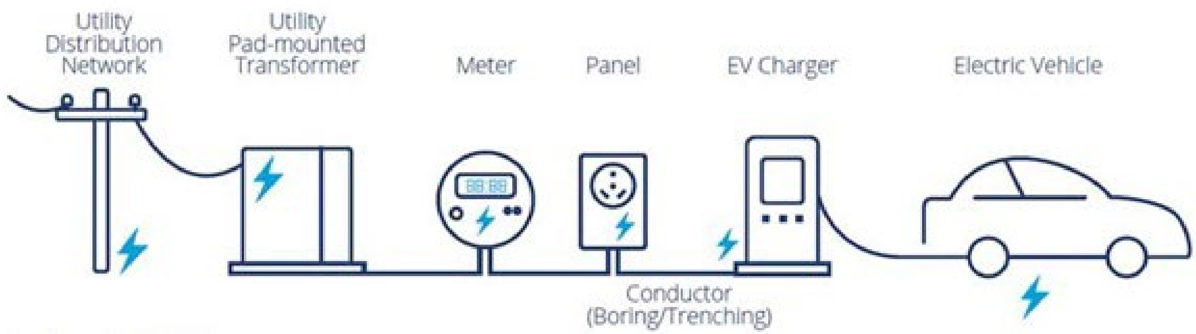


Figure A- 1 Electric Vehicle Charging Infrastructure (Source: Central Hudson)

(1) We have already worked on EV infrastructure investments, i.e., charging stations.

Please specify:

(2) We expect to have a specific plan in 1-2 years.

Please specify:

The Air Quality Planning Office at TDOT has worked with the TN Dept. of Environment and Conservation's (TDEC) Office of Energy Programs and the Tennessee Valley Authority (TVA) for the past year to develop a statewide electric vehicle fast-charging network to reduce barriers to transportation electrification and power the growth of EVs across Tennessee, called the Fast Charge TN Network. The anticipated project cost is $20 million. The Fast Charge TN Network will add approximately 50 new charging locations along prioritized corridor infrastructure gaps, with the goal of publicly available charging stations be located every 50 miles along Tennessee's interstates and major highways. TDEC has committed 15%, the maximum allowable amount of the State's Volkswagen Diesel Settlement Environmental Mitigation Trust allocation, which is approximately $5 million in funds. TDOT has committed to providing $7 million in federal Highway Infrastructure Program (HIP) funds, pending meeting the Federal Highway Administration's (FHWA) rules and regulations. TVA has committed to funding the remainder of the project, approximately $6 million.

TDEC and TVA have signed an agreement and seek initial project proposals from TVA-served Local Power Companies (LPCs) and other utilities that distribute electricity in Tennessee, where service territory is located along prioritized corridor gaps (eligible applicants). Later rounds of funding may expand applicant eligibility to include local government entities, private companies, and/or nonprofits. Proposals were due October 15th. TDEC, TVA, and TDOT prioritized submissions and recommendations are currently being made.

The Air Quality Planning Office established a monthly HIP Working Group in December of 2020, with stakeholders from various TDOT Divisions (Finance, Construction, Utilities, Local Programs, Programming, Environmental, Roadway Design, etc.), TDEC, TVA, and FHWA TN Division to gather needed information to create a path forward for EV charging stations funded with the HIP funds. Due to the nature of this funding source, federal rules and regulations must be met to ensure the federal investment is in good standing. Funds through TDEC and TVA have less stringent rules that apply, allowing site selections and stations to move forward at a quicker pace. Currently, the noted challenges with utilizing federal funds are 1) identifying vendors that meet FHWA's Buy America requirements and 2) navigating the FHWA ROW Guidance Memo.

Regardless of the funding source, selected, eligible projects will be provided up to 80% of the project cost, with a 20% local match requirement. TDEC and TVA have developed site selection guidelines, which will be provided to applicants to ensure a positive consumer experience. Minimum technical requirements will also be provided as program materials. These requirements include standards required of TDOT-funded sites while also considering what is best for the end-user and market trends. TDOT's Roadway Design Division helped develop site layouts that include accessibility requirements to ensure the Fast Charge TN Network is accessible for users with mobility limitations.

(3) We expect to have a specific plan in 3-4 years.

Please specify:

(4) We expect to have a specific plan in 5 years or more.

Please specify:

(5) We have no plans (yet) for any technologies for it.

(6) Don't know / Not sure / Not applicable or relevant to my industry

Q12. Shortage of EV charging stations might be a critical barrier to the future adoption of EVs by consumers. Has your organization conducted <u>assessments of future demand for EVs and charging infrastructure?</u>

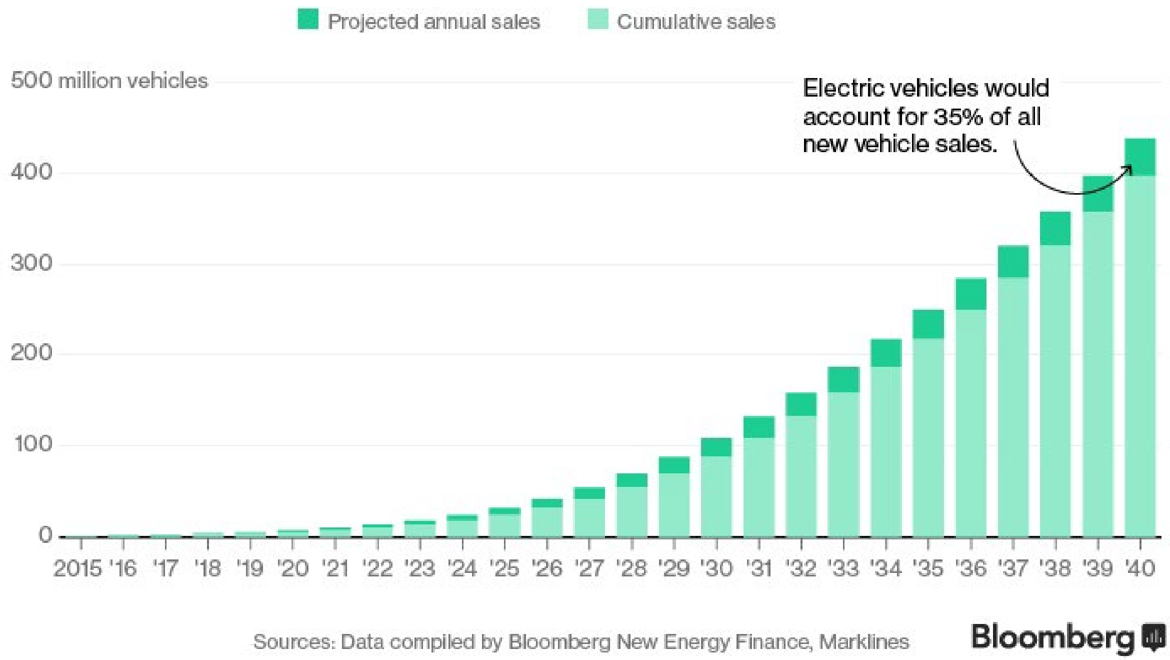


Figure A- 2 Electric Vehicle Demand (Source: Bloomberg)

(1) We have already conducted assessments of future demand for EVs and charging infrastructure.

Please specify:

Drive Electric Tennessee's Roadmap

(2) We expect to have a specific plan in 1-2 years.

Please specify:

(3) We expect to have a specific plan in 3-4 years.

Please specify:

(4) We expect to have a specific plan in 5 years or more.

Please specify:

(5) We have no plans (yet) for assessments of future demand for EV charging stations.

TDOT does not have a current plan for this (yet).

(6) Don't know / Not sure / Not applicable or relevant to my industry

Q13. To keep EVs charged up for longer trips, charging stations can be expanded along major highways. Has your organization worked on <u>expanding the number of EV charging stations?</u>

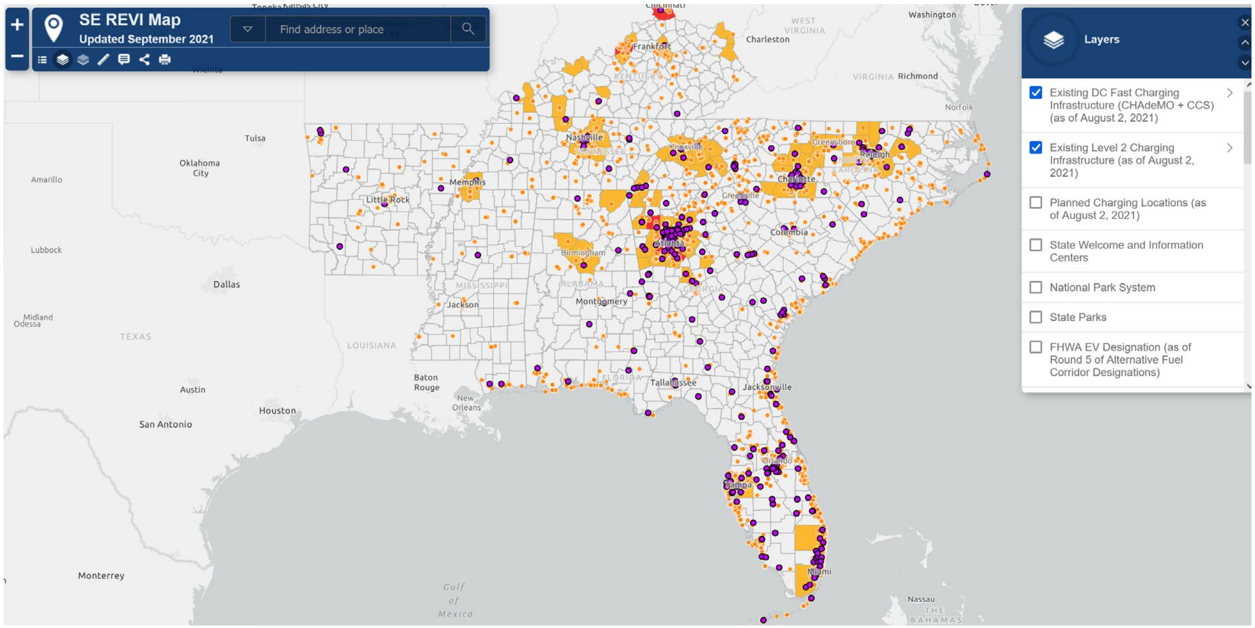


Figure A- 3 Electric Vehicle Charging Stations Sign (Source: TDEC)

(1) We have already worked on implementing increases in EV charging stations.

Please specify:

(2) We expect to have a specific plan in 1-2 years.

Please specify:

Please see response to question #11.

Additionally, TDOT leads the annual Corridor Nominations for FHWA's Alternative Fuels Corridor Designations. In 2021, Tennessee designated portions of US-64 for electric and compressed natural gas, portions of US-51 for compressed natural gas and propane, and I-81 for propane as corridor-pending. For corridor-ready, a portion of US-64 for electric, portions of I-24, I-26, I-65, I-75, and US-64 for propane. Corridor Designations allow TDOT to utilize federal funding sources to further build out the infrastructure.

(3) We expect to have a specific plan in 3-4 years.

Please specify:

(4) We expect to have a specific plan in 5 years or more.

Please specify:

(5) We have no plans (yet) to increase the number of EV charging stations.

(6) Don't know / Not sure / Not applicable or relevant to my industry