DriveOhio

1980 W Broad St. I Columbus, OH 43223

February 23, 2019

Mr. Finch Fulton
Deputy Assistant Secretary for Transportation Policy
Office of the Secretary (OST)
U.S. Department of Transportation (DOT)
1200 New Jersey Avenue S.E.
Washington, DC 20590

Re: Docket No. DOT-OST-2018-0210;

Dear Deputy Assistant Secretary for Transportation Policy Fulton:

DriveOhio is pleased to provide comments on the U.S. Department of Transportation's "V2X Communications" Notice of Request for Comments (Docket Number DOT-OST-2018-0210), issued in Washington, D.C. on December 26, 2018.

DriveOhio was established by Executive Order, as a Statewide Center for Smart Mobility, by Governor John Kasich on January 18, 2018. During this past year, Ohio has made great strides towards the Smart Mobility effort, specifically in the area V2X applications and standardization. The current project to create a Statewide System Engineering Analysis to satisfy 23 CFR 940 and to promote interoperability throughout the state is just one of the V2X projects under development in the state. The creation of this set of standards relies heavily on the development of high-level system requirements for the functionality of V2X application and infrastructure deployment.

The 5.9 GHz was allocated for Intelligent Transportation System (ITS) purposes and is considered essential for ITS services to foremost improve traveler safety, as well as improve the efficiency of the U.S. transportation infrastructure. The allocated band was originally specified for Dedicated Short Range Communications (DSRC). As such, thorough work has been performed by Original Equipment Manufacturers (OEMs) and State DOTs, in order to research and develop application and communication standards for DSRC technology. These standards have been utilized most recently in

the deployment of numerous DSRC technology projects by multiple State Departments of Transportation.

Currently, the only proven and deployed CV technology is Dedicated Short Range Communications (DSRC). However, the efforts of DriveOhio are to remain technology agnostic and to focus on the applications and the interoperability within the entire Connected Vehicle Ecosystem. The fast-paced technological advancements of today will drive to promote the deployment of a solid foundation, in which multiple technologies can function at an interoperable level. That interoperability is the key focus of DriveOhio and pushes us to work with various partners in the sustainment of an increasingly safe and effective transportation system. DriveOhio and its many project partners, such as Smart Columbus and Connected Marysville, realize the existing benefits of the DSRC technology and are therefore working today deploying applications that will have an eventual high impact on the safety of the motoring public.

DSRC is here today and should be utilized to achieve a safer system. This does not however mean that we as Infrastructure Owner Operators (IOOs) and OEMs cannot advance the technology into new forms. We simply request that the same level of testing be performed as was on DSRC technology and that interoperability amongst the technology options be strongly required. Ohio is ready to open its roadway system up to be the proving ground for interoperability of all technologies and are hopeful that interoperability is recognized as a much-needed requirement for V2X technologies.

Below are our responses to the nine questions asked in the docket:

1. Please provide information on what existing or future technologies could be used for V2X communications, including, but not limited to, DSRC, LTE C-V2X and 5G New Radio. What are the advantages and disadvantages of each technology? What is the timeframe for deployment of technologies not yet in production? Please provide data supporting your position.

   Currently, the only existing tested technology deployed among multiple states for V2X communications is DSRC. As documented in Appendix A, DriveOhio, as part of its system engineering development, has tasked AECOM to gather various data regarding DSRC applications deployment across the nation.

2. Of the V2X communications technologies previously discussed, at present only DSRC is permitted to be used in the 5.9 GHz spectrum band for transportation applications. If that allocation were to be changed to allow any communication technology for transportation applications, could DSRC and other technologies (e.g., C-V2X, 5G or any future technology) operate in the same spectrum band or even the same channel without interference? Why or why not? If there are any technical challenges to achieving this goal, what are they and how can they be overcome?

At this time, it is unknown to what extent C-V2X, DSRC, and other technologies could operate in the same band. What is known is that any technology operating in the band would need to freely interoperate with the others. The safety of the motoring public cannot be sacrificed because of interoperability issues. There is current work being performed regarding the development of equipment that could receive and transmit both utilizing the C-V2X and DSRC technologies, but that work remains unproven and untested at this time.

3. To what extent is it technically feasible for multiple V2X communications technologies and protocols to be interoperable with one another? Why or why not? Can this be done in a way that meets the performance requirements for safety of life applications, as they were discussed in the V2V NPRM? What additional equipment would be needed to achieve interoperability or changes in standards and specifications? What is the projected cost of any necessary changes? How soon can these changes and equipment prototypes be available for testing?

   DriveOhio understands that testing will need to be performed and interoperability will need to be validated with DSRC being the de facto standard, as the only technology currently deployed by multiple states. We believe that any technology can be developed to meet the standards as published in SAE J2735, SAE J2945, etc. However, development of such technology would require extensive testing to ensure that the frequency and speed needed for life saving measures can be achieved, while still maintaining interoperability with DSRC.

   For C-V2X Road-Side Units (RSUs) to function there would need to be 1 of 2 possibilities. 1. Extensive development of RSUs that would broadcast in both DSRC and C-V2X protocols. 2. Deployment or redeployment of On-Board Units (OBUs) with new development of technology that would allow the translation of C-V2X or DSRC, whichever was present at the OBUs location. Work has not yet been completed in this area and remains untested.

   DriveOhio has had conversations with its multiple industry partners regarding this testing and it remains on the radar until such time as the FCC makes a determination on the 5.9 GHz technology.

4. To what extent is it technically feasible for different generations of the same V2X communications technologies and protocols to be interoperable with one another? Why or why not? Can this be done in a way that meets the performance requirements for safety of life applications? What additional equipment or changes in standards and specifications would be needed to achieve interoperability? What is the projected cost of any necessary changes?

   The feasibility exists for different generations of the same V2X communications technologies to be interoperable with each other. DriveOhio is investigating the opportunity for development of an interoperable connected ecosystem testing platform that would allow the creation of a

connected vehicle approved product list and would require that each firmware version of a piece of equipment be tested for functionality and interoperability before being able to be deployed on the Ohio roadway system. If lifesaving applications are to be maintained functional, the testing system will need to also measure the ability of the equipment to notify the motorist in the specified period and will also need to ensure that the radio signal is not distorted to a level that is outside the standard requirements.

The most notable disadvantage would be the cost upgrade all of the OBUs to an interoperable version of equipment. DriveOhio believes the main intent of the original FCC allocation of the 5.9 GHz to the ITS industry was to increase the safety of the motoring public. This is the reason for the requirement of frequency and speed of the application messages. For this safety reason, it does not make sense for OBUs to be deployed in a manner that they could only receive and translate either DSRC, C-V2X, 5G new radio, or some other form of technology. They would need to be capable of being able to receive and translate the application message of whatever form of technology was deployed at the device's location. This could become very costly to all the deployments of OBUs that have already occurred with DSRC-only technology.

5. Even if they are interoperable across different technologies and generations of the same technology, would there be advantages if a single communications protocol were to be used for V2V safety communications? What about other V2X safety applications, such as those involving V2I and V2P communications?

   DriveOhio's position is that the applications are the life-saving additions and those applications can be supported by multiple technologies. The more important advantage is having all of the technology communicating over the same frequency band and having that frequency band specifically allocated for transportation safety. The current technology available is DSRC, but in the future this may expand to other technologies and as they are deemed interoperable and accepted by the FCC and U.S. DOT, a formal acknowledgement of this acceptance should be made. This acknowledgement will provide the State DOTs and OEMs with a level of comfort and only then can they adjust their deployments to safely integrate the new technologies into their life-saving applications. As stated before, DriveOhio has engaged with many OEM partners and is ready to assist in the testing of any new technology as an interoperable life-saving measure.

6. How would the development of alternative communication technologies affect other V2I and V2P communications, such as those supporting mobility or environmental applications? Do these applications have the same or different interoperability issues as V2V safety communications? Do different V2X applications (e.g., platooning) have different communication needs, particularly latency?

Applications can be supported by a multitude of technologies. The critical aspect is that all technologies used to support the applications are interoperable. It is imperative that all vehicles, regardless of the technology deployed in the field and/or on the vehicle, can interoperate with each other, as well as the roadside infrastructure. These applications will be utilized for multiple purposes and all messages should be required to be received by every vehicle type in the future.

While some mobility and environmental applications may not have immediate direct life-saving measures, the aspect of each of those application areas can indirectly impact the lives and lifestyles of those relying on those applications for everyday necessities.

7. Do different communication technologies present different issues concerning physical security (i.e., how to integrate alternative communication technologies into vehicle systems), message security (i.e., SCMS design or other approaches), or other issues such as cybersecurity or privacy? Would these concerns be affected if multiple but still interoperable communication technologies are used rather than one?

   Differing technologies do present new challenges in security. An environment is only as good as the security protecting it and if security is not implemented correctly, the life-saving abilities of the applications will be negated by attacker's abilities to trigger false events. Currently there is lacking federal support for the creation of national standards for securing V2X communications. Maintaining interoperability is left up to each deployment to ensure the choices they make regarding a Security Credential Management System (SCMS) maintain interoperability on an intra and interstate basis. Motorists traveling across project and state boundaries should not be concerned with functionality of their lifesaving V2X applications as they cross those boundaries. For this reason, DriveOhio's opinion is that federal guidance is needed to provide support to the IOOs and OEMs so that interoperability among SCMS providers can be achieved.

   The availability of SCMS providers to support multiple technologies is already present. This is achievable because the standards utilized to develop the technologies are the same. If those standards were dissimilar, it is unclear whether the SCMS providers would be able to support multiple technologies.

8. How could communications technologies (DSRC, C-V2X, 5G or some other technology) be leveraged to support current and emerging automated vehicle applications? Will different communication technologies be used in different ways? How?

   There are many ways to utilize different methods of communications technologies in combination to achieve the safety goals of the roadway system. DriveOhio strongly believes that the eventual operation of AV's will rely heavily on V2I applications. The infrastructure is able to communicate much more detailed information regarding the infrastructure components than can be measured by AV sensors. It is true that an AV may be able to recognize much of the environment around it,

but the interaction with the infrastructure is needed to warn of situations in which the sensors can't determine. One such application would be an instance where a vehicle may run a red light in a conflicting direction.

It is imaginable that yes, different communication technologies may be utilized in different ways, but until the testing is performed that remains unclear.

9. How could deployments, both existing and planned, assess communications needs and determine which technologies are most appropriate and whether and how interoperability could be achieved?

   This should not be a discussion of Technology A vs. Technology B. The focus should be on the technology available today that can be utilized to save lives. As testing of new technology confirms a level of interoperability, the examination of the technology most appropriate for each purpose and environment can be performed. Until that time, IOOs are facing the challenge of lack of clarity of the future for the decisions that need to be made to save lives today.

   We support deployment of DSRC now, remain open to additional testing of C-V2X as the development progresses, and encourage a future where DSRC, C-V2X, and/or other technologies can coexist and interoperate with each other to serve the larger purpose of saving lives on the nation's transportation system.

DriveOhio appreciates the opportunity to respond to the USDOT regarding the V2X technology deployments within the 5.9 GHz frequency band.

If you would like to discuss any of the issues raised in this letter, please contact Nick Hegemier, P.E., DriveOhio's Managing Director of Infrastructure at (614) 387-4099.

Respectfully,

James A. Barna P.E.
Executive Director, DriveOhio

Appendix A

DriveOhio

The Future of Smart Mobility

Ohio AV/CV Application Feasibility & Exploration Report

DriveOhio

Project number: 60585993

February 13 2019

AECOM Imagine it. Delivered.

Quality information

Prepared by	Checked by	Verified by	Approved by
Suzanne Murtha	Preeti Choudhary	Brian Keeler	John D. Gray

Revision History

Revision	Revision date	Details	Authorized	Name	Position
Draft v 1.0	10/30/2018				
Final v 2.0	2/13/2019				

Distribution List

Name	Association / Company Name
Missy Anverse	DriveOhio
Nick Hegemier	DriveOhio

Table of Contents

1. Executive Summary

This Feasibility and Exploration Report describes the range of currently known AV/CV application concepts, based on a scan of United States Department of Transportation (USDOT) AV/CV pilot program information, USDOT's Connected Vehicle Reference Implementation Architecture (CVRIA), and research on state-specific AV/CV efforts. The goal of this document is to provide an overview of each known AV/CV application, as well as their readiness for deployment based on the stage of development they are in at the time this report was prepared.

The following table provides a consolidated list of the AV/CV applications described in this report and indicates the current readiness status of each application. Note that, where possible, links to USDOT Pilot Program or CVRIA application information are embedded in the AV/CV application names.

Table 1: AV/CV Application Overview and Readiness Status

Application	Deployment Ready	Deployment Near Ready	Further Development Required	Source	
				CVRIA	USDOT Pilot Program
CV Application Group: Vehicle to Infrastructure (V2I) Safety					
Curve Speed Warning	●			✓	
End of Ramp Deceleration Warning (ERDW)	●				✓
Reduced Speed Zone Warning / Lane Closure	●			✓	
Pedestrian in Signalized Crosswalk Warning	●			✓	
Red Light Violation Warning	●			✓	
SPaT MAP Display Signal Timing, Time to Green	●				✓
Wrong Way Entry (WWE)	●				✓
Speed Limit Warning	●				✓
Spot Weather Impact Warning	●			✓	
Restricted Lane Warnings	●			✓	
Oversize Vehicle Warning	●			✓	
Pedestrian Collision Warning	●				✓
Stop Sign Violation Warning			●	✓	
Stop Sign Gap Assist			●	✓	
Warnings about Hazards in a Work Zone			●	✓	
Warnings about Upcoming Work Zone			●	✓	
Railroad Crossing Violation Warning			●	✓	
In-Vehicle Signage			●	✓	
CV Application Group: Vehicle to Vehicle (V2V) Safety					
Emergency Electronic Brake Light	●			✓	
Forward Collision Warning	●			✓	
Do Not Pass Warning	●			✓	
Intersection Movement Assist	●			✓	
Vehicle Turning Right in Front of a Transit Vehicle	●			✓	
Blind Spot Warning + Lane Change Warning		●		✓	
Left Turn Assist (LTA)			●		✓

Application	Deployment Ready	Deployment Near Ready	Further Development Required	Source	
				CVRIA	USDOT Pilot Program
Control Loss Warning			●	✓	
Emergency Vehicle Alert			●	✓	
Motorcycle Approaching Indication			●	✓	
Pre-crash Actions			●	✓	
Situational Awareness			●	✓	
Slow Vehicle Warning			●	✓	
Stationary Vehicle Warning			●	✓	
Tailgating Advisory			●	✓	
Vehicle Emergency Response			●	✓	
CV Application Group: Environmental					
Advanced Traveler Information Systems		●		✓	
Connected Eco-Driving		●		✓	
Eco-Approach and Departure at Signalized Intersections		●		✓	
Eco-Traffic Signal Timing			●	✓	
Eco-Transit Signal Priority			●	✓	
Eco-Freight Signal Priority			●	✓	
Wireless Inductive/Resonance Charging			●		✓
Eco-Lanes Management			●	✓	
Eco-Speed Harmonization			●	✓	
Eco-Cooperative Adaptive Cruise Control			●	✓	
Eco-Ramp Metering			●	✓	
Low Emissions Zone Management			●	✓	
Connected Vehicle-Enabled Environmental Probe Data Collection			●		✓
Eco-Multimodal Real-Time Traveler Information			●	✓	
Eco-Smart Parking			●	✓	
Dynamic Eco-Routing			●	✓	
Connected Eco-Driving – Gamified / Incentives-Based Applications			●		✓
Gamified / Incentives-Based Multimodal Traveler Information Applications			●		✓
Eco-Integrated Corridor Management Decision Support System			●	✓	
AFV Charging / Fueling Information			●		✓
Electric Charging Stations Management			●	✓	
Roadside Lighting			●	✓	
CV Application Group: Road Weather					
Weather Data Environment (WxDE)	●				✓
Integrated Modeling for Road Weather Condition Prediction	●				✓
Road Weather Motorist Alert and Warning		●		✓	
Enhanced Maintenance Decision Support System			●	✓	

Application	Deployment Ready	Deployment Near Ready	Further Development Required	Source	
				CVRIA	USDOT Pilot Program
Road Weather Information and Routing Support for Emergency Responders			●	✓	
Road Weather Information for Freight Carriers			●	✓	
Road Weather Information for Maintenance and Fleet Management Systems			●	✓	
Variable Speed Limits for Weather-Responsive Traffic Management			●	✓	
Weather Responsive Traffic Management – Traveler Information via Citizen Reporting			●		✓
CV Application Group: Mobility					
Intelligent Traffic Signal System	●			✓	
Freight Signal Priority	●			✓	
Transit Signal Priority	●			✓	
Emergency Vehicle Preemption	●			✓	
Emergency Communications and Evacuation	●			✓	
Incident Scene Pre-Arrival Staging Guidance for Emergency Responders	●			✓	
Speed Harmonization		●		✓	
Queue Warning		●		✓	
Incident Scene Work Zone Alerts for Drivers and Workers		●		✓	
Pedestrian Mobility and Accessibility			●	✓	
Traveler Information- Smart Parking			●	✓	
Transit Pedestrian Indication			●	✓	
Transit Vehicle at Station/Stop Warnings			●	✓	
Cooperative Adaptive Cruise Control			●	✓	
Integrated Multi-Modal Electronic Payment			●	✓	
Intermittent Bus Lanes			●	✓	
Route ID for the Visually Impaired			●	✓	
Smart Park and Ride System			●	✓	
Transit Connection Protection			●	✓	
Transit Stop Request			●	✓	
Dynamic Transit Operations			●	✓	
Dynamic Ridesharing			●	✓	
Advanced Automatic Crash Notification Relay			●	✓	
Performance Monitoring and Planning			●	✓	
Freight-Specific Dynamic Travel Planning			●	✓	
Freight Drayage Optimization			●	✓	
Electronic Toll Collection			●	✓	
Road Use Charging			●	✓	
Border Management Systems			●	✓	

Application	Deployment Ready	Deployment Near Ready	Further Development Required	Source	
				CVRIA	USDOT Pilot Program
Container Security			●	✓	
Container/Chassis Operating Data			●	✓	
Electronic Work Diaries			●	✓	
Intelligent Access Program			●	✓	
Intelligent Access Program - Mass Monitoring			●	✓	
Intelligent Speed Compliance			●	✓	
CV Application Group: Smart Roadside					
Smart Truck Parking	●				✓
Smart Roadside Initiative			●	✓	
CV Application Group: Agency Data					
Probe-enabled Traffic Monitoring	●				✓
Vehicle Data for Traffic Operations		●		✓	
Work Zone Traveler Information		●			✓
Probe-based Pavement Maintenance		●			✓
Vehicle Classification-based Traffic Studies			●		✓
CV-enabled Turning Movement & Intersection Analysis			●		✓
CV-enabled Origin-Destination Studies			●		✓
CV Application Group: Core Service					
Security and Credentials Management	●			✓	
Core Authorization			●	✓	
Data Distribution			●	✓	
Infrastructure Management			●	✓	
Location and Time			●	✓	
Map Management			●	✓	
Object Registration and Discovery			●	✓	
Privacy Protection			●	✓	
System Monitoring			●	✓	
State Specific Connected Vehicle Applications and Advancements					
Truck Platooning [California]	●				
Advanced Snowplow Project (ASP) [California]	●				
Integrated Collision Warning System [California]	●				
Smart Truck Parking (Pre-Pass, Cellular and DSRC) [Colorado]	●				
Smart 70 Project [Colorado]		●			
Driver Assisted Truck Platooning (DATP) [Florida]		●			
Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) [Florida]		●			
PedSafe [Florida]		●			
GreenWay [Florida]		●			
SmartCommunity [Florida]		●			

Application	Deployment Ready	Deployment Near Ready	Further Development Required	Source	
				CVRIA	USDOT Pilot Program
I-75 Florida's Regional Advanced Mobility Elements (FRAME) [Florida]		●			
AV/CV/ITS Freight Applications [Florida]			●		
Bike and Pedestrian Safety [Florida]			●		
Maricopa County DOT SMARTDrive Program [Arizona]	●				
Signal Phasing and Timing SPaT Operational [Michigan]	●				
Truck Parking Information and Management System [Michigan]	●				
Ann Arbor Connected Vehicle Test Environment [Michigan]	●				
Connected Corridors - Snow Plow Signal Priority System [Minnesota]		●			
Cooperative Intersection Collision Avoidance Systems (CICAS) [Minnesota]		●			
Development and Demonstration of a Cost Effective In-Vehicle Lane Departure and Advanced Curve Speed Warning System [Minnesota]		●			
Use of Connected Vehicle Data in Road Weather Applications [Minnesota]		●			
University of Minnesota Eco-Driving Research [Minnesota]		●			
Drivewyze Program [New York]	●				
New York State (NYS) Commercial Vehicle Screening Program [New York]	●				
Commercial Vehicle Infrastructure Integration [New York]	●				
Niagara International Transportation Technology Coalition: Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) [New York]	●				
Smart Belt Coalition [Pennsylvania]	●				
Connected Vehicles for Emergency Response Vehicles and Trucks [Pennsylvania]	●				
I-76 Corridor Management Project (including VSL & Q-WARN) [Pennsylvania]		●			
Austin DSRC Pedestrian Pilot [Texas]		●			
University of Texas at Austin Pedestrian Connectivity [Texas]		●			
Cooperative Truck Platooning Systems (CTPS) [Transport Canada]	●				
Truck Platooning Cooperative Adaptive Cruise Control (CACC) [Virginia]	●				
Virginia Connected Corridor (VCC) Open Cloud Computing Environment [Virginia]	●				
VCC Monitoring Application [Virginia]	●				
Traveler Information Message Generator and Manager [Virginia]	●				
VCC Mobile Application [Virginia]	●				
SmarterRoads.org Data Portal [Virginia]	●				
WSDOT CAT Pilot Projects Winter Operations [Washington]	●				
WSDOT CAT Pilot Projects Traffic Signals (AASHTO SPaT Challenge) [Washington]	●				
State Specific Automated Vehicle Applications and Advancements					
Vehicle Assist and Automation (VAA) systems [California]	●				
Development of the Advanced Rotary Plow (ARP) for Snow Removal Operations (2006) [California]	●				

Application	Deployment Ready	Deployment Near Ready	Further Development Required	Source	
				CVRIA	USDOT Pilot Program
Automated Truck Commercial Delivery [Colorado]		●			
Develop Communication Infrastructure for CV and AV to Share Road and Safety Data [Colorado]		●			
First and Last Mile Connection Pilot [Colorado]			●		
Autonomous Vehicles to Improve Worker Safety [Colorado]			●		
Autonomous Vehicle Lane [Colorado]			●		
Assessing Advanced Driver Assistance Systems [Florida]		●			
Driverless Taxi Services (Voyage) at The Villages [Florida]		●			
Downtown Tampa Autonomous Transit [Florida]		●			
Autobus Transit System [Florida]		●			
Google (Waymo) Automated Freight Deployment in Atlanta [Georgia]		●			
City of Chamblee- Self-Driving Shuttle [Georgia]		●			
STEER Tech Automated Vehicle Testing [Maryland]		●			
Self-Driving Shuttles [Michigan]	●				
Automated Shuttle Bus Pilot Project [Minnesota]	●				
Automated Truck Pilot Project [Minnesota]			●		
Autonomous Shuttle Network [Pennsylvania]		●			
Smart Spine Corridors [Pennsylvania]		●			
Texas Automated Vehicle Application Proving Ground Partnership [Texas]	●				
Texas A&M University System RELLIS Campus [Texas]	●				
Southwest Research Institute (SwRI) [Texas]	●				
City of Austin and Capital Metro's Smart Mobility Roadmap [Texas]	●				
Two-Truck Automated Platoon Test [Texas]	●				
Austin INRIx AV Road Rules [Texas]	●				
Drive.ai [Texas]	●				
Easy Mile (Milo) [Texas]	●				
Capital Metro no-pilot shuttle pilot (Austin) [Texas]			●		
Marble [Texas]			●		
Advance Connectivity and Automation in the Transportation System (ACATS) [Transport Canada]			●		
Virginia Automated Corridor [Virginia]		●			
Pierce County, Washington, Transit Deploys System to Help Buses Avoid Collisions with Pedestrians, Bicyclists [Washington]	●				
WSDOT CAT Pilot Projects Automated work zone vehicles [Autonomous Truck Mounted Attenuator (TMA) Pilot] [Washington]		●			
WSDOT Pilot Interests [Washington]		●			
Certified Autonomous Vehicle Pilot Test [Washington]		●			

2. Introduction

Automated and connected vehicle (AV/CV) technology is currently being developed and deployed in a range of capacities to address the safety, mobility and environmental challenges associated with transportation. Various stakeholders are making strides to advance the technology and use of AV/CV applications for all roadway users; vehicle manufacturers are deploying CV technology in modern vehicles, while state and federal agencies equip roadway infrastructure and deploy CV application prototypes.

The purpose of this project is to develop a statewide framework for the implementation of AV/CV roadside infrastructure and Intelligent Transportation Systems (ITS) that will support seamless operations and interoperability from region to region, and even nationwide. With numerous AV/CV pilot projects and deployment efforts emerging across the country, an initial exploration step was performed to review the known AV/CV application concepts and assess their readiness for deployment based on the stage of development they are in at the time this report was prepared. A comprehensive scan of United States Department of Transportation (USDOT) AV/CV pilot program information and USDOT's Connected Vehicle Reference Implementation Architecture (CVRIA) was performed to gather data on CV applications, including descriptions, potential benefits, and instances of deployment, where applicable. Additionally, research on state-specific AV/CV projects was performed in an effort to compile the latest available information on peer agency AV/CV work and progress.

The AV/CV applications included in this report have been classified by their deployment status: deployment ready, deployment near-ready, and further development required. Deployment ready applications are currently being tested or are already field deployed. Deployment near-ready applications are being researched or planned. Applications that are require further development typically have a concept of operations developed but would necessitate research, infrastructure investments, and potentially more time for technologies to develop before deployment is feasible.

3. Connected Vehicle Applications

The USDOT CV Pilot Deployment Program is maintaining a suite of CV applications for the following overall categories:

- Vehicle-to-Infrastructure (V2I) Safety
- Vehicle-to-Vehicle (V2V) Safety
- Environment
- Road Weather
- Mobility
- Smart Roadside
- Agency Data
- Core Services

Known CV applications for each category are described in the following sections. Note that application headers are color coded to reflect their deployment status (deployment ready = green; deployment near-ready = orange; and, further development = purple).

CV Application Standards

The Society of Automotive Engineers (SAE) continues to develop standards to support the deployment of CV applications. Below is a description of the status of the development of those standards:

Published

- J2945: Systems engineering guidance and common design concepts
- J3061: Systems engineering enhancements to J2735 (information report)

- J2945/9: Vulnerable road user recommended practice

In development

- 2945/2: V2V safety awareness (add on to 2945/1)
- 2945/3: Road weather applications
- 2945/4: Road safety applications
- J2945/5: Security guidelines for connected vehicle applications
- J2945/6: Adaptive cruise control and platooning
- 2945/10: Signal Phase and Timing (SPaT) / Intersection map (MAP) recommended practice
- 2945/11: Signal pre-emption recommended practice
- J3180: Cooperative perception system

3.1 V2I Safety Applications

3.1.1 Deployment Ready

Curve Speed Warning

Description: The Curve Speed Warning application is a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes. The application provides alerts to drivers who are approaching a curve at a speed that may be too high to safely travel through that curve. Alerts are based on the location of the vehicle within the curve and the vehicle speed.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	Tampa-Hillsborough Expressway Authority (THEA) (deployment), New York (testing), Florida (testing), Michigan (planning), and Minnesota (researching)

End of Ramp Deceleration Warning (ERDW)

Description: The End of Ramp Deceleration Warning application was developed for the USDOT Connected Vehicle Pilot in Tampa FL. The application warns the driver to slow down to a recommended speed as the driver approaches the end of a queue. It can be enhanced to measure queue lengths and dynamically adjust the speed advice messages based on the end of the queue. In this case the speed advice varies according to the safe stopping distance to the end of the queue ahead. This application differs from simple in-vehicle signage in that:

- Drivers decelerating properly are not distracted by false positive alerts
- Drivers not decelerating properly are first alerted and then warned

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	THEA (deployment)

Reduced Speed Zone Warning/Lane Closure Warning

Description: The Reduced Speed Zone Warning / Lane Closure (RSZW/LC) application provides connected vehicles which are approaching a reduced speed zone or closed lane with information on the zone's posted speed limit and/or the configuration of the roadway if altered (such as lane closures and lane shifts). Reduced speed zones can include work zones, school zones, pedestrian crossing areas, and rural towns. The RSZW/LC application inside the connected vehicle can receive the revised speed limit and any roadside configuration changes to determine if the driver should receive a warning message. To provide warnings to non-connected vehicles, infrastructure equipment static infrastructure can measure the speed of the approaching vehicle and, if greater than the reduced speed, provide a warning on a sign. The application can provide an advance warning message to drivers when rapid deceleration is required to reduce to the posted speed limit.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	THEA (deployment), Maricopa County, Arizona (deployment), New York (planning), and Virginia (planning)

Pedestrian in Signalized Crosswalk Warning

Description: The Pedestrian in Signalized Crosswalk Warning (Transit) application utilizes roadside equipment and pedestrian detection equipment to warn transit bus operators when pedestrians, within the crosswalk of a signalized intersection, are in the path of the bus. The application could also provide warning information to the pedestrian regarding crossing status or potential vehicle infringement into the crosswalk.

Potential Benefits: Safety Benefits for Transit Drivers on Undivided Roads

DEPLOYMENT:	Florida (testing), Georgia (deployment), New York (testing), Minnesota (planning), and Texas (planning)

Red Light Violation Warning

Description: The Red Light Violation Warning application is a cooperative vehicle and infrastructure application that assists drivers in avoiding crashes. The application cross references the driver's approach speed, acceleration profile, and distance to the intersection, with the intersection's signal phasing and timing (SPaT) information, and geometry (MAP) to determine if it appears likely that the vehicle will violate a red light signal. The intersection geometry information can be received by the connected vehicle from road side equipment at the intersection or earlier in the trip. If received at the intersection, the geometric information can cross reference the weather information, further improving the effectiveness of the safety message. The application will broadcast a warning message if it appears likely that the driver may violate an upcoming red light. The application can work in tandem with the Queue Warning (Q-WARN) application to ensure the vehicle will be issued a warning if there is a queue at the intersection.

Potential Benefits: Safety Benefits for Drivers on Undivided Roads

DEPLOYMENT:	Michigan (testing), Virginia (planning), THEA (testing), and New York (testing)

SPaT MAP Display Signal Timing, Time to Green

Description: The RSU broadcasts a standard SPaT message containing the current signal states plus the time remaining until the signal change. The RSU also broadcasts standard MAP messages indicating the lane locations and the signal phase associated with each lane. The OBU compares its location, direction, and speed to the MAP and SPaT. The signal countdown for the phase associated with the lane is displayed to the driver. Distracted drivers blocking traffic are alerted to start up. Drivers starting up normally are not distracted with a startup warning.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	THEA (deployment), Las Vegas, NV (deployment), Anaheim, CA (deployment), Columbus, OH (deployment), Oakland County, MI (deployment), and New York (testing)

Wrong Way Entry (WWE)

Description: Wrong Way Entry was developed for the USDOT Connected Vehicle Pilot in Tampa, FL. The RSU transmits standard MAP messages identifying one-way, reversible, or closed lane locations. The RSU also transmits standard SPaT message indicating the time-of-day lanes are closed or reversed, without need of a signal controller. The OBU compares its location, direction and speed towards the closed or one-way lane, and then responds:

- "Do Not Enter" graphic alert is displayed to the driver before the violation occurs
- "Wrong Way" graphic warning is displayed to the driver when the violation occurs

- "Head On" graphic warning is displayed to oncoming drivers
- Alerts and warnings are canceled when wrong-way driver corrects or exits

The RSU can be connected to a traditional vehicle detector to detect unequipped violators in order to warn oncoming equipped vehicles.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	THEA (deployment)

Speed Limit Warning

Description: Driver is alerted when the vehicle is exceeding the legal posted speed limit.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	THEA (deployment) and New York (planning)

Spot Weather Impact Warning (SWIW)

Description: The Spot Weather Impact Warning application warns drivers of local hazardous weather conditions, road closures at specific points due to inclement weather, and potential detours. Weather conditions causing alerts can include floods, snow, fog, high winds, and ice. The weather information is processed to determine the nature of the alert or warning to be delivered and is then broadcasted to the connected vehicles. The application receives weather data from multiple sources (which can include traffic management centers and road weather information systems [RWIS]) to the road side equipment which broadcasts the weather information to near-by connected vehicles. Weather alerts and warnings can be broadcasted to non-equipped vehicles using physical infrastructure such as dynamic message signs (DMS). The SWIW application weather information can be assisted by or used to assist the Weather Responsive Traffic management Variable Speed Limit application which adjusts the speed limit on a road based on weather conditions.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	Wyoming; Ohio (US-33 SMC DriveOhio initiative)

Restricted Lane Warning

Description: The Restricted Lane Warnings application provides the connected vehicle with restriction information about the travel lanes, such as if the lane is restricted to high occupancy vehicles (HOV), transit, or public safety vehicles only or has defined eco-lane criteria. A connected vehicle can use this information to determine if the vehicle is in a lane that has lane restrictions.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	Las Vegas (deployment)

Oversize Vehicle Warning (OVW)

Description: The Oversize Vehicle Warning (OVW) application provides connected heavy vehicle operators a warning if the vehicle will collide with a bridge or tunnel. The application utilizes roadside infrastructure to calculate the vehicle's width and height. The roadside infrastructure transmits the vehicle measurements, along with the infrastructure's available width and height to the OVW vehicle application. The application cross references the infrastructure and vehicle information and, if the application determines that the vehicle cannot clear the bridge or tunnel, the roadside equipment transmits a warning message to the vehicle. OVW warnings can be broadcasted to non-equipped vehicles using physical infrastructure such as dynamic message signs (DMS).

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	New York (deployment)

Pedestrian Collision Warning

Description: This application will alert and/or warn drivers who are approaching any crossing if it is determined that the vehicle's path will collide with an oncoming pedestrian. The application uses both vehicle-based and infrastructure-based technologies to determine if a warning is transmitted or not. The roadside equipment (RSE) will send the vehicle the intersection geometry, and information about the pedestrian approaching (or already at) the crossing to the vehicle. The information about the approaching pedestrian can be obtained from the intersection infrastructure or from a connection between the pedestrian and the RSE. To enhance the safety improvements of the application, the weather related information and road condition information can be incorporated into determining which vehicles receive a message.

Potential Benefits: Safety Benefits for Pedestrians at midblock and non-signalized intersections

DEPLOYMENT:	Tampa, FL (deployment)

3.1.2 Further Development

Stop Sign Violation Warning

Description: The Stop Sign Violation Warning application utilizes vehicle and infrastructure information to assist drivers in avoiding crashes at stop controlled intersections. The application references the driver's approach speed, acceleration profile, and distance to the intersection, with the intersection's geometry (MAP) to determine if it appears likely that the vehicle will violate a stop sign. The intersection geometry information can be received by the connected vehicle from road side equipment at the intersection or earlier in the trip. If received at the intersection, the geometric information can cross reference the weather information, further improving the effectiveness of the safety message. The application will broadcast a warning message if it appears likely that the driver may violate an upcoming stop sign. The application can work in tandem with the Queue Warning (Q-WARN) application to ensure the vehicle will be issued a warning if there is a queue at the intersection.

Potential Benefits: Safety Benefits for Drivers on Undivided Roads

Stop Sign Gap Assist

Description: The Stop Sign Gap Assist (SSGA) application is a cooperative vehicle and infrastructure system that warns drivers of potential collisions at non-signalized intersections where the minor road has stop signs and the main road has no stop control. The system will assist drivers stopped on the minor-road in identifying unsafe gaps in cross-traffic at major road intersections. The application collects and processes all available data (on the major road, minor road, and at the median) to determine the state of the intersection. The state of the intersection is used to present the crossing assist alert, warning, or advisory message to connected vehicles using the on board unit, and to non-connected vehicles using connected physical road signs.

Potential Benefits: Safety Benefits for Drivers on Undivided Roads

Warnings about Hazards in a Work Zone

Description: The Warnings about Hazards in a Work Zone (WHWZ) application provides warnings to workers within a work zone about potentially hazardous situations within the work zone. This application enables vehicles or the infrastructure to send applicable warning messages to workers in a work zone when a vehicle is moving in a manner that appears to create an unsafe condition. Potentially unsafe conditions can include a vehicle moving at high speeds approaching the workers, a wide load vehicle approaching the workers, or a vehicle entering the work zone.

Potential Benefits: Safety Benefits for Workers on Divided and Undivided Roads

Warnings about Upcoming Work Zones

Description: The Warnings about Upcoming Work Zone (WUWZ) application provides information about the state of the work zone to drivers on the road approaching the work zone. The application provides drivers information about

work zone activities that result in unexpected or unsafe roadway conditions for the approaching vehicle, such as travel lane closures, lane narrowing, lane shifts, and construction vehicles entering and exiting the work zone.

Potential Benefits: Safety Benefits for Drivers and Workers on Divided and Undivided Roads

Railroad Crossing Violation Warning

Description: The Railroad Crossing Violation Warning (RCVW) application will alert and/or warn drivers who are approaching an at-grade railroad crossing if it is determined that the vehicle's path will collide with an oncoming train. The application uses both vehicle-based and infrastructure-based technologies to determine if a warning is transmitted or not. The RSE will send the vehicle the railroad crossing intersection geometry, and information about trains approaching (or already at) the crossing to the vehicle. The information about the approaching train can be obtained from the intersection infrastructure or from a connection between the train and the RSE. To enhance the safety improvements of the application, the weather related information and road condition information can be incorporated into determining which vehicles receive a message. Like the SPaT MAP Display Signal Timing, Time to Green application, the amount of time the railroad will be blocking the intersection can also broadcasted to the vehicles.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

In-Vehicle Signage

Description: The In-Vehicle Signage application moves physical infrastructure into a connected vehicle. The application can move regulatory, warning, and informational signs and signals into the vehicle providing information directly to drivers through in-vehicle devices. The information provided can include static signs (such as stop signs, yield signs, curve warning signs, and service signs) and dynamic signs (such as the current signal phase states, weather information, and speed limits). The application can also include the capability for maintenance, construction, and emergency vehicles to broadcast virtual sign information to near-by connected vehicles which can display appropriate information (such as lane closure and work zone ahead signs) to the drivers without fixed infrastructure.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

3.2 V2V Safety Applications

3.2.1 Deployment Ready

Emergency Electronic Brake Lights

Description: The Emergency Electronic Brake Lights (EEBL) application alerts the driver if there is hard braking in the traffic stream ahead. The advance warning provides the driver with additional time to look for, and assess the traffic situation developing ahead. The EEBL application receives information from other connected vehicles that broadcast a self-generated emergency brake event to surrounding vehicles. After the information is broadcasted, the vehicles receiving the event information determines the relevance of the event and if it is appropriate provides a warning to the driver in order to avoid a collision. This application is particularly useful when the driver's line of sight is obstructed by other vehicles, the roadway geometry, or bad weather conditions.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	THEA (deployment), Florida (testing), and Virginia (planning)

Forward Collision Warning

Description: The Forward Collision Warning (FCW) attempts to warn the driver of the vehicle who may cause a rear-end collision with another vehicle ahead in traffic (in the same lane and direction of travel) to help avoid or mitigate the severity of the rear end collision. The application uses data received from other vehicles to determine the likelihood of a roar end collision and, if determined that a crash is likely, the application broadcasts an alert to the driver.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	THEA (deployment), Florida (testing), New York (testing), and Virginia (planning)

Do Not Pass Warning

Description: The Do Not Pass Warning (DNPW) application broadcasts alerts to drivers to help avoid a head-on crash resulting from passing maneuvers. The DNPW application warns the driver of the vehicle during a passing maneuver attempt when a slower moving vehicle, ahead and in the same lane, cannot be safely passed in a passing zone because the adjacent lane is occupied by vehicles in the opposite direction of travel. The application provides advisory information that is intended to inform the driver of the vehicle that the passing zone is occupied when a vehicle is ahead and in the same lane even if a passing maneuver is not being attempted.

Potential Benefits: Safety Benefits for Drivers on Undivided Roads

DEPLOYMENT:	THEA (deployment)

Intersection Movement Assist

Description: The Intersection Movement Assist (IMA) application warns the driver when it is not safe to enter an intersection due to a high collision probability with other vehicles. The IMA application is particularly useful when a driver's view of the intersection is obstructed and additional information would allow for safe passage through the intersection, similar to the SSGA application. The IMA application can provide collision warning information to the vehicle on board unit (OBU) which can display a message to the driver who can perform actions to reduce the likelihood of crashes at the intersections.

Potential Benefits: Safety Benefits for Drivers on Undivided Roads

DEPLOYMENT:	THEA (deployment), Florida (planning), and New York (planning)

Vehicle Turning Right in Front of a Transit Vehicle

Description: The Vehicle Turning Right in Front of a Transit Vehicle (VTRFTV) application determines the movement of vehicles adjacent to a transit vehicle stopped at a transit stop. The application provides a warning to the transit vehicle operator if it detects that a nearby vehicle will pull in front of the transit vehicle to make a right turn. This application will help the transit vehicle determine if the area in front of it will or will not be occupied as it begins to pull away from a transit stop.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	Cleveland and US DOT Safety Pilot; Florida (planning), and New York (planning)

3.2.2 Deployment Near-ready

Blind Spot/Lane Change Warning

Description: The Blind Spot Warning and Lane Change Warning (BSW/LCW) application assists the driver in monitoring their vehicle's blind spots and other vehicles on the road to help avoid collisions associated with potentially hazardous lane changes. The BSW application monitor the adjacent lanes of the driver; if the BSW portion of the application detects that the driver is changing lanes and there is a vehicle in the driver's blind spot, a warning message can be sent to the driver. The LCW portion of the application can send a warning message to drivers if the application detects a host vehicle is changing lanes into the same lane. The application can also be used to provide the driver advisory information if another vehicle in an adjacent lane is positioned in a blind-spot zone of the vehicle even if a lane change is not being attempted.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	New York (planning)

3.2.3 Further Development

Left Turn Assist

Description: The Left Turn Assist (LTA) application provides warnings to driver as they attempt an unprotected left turn across traffic, to help them avoid crashes with opposite direction traffic, similar to the SSGA application. The LTA application collects and processes all available data (on the major road, minor road, and at the median) to determine the state of the intersection. The state of the intersection is used to present the crossing assist alert, warning, or advisory message to connected vehicles using the on board unit, and to non-connected vehicles using connected physical road signs.

Potential Benefits: Safety Benefits for Drivers on Undivided Roads

Control Loss Warning

Description: The Control Loss Warning (CLW) application enables a connected vehicle to broadcast a self-generated, control loss event to surrounding vehicles. When the surrounding vehicles receive the control loss event information, the receiving vehicles determines if the received information is relevance, and if applicable, provide a warning to the driver.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

Emergency Vehicle Alert

Description: The Emergency Vehicle Alert (EVA) application provides the driver a warning about the location, heading, and movement of public safety vehicles responding to an incident so the driver does not interfere with the emergency response. The application on the OBU in the connected vehicle receives the emergency vehicle information from a RUS; the RSU receives the emergency vehicle information from a public safety vehicle.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

Motorcycle Approaching Indication

Description: The Motorcycle Approaching Indication application can send warnings the driver of a vehicle that a motorcycle is approaching. The motorcycle could be approaching from behind or crossing at an intersection. The application is similar to the LTA application and SSGA application, but specifically focuses on motorcycles due to their relatively small size. The Motorcycle Approaching Indication application provides advisory information that is intended to inform the driver that a vehicle which affords limited visibility due to its size is approaching.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

Pre-Crash Actions

Description: The Pre-Crash Actions (PCA) application enables a vehicle to mitigate the injuries in a crash by automatically activating countermeasures in the vehicle when a crash is about to happen without the driver's involvement. This application uses the information from applications like the FCW application to determine if a crash is imminent, and, if so, activates countermeasures such as air bag pre-arming, emergency breaking, and seat belt pre-tensioning.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

Situational Awareness

Description: The Situational Awareness (SA) application provides drivers alerts of potentially hazardous roadway conditions. The drivers in the vehicles receive relevant road condition information broadcasted by other vehicles. Potentially hazardous road conditions can include floods, fog, or icy roads. This application can be useful to vehicles that are not equipped with weather sensors, or for vehicles entering areas with hazardous conditions that could not be anticipated. The SA application is similar to the SWIW application but, the SA application enables connected vehicles to share situational awareness information in areas where no RSE infrastructure exists

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

Slow Vehicle Warning

The Slow Vehicle Warning application provides drivers a warning or advisory information if the driver is approaching a slow moving vehicle. Depending on the driver's location, speed, and heading, and the speed, location, and heading of the slow moving vehicle, the application can determine the likelihood of a collision and adjust the severity of the warning message and advisory information to avoid or mitigate the severity of a collision.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

Stationary Vehicle Warning

The Stationary Vehicle Warning application provides drivers a warning if the driver is approaching a stationary vehicle. Depending on the driver's location, speed, and heading, and the speed, location, and the location of the stationary vehicle, the application can determine the likelihood of a collision and adjust the severity of the warning message and advisory information to avoid or mitigate the severity of a collision (if the stationary vehicle is blocking a travel lane). A stationary vehicle can be blocking a travel lane due to a break down, a collision with other vehicles, or a road having no shoulder to pull off on.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

Tailgating Advisory

The Tailgating Advisory (TA) application sends an advisory message to a driver if the driver is following another vehicle too closely, creating unsafe driving conditions. The application uses information (such as vehicle speed, location, and heading) to determine if the rear vehicle is too close to the vehicle in front of it.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

Vehicle Emergency Response

The Vehicle Emergency Response (VER) application provides public safety vehicles with information from collected from connected vehicles involved in a crash. The information received by the public safety vehicles can be used to safely, effectively, and rapidly respond to a collision. Information such as collision location, vehicle type (such as electric passenger vehicle, diesel passenger vehicle, petroleum truck) and HAZMAT data, can help emergency responders properly prepare for and travel to the site of the collision. Additional vehicle information such as air bag activations and seatbelt pre-tensioning can provide useful information to the emergency response team.

Potential Benefits: Safety Benefits for Drivers on Divided and Undivided Roads

3.3 Environmental Applications

3.3.1 Deployment Near-ready

Advanced Traveler Information Systems

The Advanced Traveler Information Systems application provides a database for the collection, aggregation, and dissemination of a wide range of transportation information. The collection of information can include traffic and congestion along a route, transit arrival time and delays, road weather, work zone locations, and connected vehicle related data. All data can be aggregated into a database which can be used to process and discriminate appropriate travel using technologies such as mobile devices, in vehicle displays, web portals, and roadside signage.

Potential Benefits: Environmental Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	Tennessee (planning), and Virginia (planning)

Connected Eco-Driving

Description: The Connected Eco-Driving application uses vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) data to provide customized real-time driving advice to drivers so they can adjust their driving behavior to optimize fuel efficiency and safety. Eco-driving advice can include recommendations for driving speeds and optimal acceleration/ deceleration profiles based on traffic conditions, roadway geometric conditions, and adjacent vehicles. The application can also provide the driver about existing driving behaviors and encourage drivers to drive in a safer and more environmentally efficient manner. If the vehicle is capable, the application can automatically adjust vehicle

settings to improve eco-driving strategies (such as automatically changing gears, changing fuel power source, and adjusting speeds).

Potential Benefits: Environmental Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT: Minnesota (research)

Eco-Approach and Departure at Signalized Intersections

Description: The Eco-Approach and Departure at Signalized Intersections application is a V2I application where intersection traffic signals broadcast the current state of signal phasing (red, yellow, or green) and time remaining in that phase. The broadcasted data is received by connected vehicles to support eco-friendly speed trajectories as vehicles approach and depart from a signalized intersection. The application broadcasts necessary information (such as the traffic signal state and intersection geometry) using RSE. The application in the vehicle receives information from the RSE and other vehicles (using V2V communication) to provide the driver approach speed advice and acceleration/ deceleration information, so the driver can pass through the intersection on green, or come to a stop in the most eco-friendly manner. The application also considers stopped vehicles departing the intersections by providing acceleration information. The application can also adjust the vehicle to increase fuel efficiency (such as changing gears and fuel sources).

Potential Benefits: Environmental Benefits for Drivers on Undivided Roads

DEPLOYMENT: Turner Fairbank Research Center (research)

3.3.2 Further Development

Eco-Traffic Signal Timing

Description: The Eco-Traffic Signal Timing application wirelessly collects and analyzes (in real time) connected vehicle data, RSE data, and data from historic traffic trends to optimize the traffic network to service the existing traffic demands while minimizing the environmental impact. The application is similar to existing adaptive traffic signal control systems except, instead of optimizing the signal timing plan for traffic throughput like adaptive signal control systems, the Eco-Traffic Signal Timing application optimizes the signal control system to minimize environmental impacts (such as minimizing fuel consumption and emissions).

Potential Benefits: Environmental Benefits for Drivers on Undivided Roads

Eco-Transit Signal Priority

Description: The Eco-Transit Signal Priority application allows transit vehicles approaching a signalized intersection to request signal priority, thereby adjusting the signal timing to improve service for the vehicle. Priority can be given to the transit vehicle by extending the green time for the transit vehicle, or shortening red-time for the transit vehicle. Priority decisions are optimized for the environment by considering vehicle type, passenger load, or adherence to schedule. The application works like existing signal priority systems but the application can include more vehicle specific information (such as vehicle type, passenger load, or adherence to schedule) into determining if priority is granted to the transit vehicle.

Potential Benefits: Environmental Benefits for Drivers on Undivided Roads

Eco-Freight Signal Priority

The Freight Signal Priority application (FSP) application allows freight and commercial vehicles approaching a signalized intersection to request signal priority, thereby adjusting the signal timing to improve service, travel time reliability, and safety for the freight and commercial vehicle. Priority can be given to the freight and commercial vehicles by extending the green time for the freight and commercial vehicles, or shortening red-time for the freight and commercial vehicles. Priority decisions are optimized for the environment by considering vehicle type and emissions. The application works like existing signal priority systems but the application can include more vehicle specific information (such as the vehicle's load, location, and emissions) into determining if priority is granted to the transit vehicle.

Potential Benefits: Environmental Benefits for Drivers on Undivided Roads

Wireless Inductive/Resonance Charging

Description: The Wireless Inductive/Resonance Charging infrastructure application uses magnetic fields embedded in the pavement to wirelessly transmit electric currents between metal coils, enabling the wireless charging of electric vehicles while the vehicle is stopped or in motion.

Potential Benefits: Environmental Benefits for Drivers on Divided and Undivided Roads

Eco-Lanes Management

Description: The Eco-Lanes Management application establishes parameters and defines the operations of eco-lanes. Eco-lanes are similar to existing managed lanes, but optimized for the environment. The eco-lane management utilizes data from RSE and from connected vehicles to, in real-time, determines whether an eco-lane should be or not along a roadway. The application can be responsive to real-time traffic and environmental conditions. Lanes can be optimized based on multiple parameters such as low emission, high occupancy, transit, and alternative fuel vehicles. While the eco-lanes have to be flexible to respond to real-time environmental and traffic conditions, the eco-lane creation needs to happen in a clear manner and only when needed to ensure travelers are not confused by the system. The application needs to clearly define the boundaries for the potential eco-lanes, and rules for what types of vehicles and how many vehicles can use the eco-lanes. The Eco-Lanes Operational Scenario plan can receive information from multiple applications such as Eco-Lane Management, Eco-Speed Harmonization, Eco-Cooperative Adaptive Cruise Control, Eco-Ramp Metering, Connected Eco-Driving, and Wireless Inductive/ Resonance Charging.

Potential Benefits: Environmental Benefits for Drivers on Divided Roads

Eco-Speed Harmonization

Description: The Eco-Speed Harmonization application determines eco-speed limits based on traffic conditions, weather information, greenhouse gas (GHG) emissions, and criteria pollutant information. The application functions in a similar manner to the variable speed limit application but, instead of sending drivers a speed advisory message based on traffic congestion, a speed advisory message is sent to drivers to minimize emissions and fuel consumption. Speed harmonization helps to stabilize flow on a roadway by reducing unnecessary accelerating and decelerating to maintain a consistent speed, which reduces fuel consumption and greenhouse emissions. The eco-speed alert can be broadcasted to the connected vehicles using RSE. The eco-speed alert can be broadcasted to non-connected vehicles using existing infrastructure such as dynamic message signs (DMS).

Potential Benefits: Environmental Benefits for Drivers on Divided Roads

Eco-Cooperative Adaptive Cruise Control

Description: The Eco-Cooperative Adaptive Cruise Control (Eco-CACC) application is a V2V application that uses connected vehicle technologies to collect speed, acceleration, and location information of adjacent vehicles and integrates these data into a vehicle's adaptive cruise control (ACC) system. The application also used RSU devices to collect information such as road geometry, grade, and weather information to assist in adjusting a vehicle's adaptive cruise control (ACC) system. The Eco-CACC application allows for automated longitudinal control capabilities and vehicle platooning that seek to reduce fuel consumption and emissions. The Eco-CACC application allows vehicles to follow each other based on a safe gap time, not based on the driver manually adjusting their speed to maintain a safe gap distance. The Eco-CACC application can also be to assist in platooning vehicles, a concept where two or more vehicles automatically follow one another to reduce wind resistance and drag to improve fuel economy and reduce GHG emissions.

Potential Benefits: Environmental Benefits for Drivers on Divided Roads

Eco-Ramp Metering

Description: The Eco-Ramp Metering application collects traffic and environmental conditions data to determine the most environmentally efficient operation of traffic signals at freeway on-ramps to manage the rate of entering vehicles. The application collects traffic and environmental information from connected vehicles approaching the ramp and already on the freeway to optimize the ramp metering signal timing plan to minimize overall emissions.

Potential Benefits: Environmental Benefits for Drivers on Divided Roads

Low Emissions Zone Management

Description: The Low Emissions Zone Management application supports the operations of low emissions zones. Low Emissions Zones are geographic areas that respond to real-time traffic and environmental conditions to incentivize green transportation choices in the zone. Low emission zones restrict or deter access to specific categories of high-polluting vehicles into the area for the purpose of improving the air quality within the geographic area. Like the Eco-Managed Lane application, the Low Emissions Zone Management application collects information from connected vehicles and RSE to create defined low emission zone areas (potentially using geofences so the areas are adjustable and scalable), which includes information such as types of vehicles allowed in the zone, emission criteria, and potential fees to incentivize low emission vehicles. The application can provide an electronic toll payment system for paying fees. Like the Eco-Managed Lane application, the Low Emissions Zone Management application also has to provide clear information about the low emission zones to the travelers, such as potential fees and geographic location of the low emission zone.

Potential Benefits: Environmental Benefits for Drivers on Divided and Undivided Roads

Connected Vehicle-Enabled Environmental Probe Data Collection

Description: The Connected Vehicle-Enabled Environmental Probe Data Collection application supports the collection of fuel consumption and emissions data from vehicles. Real-time air quality maps can be created for roadway segments using the data collected.

Potential Benefits: Environmental Benefits for Drivers on Divided and Undivided Roads

Eco-Multimodal Real-Time Traveler Information

Description: The Eco-Multimodal Real-Time Traveler Information application provides pre-trip and en-route traveler information to all roadway users to encourage more sustainable travel. The application collects multimodal data to support trip planning tools that provide travelers with information about travel options. The application can provide travelers with real-time traffic conditions so departure times and mode choices can be selected and adjusted.

Potential Benefits: Environmental Benefits for Drivers on Divided and Undivided Roads

Eco-Smart Parking

Description: The Eco-Smart Parking application provides users with real-time parking information including location, availability, type, and price of parking to reduce the time vehicles spend circulating while searching for parking. The Eco-Smart Parking applications can also supports dynamic pricing or incentives for parking based on vehicle type. Adjusting parking pricing and incentives can serve as a strategy to help reduce vehicle miles traveled in an area and can also help to incentivize travel by eco-friendly vehicles. The application also allows travelers to reserve parking spaces in advance, as well as pay for parking in advance, using mobile devices and connected vehicle technologies.

Potential Benefits: Environmental Benefits for Drivers on Undivided Roads

Dynamic Eco-Routing

Description: The Dynamic Eco-Routing application is a navigation routing application that determines the most eco-friendly route for a traveler. The route can be planned and adjusted during the trip based on real-time data. The application can evaluate criteria such as minimizing fuel consumption and minimizing GHG emissions. To find the best routes, the application uses roadway geometric data and historic, real-time, and predictive connected vehicle data. The application can provides feedback to drivers on their driving behavior and provide alerts to drivers to encourage driving in a more environmentally efficient manner. Like other Eco-applications, the Dynamic Eco-Routing application can assist in automatically implementing eco-driving strategies to improve eco-driving capabilities such as changing gears and fuel sources.

Potential Benefits: Environmental Benefits for Drivers on Divided and Undivided Roads

Connected Eco-Driving – Gamified / Incentives-Based Applications

Description: The Connected Eco-Driving application allows vehicular systems to communicate information about the vehicle's performance directly to the driver using the connected vehicle dashboard or smartphone. Using the application, drivers receive eco-driving recommendations and post-trip feedback on their driving behavior adapted to them and to their vehicle's characteristics to improve eco-driving behaviors. The Eco-Driving information applications

provide recommendations using an OBU to promote energy efficient driving techniques. The Connected Eco-Driving applications can be used in a social media setting where people can compete on leaderboards.

Potential Benefits: Environmental Benefits for Drivers on Divided and Undivided Roads

Gamified / Incentives-Based Multimodal Traveler Information Applications

Description: The Gamified / Incentives-Based Multimodal Traveler Information Applications application allows travelers to use a smartphone application to earn points based on their travel choices. Travelers would earn points for green transportation choices including traveling during off-peak hours, using transit, or using a bicycle. These applications would allow system operators to collect data from travelers on their traveling behavior and would allow application users to receive customized traveler information. The application can have a social media component where travelers would compete on leaderboards on how much fuel and emissions they save from making green transportation choices.

Potential Benefits: Environmental Benefits for Drivers and Pedestrians on Divided and Undivided Roads

Eco-Integrated Corridor Management (ECO-ICM)

Description: The goal of the Eco-Integrated Corridor Management (ECO-ICM) is to improve the movement of people and goods through integrated and proactive management of major multimodal transportation corridors while minimizing the environmental impacts. The Eco-ICM Operational Scenario, like previous ICM initiatives, considers how connected vehicle and other future technologies may support the integrated operation of a major travel corridor and reduces transportation-related emissions on arterials and freeways. Environmental oriented strategies can include eco-traffic signal timing, eco-speed harmonization, and eco-traveler information.

Potential Benefits: Environmental Benefits for Agencies, Drivers, and Pedestrians on Divided and Undivided Roads

Eco-Integrated Corridor Management (ICM) Decision Support System (DSS)

Description: The Eco-Integrated Corridor Management (ECO-ICM) Decision Support System (DSS) application seeks to assist managers in the process of collaboratively managing a multimodal transportation network with a focus on environmental improvements. The Eco-Integrated Corridor Management (Eco-ICM) Decision Support System application aggregates environmental information from various multimodal systems. Data from these systems is used to determine operational strategies for arterials, freeways, and transit, ensuring that environmental data and performance measures are considered in making operational decisions. An environmental operational decision can be to recommend eco-signal timing plans, eco-ramp metering, and transit travel when a divided highway is over capacity.

Potential Benefits: Environmental Benefits for Agencies on Divided and Undivided Roads

AFV Charging / Fueling Information

Description: The AFV Charging / Fueling Information application informs travelers of locations and availability of alternative fuel vehicle charging and fueling stations and inductive/resonance charging infrastructure.

Potential Benefits: Environmental Benefits for Drivers on Divided and Undivided Roads

Electric Charging Stations Management

Description: The Electric Charging Stations Management application provides an exchange of information between vehicle and charging station to manage the charging operation. The agency or company operating the charging station can use connected vehicle information (such as the operational status of the electrical system, how many amps can the vehicle handle, and percent charge required to fully charge the vehicle) to ensure the charge to the vehicle is being properly applied and to determine an estimated time to complete charging.

Potential Benefits: Environmental Benefits for Agencies Drivers on Divided and Undivided Roads

Roadside Lighting

Description: The Roadside Lighting application is a connected vehicle application that automated roadside lighting systems. The application uses connected vehicle information to detect if a vehicle is present. The application is connected to the roadway lighting infrastructure. If the application detects the presence of a vehicle (based on V2I communications) the application can alter roadside lighting levels. The application can use environmental data

obtained from the vehicles as an input to support adjustment of the lighting based on adverse weather conditions such as fog, rain, or snow.

Potential Benefits: Environmental Benefits for Agencies on Divided and Undivided Roads

3.4 Road Weather Applications

3.4.1 Deployment Ready

Weather Data Environment

Description: The Weather Data Environment (WxDE) is a research based data system that acquires, validates, stores, and shares transportation-related weather data. The WxDE application collects data in near real-time from both fixed environmental sensor stations (ESS) and mobile sources. The database quality checks the observations, and makes the data available through a map interface, or through queries and subscriptions. The WxDE application also integrates with the United States Department of Transportation Research Data Exchange (RDE) database so that transportation-related weather data can be easily accessed for researchers and application developers.

Potential Benefits: Safety and Weather Warnings for Agencies on Divided and Undivided Roads

DEPLOYMENT:	United Stated Department of Transportation Joint Program Office

Integrated Modeling for Road Weather Condition Prediction

Description: The Integrated Modeling for Road Weather Condition Prediction system uses connected vehicle data to predict future road conditions. These predictions can be incorporated into a variety of applications for travelers, transportation operators, and maintenance providers. Advanced algorithms in this system use various types of weather, traffic and maintenance data including, archived and real-time data, as well as probabilistic models and forecasts.

Potential Benefits: Safety and Weather Warnings for Drivers on Divided and Undivided Roads

DEPLOYMENT:	United Stated Department of Transportation Joint Program Office

3.4.2 Deployment Near-ready

Road Weather Motorist Alert and Warning

Description: The Road Weather Motorist Alert and Warning application provides localized, real-time road weather information to the travelling public including current inferences for visibility, road condition, and road precipitation. The application will also be able to combine vehicle information with observations and forecasts from other sources to provide 24-hour forecasts of road weather conditions.

Potential Benefits: Safety and Weather Warnings for Drivers on Divided and Undivided Roads

DEPLOYMENT:	Colorado (planning), and Washington (planning)

3.4.3 Further Development

Enhanced Maintenance Decision Support Systems

Description: The Enhanced Maintenance Decision Support Systems (EMDSS) application incorporates connected vehicle data, processes it through the VDT, and uses the outputs in road weather forecasting and to improve the maintenance decision processes. With this application, maintenance managers can better monitor and react to changing road conditions. The information can come from vehicles operated by the general public, commercial vehicles, specialty vehicles, and public fleet vehicles (such as snowplows, maintenance trucks, and other agency pool vehicles). The EMDSS application can also gather data from fixed Environmental Sensor Station (ESS) sites and the National Weather Service. Because the data comes from a variety of sources, the users can obtain

information along an entire corridor. With corridor wide data, maintenance managers will be better equipped to make spot treatments on the road, improving safety, mobility, and reducing the environmental impact of de-icing chemicals. It allows enhanced ability to assess the nature and magnitude of storms, determine staffing needs, plan road treatment strategies and timing, and activate pre-treatment/post-treatment systems.

Potential Benefits: Safety and Weather Warnings for Agencies on Divided and Undivided Roads

Road Weather Information and Routing Support for Emergency Responders

Description: The Road Weather Information and Routing Support for Emergency Responders application provide the capability of collecting road weather data from connected vehicles and other sources. Using the data, the application can help develop short term warnings or advisories that can be provided to individual emergency response vehicles or to emergency response dispatchers. The data can come from vehicles operated by the general public, commercial entities, specialty vehicles, public fleet vehicles (such as snowplows, maintenance trucks, and other agency pool vehicles), and from other fixed and remote observation systems. At the control center, where the information is collected can processed, data can be combined with observations and forecasts from other sources to provide medium (2-12 hours) or long term (more than 12 hours) advisories which can be broadcasted to the connected vehicles.

Potential Benefits: Safety and Weather Warnings for Agencies on Divided and Undivided Roads

Road Weather Information for Freight Carriers

Description: The Road Weather Information for Freight Carriers application is a specific use case of the Road Weather Advisories and Warnings for Motorists application focusing on freight vehicles because freight vehicles are more susceptible to inclement weather than other vehicle types. This application provides the capability of collecting road weather data from connected vehicles and using that data develop short term warnings or advisories that can be broadcasted to individual commercial vehicles or to commercial vehicle dispatchers. The data can come from vehicles operated by the general public, commercial entities, specialty vehicles, public fleet vehicles (such as snowplows, maintenance trucks, and other agency pool vehicles), and from other fixed and remote observation systems. At the control center, where the information is collected can processed, data can be combined with observations and forecasts from other sources to provide medium (2-12 hours) or long term (more than 12 hours) advisories which can be broadcasted to the connected vehicles.

Potential Benefits: Safety and Weather Warnings for Drivers on Divided and Undivided Roads

Road Weather Information for Maintenance and Fleet Management Systems

Description: The Road Weather Information for Maintenance and Fleet Management Systems application is used by maintenance or fleet dispatchers to monitor the status of the maintenance operations. The application can be either a stand-alone application or an adjunct to the EMDSS application. Vehicle data is collected from vehicles used during winter maintenance and from other maintenance vehicles and equipment used year round. Additionally, road weather data and specialized maintenance information (such as status of vehicle systems, material distribution rate, and materials remaining) data is collected.

Potential Benefits: Safety and Weather Warnings for Agencies on Divided and Undivided Roads

Variable Speed Limits for Weather-Responsive Traffic Management

Description: The Variable Speed Limits for Weather-Responsive Traffic Management application uses road weather information from connected vehicles as well as current and historical data from multiple sources to determine the appropriate current safe speed. The application provides real-time information on appropriate speeds for current conditions and warns drivers of coming road conditions. The information will come from either vehicles operated by the general public and commercial entities.

Potential Benefits: Safety and Weather Warnings for Drivers on Divided and Undivided Roads

Weather Responsive Traffic Management – Traveler Information via Citizen Reporting

Description: The Weather Responsive Traffic Management – Traveler Information via Citizen Reporting application uses citizen reporting to obtain data information on road and weather conditions information, which help traffic management center operations. Citizen reporting differs from other crowdsourcing efforts because citizen reporting is developed and controlled by the State DOTs and requires training to use. Citizen reporting programs allow agencies

to build the data collection application to suit their needs, funnel the information into pre-existing TI architectures, and train the reporters to ensure a high quality of information.

Potential Benefits: Safety and Weather Warnings for Agencies on Divided and Undivided Roads

3.5 Mobility Applications

3.5.1 Deployment Ready

Intelligent Traffic Signal System

Description: The Intelligent Traffic Signal System application (ISIG) optimizes the signal timing plan at an intersection for all roadway users. The application serves as an over-arching system optimization application, accommodating other mobility applications such as Transit Signal Priority, Freight Signal Priority, Emergency Vehicle Preemption, and Pedestrian Mobility to maximize overall arterial network performance. To adjust the signal timing plan for an intersection to improve traffic flow through the intersection, the ISIG application receives speed, location, and heading data from connected vehicles, measurements from non-equipped vehicles, and roadway geometric information from road side equipment (RSE).

Potential Benefits: Mobility Benefits for Drivers on Undivided Roads

DEPLOYMENT:	Maricopa Co., Arizona (deployment), Florida (testing), New York (testing), and Virginia (planning)

Freight Signal Priority

Description: The Freight Signal Priority (FSP) application provides signal priority to freight and commercial vehicles in signalized networks. This application can contribute to improved operating performance of freight vehicles by reducing stops and delays, and enhancing safety at intersections.

Potential Benefits: Mobility Benefits for Drivers on Undivided Roads

DEPLOYMENT:	Maricopa Co., Arizona (deployment), Colorado (planning), Florida (planning), Michigan, (testing), Minnesota (planning), Pennsylvania (planning), Tennessee (planning), Utah (deployment), and Virginia (planning)

Transit Signal Priority (TSP) &

Description: The Transit Signal Priority (TSP) application provides signal priority to transit at intersections. TSP uses transit vehicle to infrastructure communications to allow a transit vehicle to request a priority at one or a series of intersection. The application includes feedback to the transit driver indicating whether the signal priority has been granted or not. This application can contribute to improved operating performance of the transit vehicles by reducing the time spent stopped at a red light.

Potential Benefits: Mobility Benefits for Drivers on Undivided Roads

DEPLOYMENT:	Maricopa Co., Arizona (deployment), Colorado (planning), Florida (planning), Michigan, (testing), Minnesota (planning), Pennsylvania (planning), Tennessee (planning), Utah (deployment), and Virginia (planning)

Emergency Vehicle Preemption

Description: The Emergency Vehicle Preemption (PREEMPT) application provides signal preemption to emergency vehicles, and accommodates multiple emergency requests. Similar to existing intersections with preemption, the Emergency Vehicle Preemption application is a high priority preemption application for emergency and first responder vehicles that will adjust the signal timing plan to ensure emergency vehicles will have a minimal delays and a green light when the vehicle arrives at the intersection. Because primary goal of the Emergency Vehicle Preemption application is to ensure the emergency vehicle can safely and efficiently move through the intersection, it may take

additional time to clear a standing queue for congested conditions. Transitioning back to normal traffic signal operations after providing emergency vehicle preemption is an important consideration because the signal timing plan is modified.

Potential Benefits: Mobility Benefits for Drivers on Undivided Roads

DEPLOYMENT:	THEA (deployment), Maricopa county (Co.), Arizona (deployment), Pennsylvania (planning), and Virginia (planning)

Emergency Communications and Evacuation (EVAC)

Description: The Emergency Communications and Evacuation (EVAC) application addresses needs of evacuees with and without special needs or their own transportation. The EVAC application provides real-time communications of evacuation instructions, evacuation information (such as shelter locations, and food and water resources, and general information about returning back to their jurisdiction), and routing guidance that accounts for current road and traffic conditions. This application integrates many of the existing functions that relate to emergency communications and evacuation, such as mass warning, notification systems, computer-aided dispatch, automated vehicle location, traffic information, and weather data. During an incident, emergency management agencies will have the ability to push information to registered users of the system. The traffic management center (TMC) working with the Emergency Operations Center (EOC) can use the EVAC application to send information about available transportation resources to the application users. The EVAC application can assist in dispatching and routing the transportation resources to the appropriate location, while providing communications update to those special needs individuals in need of assistance. For non-special needs evacuees, the EVAC application will provide evacuation route guidance that accounts for road conditions, traffic conditions, and final destination.

Potential Benefits: Mobility Benefits for Agencies and Drivers on Divided and Undivided Roads

DEPLOYMENT:	New York (planning)

Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)

Description: The Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG) application provides routing and coordination input to emergency responders while en-route to an incident, which setting up at the scene of the incident, during the incident if additional resources are required, and after the incident if additional guidance is needed. The application collects data from a variety of sources, including connected vehicles, emergency management centers, traffic operation centers, and maintenance centers. The application also includes information for the emergency responders regarding any updates to the scene of an incident. The dynamic routing functionality built into the application can route the emergency responders using real-time traffic data and road closures. The application also includes a function that monitors the location of the emergency responders while traveling to the scene (to provide an accurate ETA) and while at the scene.

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

DEPLOYMENT:	THEA (deployment), Florida (planning), and New York (planning)

Deployment: California (deployment), Texas (testing), and Transport Canada (testing)

3.5.2 Deployment Near-ready

Speed Harmonization

Description: The Speed Harmonization (SPD-HARM) application recommends target speeds to drivers in response to congestion, incidents, weather, and road conditions to maximize throughput and reduce crashes. The SPD-HARM application helps to maintain the flow, particularly, at critical choke points (such as bottlenecks incidents, and work zones) by reducing unnecessary stops and starts, and maintaining consistent speeds. The application uses connected vehicle information to detect where a slowdown is occurring on the roadway, determine if the slow-down necessitates speed harmonization, generate an appropriate response plans and speed recommendation for upstream

traffic, and broadcast the calculated recommendations to the upstream vehicles. The speed recommendations can be provided in-vehicle for connected vehicles, or through roadside signage for non-connected vehicles.

Potential Benefits: Mobility Benefits for Drivers on Divided Roads

DEPLOYMENT:	Tennessee (planning)

Queue Warning

Description: The Queue Warning (Q-WARN) application aims to provide drivers timely warnings of existing and impending queues. The Q_WARN application detects the presence of a queue and disseminates queue information to upstream vehicles. The Q-WARN application utilizes V2I and V2V communication technologies to enable vehicles within the queue event to automatically broadcast their queued status information (such as lane location, current speed, or disabled status) to nearby upstream vehicles. The application can also broadcast the vehicle's information to RSE which broadcasts the information to a infrastructure-based central location (such as the TMC) which can broadcast the queue warnings to other upstream vehicles. Broadcasting to other upstream vehicles will warn the drivers of the upcoming queue, potentially minimizing or preventing rear-end collisions. Unlike the FCW application, the Q-WARN application will broadcast the queue message in advance of any potential crash situation, providing the drivers ample time to process and react to the messages.

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

DEPLOYMENT:	Tennessee (planning), and Virginia (planning)

Incident Scene Work Zone Alerts for Drivers and Workers

Description: The Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE) application warns on-scene workers of vehicles with trajectories or speeds that pose a high risk to their safety. The application also warns drivers passing incident zone with merging and speed guidance and with in-vehicle incident scene alerts for the protection of the drivers as well as incident zone personnel. Additional information such as arriving and staging of additional responders would also be provided to assist in staging decisions and response to the incident.

Potential Benefits: Mobility and Safety Benefits for Drivers on Divided and Undivided Roads

DEPLOYMENT:	Tennessee (planning), and Virginia (planning)

3.5.3 Further Development

Pedestrian Mobility and Accessibility

Description: The Pedestrian Mobility and Accessibility application will tie pedestrians at an intersection into the connected vehicle network. The application integrates traffic and pedestrian information from roadside and intersection detectors and new forms of data from wirelessly connected, pedestrian (or bicyclist) carried mobile devices (nomadic devices) to request dynamic pedestrian signals or to inform pedestrians when to cross and how to remain aligned with the crosswalk based on real-time Signal Phase and Timing (SPaT) and MAP information. In some cases, priority will be given to pedestrians, such as persons with disabilities who need additional crossing time, or in special conditions (e.g., weather) where pedestrians may warrant priority or additional crossing time. This application will enable a "pedestrian call" to be routed to the traffic controller from a nomadic device of a registered person with disabilities after confirming the direction and orientation of the roadway that this pedestrian is intending to cross. The application also provides warnings to the personal information device user of possible infringement of the crossing by approaching vehicles.

Potential Benefits: Mobility Benefits for Drivers and Pedestrians on Undivided Roads

Traveler Information- Smart Parking

Description: The Traveler Information -Smart Parking application provides users with real-time location, availability, type (e.g., street, garage, AFV only), and the price of parking. The parking information can be provided via DSRC or

wide area communications. The application reduces time required for drivers to search for a parking space, which can have eco benefits such as reducing emissions. The application also supports dynamic pricing of parking based on factors such as demand, emissions, or vehicle type.

Potential Benefits: Mobility Benefits for Drivers on Undivided Roads

Transit Pedestrian Indication

Description: The Transit Pedestrian Indication application provides vehicle to device communications to inform pedestrians at a station or stop about the presence of a transit vehicle. In addition, this application would inform the transit vehicle operator about the presence of pedestrians nearby and those waiting for the bus. It would help prevent collisions between transit vehicles and pedestrians.

Potential Benefits: Mobility Benefits for Drivers on Undivided Roads

Transit Vehicle at Station/Stop Warnings

Description: The Transit Vehicle at Station/Stop Warnings application inform nearby vehicles of the presence of a transit vehicle at a station or stop. The application also indicates the intention of the transit vehicle in terms of pulling into or out of a station/stop.

Potential Benefits: Mobility and Safety Benefits for Drivers on Undivided Roads

Cooperative Adaptive Cruise Control

Description: An application that aims to dynamically adjust and coordinate cruise control speeds among platooning vehicles to improve traffic flow stability and increase throughput

The Cooperative Adaptive Cruise Control application represents an evolutionary advancement of conventional cruise control (CCC) systems and adaptive cruise control (ACC) systems by utilizing V2V communication to automatically synchronize the movements of many vehicles within a platoon.

Potential Benefits: Mobility Benefits for Drivers on Divided Roads

Integrated Multi-Modal Electronic Payment

Description: The Integrated Multi-Modal Electronic Payment application uses connected vehicle roadside and vehicle systems to provide the electronic payment capability for toll systems, parking systems, and other areas requiring electronic payments.

Potential Benefits: Mobility Benefits for Drivers on Divided and Undivided Roads

Intermittent Bus Lanes

Description: The Intermittent Bus Lane (IBL) application provides dedicated bus lanes during peak demand times to enhance transit operations mobility. IBL consists of a lane that can change its status from regular lane (accessible for all vehicles) to bus lane, for the time strictly necessary for a bus or set of buses to pass. The status of the IBL is communicated to drivers using roadside message signs and through in-vehicle signage. The creation and removal of dedicated bus lanes is managed through coordination between traffic and transit centers.

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

Route ID for the Visually Impaired

Description: The Route ID for the Visually Impaired (RVI) application assist visibly impaired travelers to identify the appropriate bus and route to their intended destination. The application provides information from bus stop infrastructure to visually impaired travelers portable devices that can be converted to audible information regarding the appropriate bus and route. The application could allow the visually impaired traveler to query the portable device to identify route options.

Potential Benefits: Mobility Benefits for Pedestrian on Undivided Roads

Smart Park and Ride System

Description: The Smart Park and Ride application provides real-time information on Park and Ride capacity and supports traveler's decision-making on where best to park and make use of transit alternatives. The application uses

connected vehicles to monitor in real time the occupancy of parking spaces and provide the information to travelers via smartphones and to connected vehicles.

Potential Benefits: Mobility Benefits for Drivers on Undivided Roads

Transit Connection Protection

Description: The Transit Connection Protection application allows travelers to initiate a request for connection protection anytime during the trip using a personal mobile device, or potentially via transit vehicle or personal automobile onboard equipment / interface, and receive a confirmation indicating whether the request is accepted. Connection protection uses real time data to examine the arrival status of a transit vehicle and to transmit a hold message to a vehicle or other mode of transportation (e.g. rail) in order for the traveler to make a successful transfer from one vehicle to another. Connection protection can be performed within a single agency, across multiple agencies, and across multiple modes. In order to make this application viable a central transfer request brokerage system for processing transfer requests could be created. This tool would be particularly important in an intermodal, multimodal or interagency environment since the existing computer-aided dispatch/ automated vehicle location (CAD/AVL) systems at individual agencies may not have the ability to share or process real-time data available from various external sources (e.g., multi-agency and multimodal operational subsystems) to determine the feasibility of a connection protection request. The system will first determine the feasibility of a transfer based on fixed-schedule and then monitor the real-time status using input from the control center(s).

Potential Benefits: Mobility Benefits for Pedestrian on Undivided Roads

Transit Stop Request

Description: The Transit Stop Request application allows a transit passenger to send a stop request to an approaching transit vehicle. This application allows a transit vehicle to know that a passenger has requested a transit stop from an infrastructure device.

Potential Benefits: Mobility Benefits for Pedestrian on Undivided Roads

Dynamic Transit Operations

Description: An application that links available transportation service resources with travelers through dynamic transit vehicle scheduling, dispatching and routing capabilities. The Dynamic Transit Operations application allows travelers to request trips and obtain itineraries using a handheld mobile device (or personal computer). The trips and itineraries would cover multiple transportation services (public transportation modes, private transportation services, shared-ride, walking and biking). This application builds on existing technology systems such as computer-aided dispatch/ automated vehicle location (CAD/AVL) systems and automated scheduling software, providing a coordination function within and between transit providers that would dynamically schedule and dispatch or modify the route of an in-service vehicle by matching compatible trips together.

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

Dynamic Ridesharing

Description: An application that uses dynamic ridesharing technology, personal mobile devices, and voice activated on-board equipment to match riders and drivers. The Dynamic Ridesharing application allows travelers to arrange carpool trips through a stand-alone personal device with a wireless connection and/or an automated ride matching system (e.g., call center or web-based application loaded on a personal computer or kiosk at a transit facility). The application uses inputs from both passengers and drivers pre-trip, during the trip, and post-trip . These inputs are then translated into "optimal" pairings between passengers and drivers to provide both with a convenient route between their two origin and destination locations. After the trip, information is provided back to the application to improve the user's experience for future trips and monitor use of high-occupancy lanes.

Potential Benefits: Mobility Benefits for Pedestrian on Divided and Undivided Roads

Advanced Automatic Crash Notification Relay

Description: The Advanced Automatic Crash Notification Relay application (which was previously called Mayday Request) provides the capability for a vehicle to automatically transmit an emergency message when the vehicle has been involved in a crash or other distress situation. An automatic crash notification feature transmits key data on the crash recorded by sensors mounted in the vehicle (e.g. deployment of airbags) without the need for involvement of

the driver. The emergency message is broadcast to passing connected vehicles, who can relay the message to other connected vehicles as well as roadside "hotspots." Once received by emergency response services (either through emergency vehicles or through the roadside equipment), the appropriate response to the vehicle situation can be carried out by emergency response services. This application allows a vehicle to forward mayday requests even in areas where no V2I infrastructure exists.

Potential Benefits: Mobility and Safety Benefits for Drivers on Divided and Undivided Roads

Performance Monitoring and Planning

Description: The Performance Monitoring and Planning application uses information collected from connected vehicles to support performance monitoring and other uses of historical data including transportation planning, condition monitoring, safety analyses, and research. The information may be probe data information obtained from vehicles in the network to determine network performance measures such as speed and travel times, or it may be information collected from the vehicles and processed by the infrastructure, e.g. environmental data and infrastructure conditions monitoring data. This application supports archiving of all types of data either directly from the connected vehicles or processed by the infrastructure.

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

Freight-Specific Dynamic Travel Planning

Description: An application that enhances traveler information systems to address specific freight needs. Provides information such as wait times at ports, road closures, work zones, and route restrictions. The Freight-Specific Dynamic Travel Planning application provides both pre-trip and enroute travel planning, routing, and commercial vehicle related traveler information, which includes information such as truck parking locations and current status. The information will be based on data collected from the commercial fleet as well as general traffic data collection capabilities. The information, both real time and static can be provided directly to fleet managers, to mobile devices used by commercial vehicle operators, or directly to in vehicle systems as commercial vehicles approach roadway exits with key facilities such as parking. The application can also provide oversize/ overweight permit information to commercial managers.

Potential Benefits: Mobility Benefits for Drivers on Divided and Undivided Roads

Freight Drayage Optimization

Description: An application that optimizes truck/load movements between freight facilities, balancing early and late arrivals. The Freight Drayage Optimization application covers the information exchanges between all intermodal parties to provide current drayage truck load matching and container availability and appointment scheduling at railroad and steamship line terminals. The application includes a link from drivers and freight management systems dispatchers to an intermodal terminal reservation system and integrates an appointment function with Terminal Queue Status and Load Matching. The application set provides information to the dispatcher and driver concerning the availability status for pickup of a container at an intermodal terminal. The application bundle also provides drivers and dispatchers with both intermodal terminal queue length, and estimated time from the back of the queue to the gate.

Potential Benefits: Mobility Benefits for Drivers on Divided and Undivided Roads

Electronic Toll Collection

Description: The Electronic Toll Collection application provides transit operations toll operators with the ability to collect tolls electronically and detect and process violations. The fees that are collected may be adjusted to implement demand management strategies. Field-Vehicle Communication between the roadway equipment and the vehicle is required as well as Fixed Point-Fixed Point interfaces between the toll collection equipment and transportation authorities and the financial infrastructure that supports fee collection. Toll violations are identified and electronically posted to vehicle owners. Standards, inter-agency coordination, and financial clearinghouse capabilities enable regional, and ultimately national interoperability for these services.

Potential Benefits: Mobility Benefits for Drivers on Divided Roads

Road Use Charging

Description: The Road Use Charging application supports the capability to charge fees to roadway vehicle owners for using specific roadways with potentially differential payment rates based on time-of-day, which specific roadway is used, and class of vehicle (a local policy decision by each roadway owner). These payment schemes could be forms of Vehicle Miles Traveled (VMT) or other schemes that are yet to be defined. Vehicle owners need only register with a single payment entity of their choice (a participating state, municipal, or regional DOT, an authority, or a private entity), and payments are reconciled by the entity receiving payment (and travel history) with all roadway owners that participate in the road use payment scheme, which may also include the Federal government. Vehicle owners would pay nothing for distances traveled where there are no payments required (e.g. in jurisdictions that have not implemented a distance based payment or for roadway operators that collect payment using traditional tolls), although a Federal payment rate might cover some or all roadway operations (a Federal policy decision). Basic operation depends on the vehicle tracking its own location, and periodically reporting its travel history to the registered entity receiving payment using connected vehicle communications.

Potential Benefits: Mobility Benefits for Drivers on Divided and Undivided Roads

Border Management Systems

Description: The Border Management Systems applications provide international border registration, pre-processing and border inspection capabilities. The registration and pre-processing cover electronic interactions between the border agencies and the fleet management agencies. The border inspection capabilities include electronic communications between the commercial vehicles, freight containers, and border inspection services.

Potential Benefits: Mobility Benefits for Drivers on Divided and Undivided Roads

Container Security

Description: The Container Security application uses container to infrastructure communications to allow security and public safety agencies to interrogate a container relative to its contents. The application also includes the capability to check the received container information against manifest information previously obtained through other clearance activities. This application is particularly relevant at ports and international borders. This application will also enable law enforcement and security agencies to identify container contents in support of security and incident response functions.

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

Container/Chassis Operating Data

Description: The Container/Chassis Operating Data (CCOD) application allows the commercial vehicle driver (and fleet operator) to monitor the operating status of their containers or chassis. The data monitored may include temperature, humidity, battery levels, etc. This application could be implemented through the power unit providing information for the containers or chasses directly to the commercial vehicle (e.g. a variation of a vehicle to vehicle interface), or the information could be transmitted from each container or chassis directly to the infrastructure (e.g. a container to infrastructure interface).

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

Electronic Work Diaries

Description: The Electronic Work Diaries application is designed to collect information salient to the operation of a commercial vehicle, to log driver activity (work), and to report that information to regulators as well as fleet managers, while operating under various privacy regimes including that of the fleet manager, the local government and the national government.

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

Intelligent Access Program

Description: The Intelligent Access Program application enables commercial vehicle operators simplified access to permit operations in exchange for remote compliance monitoring.

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

Intelligent Access Program - Mass Monitoring

Description: The Intelligent Access Program - Mass Monitoring application enables commercial vehicle operators simplified access to permit operations in exchange for remote mass monitoring.

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

Intelligent Speed Compliance

Description: The Intelligent Speed Compliance application uses the Global Navigation Satellite System (GNSS) to independently monitor the speed of a heavy vehicle and provide that information to regulatory authorities. It can be used to verity that commercial vehicles are not exceeding a set speed threshold, and/or to detect faulty speed limiter devices.

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

3.6 Smart Roadside Applications

3.6.1 Deployment Ready

Smart Truck Parking

Description: An application that will provide information such as hours of service constraints, location and supply of parking, travel conditions, and loading/unloading scheduling to allow commercial drivers to make advanced route planning decisions

Potential Benefits: Smart Roadside Benefits for Agencies and Drivers on Divided and Undivided Roads

DEPLOYMENT:	Colorado (testing), and Michigan (deployment)

3.6.2 Further Development

Smart Roadside Initiative

Description: The Smart Roadside Initiative (SRI) application describes a set of capabilities intended to improve the efficiency and safety of the Nation's roadways by providing for the exchange of important safety and operational information regarding commercial vehicles. SRI includes the delivery of capabilities related to wireless roadside inspections and electronic screening/virtual weigh stations, as well as the enabling capability of determining via electronic communications the commercial motor vehicle (CMV) identification. The wireless roadside inspection is defined by a safety screening capability that employs communications technologies to obtain information from a commercial vehicle that will allow safety screening of the vehicle and its driver. This capability provides for the interrogation at mainline speeds of a commercial vehicle when it has entered a control segment or geofenced area. Vehicle identification and driver information are provided to the roadside unit. The information communicated can be used to verify compliance with safety requirements, allowing a decision to be made regarding whether the vehicle should pull in to a roadside check station. A more advanced version of this application would download safety information measured on the vehicle including driver related information such as the driver log allowing real time evaluation that the vehicle and driver are meeting safety requirements. The electronic screening/virtual weigh stations capability employs communications technologies to obtain information from a commercial vehicle that will allow verification of permits or credentials for the vehicle. The capability provides for the interrogation at mainline speeds of a commercial vehicle when it has entered a control segment or geofenced area. Vehicle identification is provided to the roadside unit. Driver information may also be provided. The information communicated is used to verify compliance with credentials requirements, allowing a decision to be made regarding whether the vehicle should pull in to a roadside check station. This application can also be used to verify that the commercial vehicle meets vehicle weight (via weigh in motion capability) or dimension requirements. In this case sensors at the roadside measure the vehicle weight, length, or height and a pull-in request can be made if these do not meet requirements. One additional aspect of SRI, providing information on truck parking is described in the CVRIA by the Freight -Specific Dynamic Travel Planning application.

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

3.7 Agency Data Applications

3.7.1 Deployment Ready

Probe-enabled Traffic Monitoring

Description: This application utilizes communication technology to transmit real time traffic data to transportation management centers for monitoring and improvement of system-wide performance.

Potential Benefits: Agency Data Benefits on Divided and Undivided Roads

DEPLOYMENT:	THEA (deployment), Tennessee (planning), and Virginia (planning)

3.7.2 Deployment Near-ready

Vehicle Data for Traffic Operations

Description: The Vehicle Data for Traffic Operations (VDTO) application uses probe data information obtained from vehicles in the network to support traffic operations, including incident detection and the implementation of localized operational strategies. The implantation of incident detection enables transportation agencies to determine the location of potential incidents so the agencies can respond more quickly to the incident and mitigate any negative impacts to the transportation network. Vehicle data that can be used to detect potential incidents include changes in vehicle speeds indicating the disruption of traffic flow, when a vehicle's safety systems have been activated or deployed, or sudden vehicle turns or deceleration at a specific location (indicating a potential obstacle in the roadway). Operational strategies might include altering signal timing based on traffic flows or using vehicle data collected on the freeway mainline to employ speed harmonization or to optimize ramp metering rates.

Potential Benefits: Mobility Benefits for Agencies on Divided and Undivided Roads

Work Zone Traveler Information

Description: This application monitors and aggregates work zone traffic data.

Potential Benefits: Agency Data Benefits for Divided and Undivided Roads

DEPLOYMENT:	Pennsylvania (planning), and Virginia (planning)

3.7.3 Further Development

Probe-based Pavement Maintenance

Description: This application allows vehicles to automatically report potholes or other pavement anomalies.

Potential Benefits: Agency Data Benefits on Divided and Undivided Roads

Vehicle Classification-Based Traffic Studies

Description: This application would allow sorting of vehicle behavior data by vehicle type.

Potential Benefits: Agency Data Benefits on Divided and Undivided Roads

DEPLOYMENT:	Florida (planning), Tennessee (planning), and Virginia (planning)

CV-enabled Turning Movement & Intersection Analysis

Description: This application uses paths self-reported by vehicles to track turning ratios, delay, and other intersection metrics.

Potential Benefits: Agency Data Benefits on Divided and Undivided Roads

CV-enabled Origin-Destination Studies

Description: This application uses connected vehicle technology to monitor the beginning and end points of a vehicle's journey and extrapolate the route in between.

Potential Benefits: Agency Data Benefits on Divided and Undivided Roads

3.8 Core Service Applications

3.8.1 Deployment Ready

Security and Credentials Management

Description: Security and Credentials Management (SCM) is a support application that is used to ensure the trusted communications between mobile devices and other mobile devices or roadside devices and protect data they handle from unauthorized access. The application grants trust credentials to qualified mobile devices and infrastructure devices in the Connected Vehicle Environment so that those devices may be considered trusted by other devices that receive trust credentials from the SCM application. The application allows credentials to be requested and revoked, as well as to secure the exchange of trust credentials between parties, so that no other party can intercept and use those credentials illegitimately. The application provides security to the transmissions between connected devices, ensuring authenticity and integrity of the transmissions. Additional security features include privacy protection, authorization and privilege class definition, as well as non-repudiation of origin.

Potential Benefits: Connected Vehicle Support Benefits for Agencies on Divided and Undivided Roads

DEPLOYMENT:	Tampa, FL (deployment), and New York (planning)

3.8.2 Further Development

Core Authorization

Description: Core Authorization is a connected vehicle support application that manages the authorization mechanisms to define roles, responsibilities and permissions for other connected vehicle applications. This allows system administrators to establish operational environments where different connected vehicle system users may have different capabilities. For instance, some Mobile elements may be authorized to request signal priority, or some Centers may be permitted to use the geographic broadcast service, while those without those permissions would not.

Potential Benefits: Connected Vehicle Support Benefits for Agencies on Divided and Undivided Roads

Data Distribution

Description: Data Distribution is a support application that manages the distribution of data from data providers to data consumers and protects those data from unauthorized access. The application informs data providers of how to provide data, manages data subscriptions, and provides data forwarding capabilities. The application also maintains a directory of System Users that want data and supports multiple distribution mechanisms including publish-subscribe and directly from data provider to data consumer. The application allows data consumers to specify (and change the specification of) data they wish to receive.

Potential Benefits: Connected Vehicle Support Benefits for Agencies on Divided and Undivided Roads

Infrastructure Management

Description: Infrastructure management is a support application that maintains and monitors the performance and configuration of the infrastructure portion of connected vehicle. This includes tracking and management of the infrastructure configuration as well as detection, isolation, and correction of infrastructure service problems. The application also includes monitoring of performance of the infrastructure equipment, which includes the RSE as well as the communication link to back office functions.

Potential Benefits: Connected Vehicle Support Benefits for Agencies on Divided and Undivided Roads

Location and Time
Description: Location and Time is a support application that shows the external systems and their interfaces to provide accurate location and time to connected vehicle devices and systems.

Potential Benefits: Connected Vehicle Support Benefits for Agencies on Divided and Undivided Roads

Map Management
Description: The Map Management application defines interfaces that can be used download or update all types of map data used to support connected vehicle applications. This map data will be accessed by centers, field, and vehicle physical objects. The application can be used to harness the Connected Vehicle Environment to provide rich source data that can be used to verify, refine, and enhance geographic map data.

Potential Benefits: Connected Vehicle Support Benefits for Agencies on Divided and Undivided Roads

Object Registration and Discovery
Description: The Object Registration and Discovery application provides registration and lookup services necessary to allow objects to locate other objects operating within the Connected Vehicle Environment. This is a support application that enables other connected vehicle applications.

Potential Benefits: Connected Vehicle Support Benefits for Agencies on Divided and Undivided Roads

Privacy Protection
Description: Privacy Protection is a connected vehicle support application that provides the privacy protection essential to the operation of other connected vehicle applications. Privacy Protection obscures the network identifiers of mobile devices in order to allow communications with credentials management and other centers.

Potential Benefits: Connected Vehicle Support Benefits for Agencies on Divided and Undivided Roads

System Monitoring
Description: The System Monitoring application provides monitoring, management and control services necessary to other applications and/or devices operating within the Connected Vehicle Environment. These support services enable other applications to provide transportation services.

Potential Benefits: Connected Vehicle Support Benefits for Agencies on Divided and Undivided Roads

4. State Specific CV Applications and Advancements

This section provides a review of known, specific CV applications and CV program advancements across North America.

4.1.1 California

Integrated Dynamic Transit Operation (IDTO)
Under the sponsorship of California Department of Transportation (CalTrans), California Partners for Advanced Transportation Technology (PATH) has been conducting efforts developing an Integrated Dynamic Transit Operation (IDTO) System for multimodal suburban transit, in collaboration with Contra Costa Transportation Authority (CCTA) and Tri-Delta Transit.

Truck Platooning
PATH has been working on development of a cooperative adaptive cruise control (CACC) system for heavy trucks in collaboration with the Volvo Group since 2015, under the sponsorship of the FHWA Exploratory Advanced Research Program and CalTrans. The reports posted here describe the technical results of this research, which also led to public demonstrations in San Jose, CA (June 2016 during the ITS America Annual Meeting), at the Port of Los Angeles (March 2017) and on I-66 in the northern Virginia suburbs of Washington DC (September 2017).

Transport Canada supported two series of test track experiments to measure the fuel economy of this system at their Motor Vehicle Test Centre in Blainville, Quebec. The first of those experiments was conducted in October 2016, in

collaboration with the FHWA and Caltrans supported project and the second experiment was conducted in August 2017 in collaboration with PATH research sponsored by the U.S. Department of Energy's Energy Efficient Mobility Systems program.

Advanced Snow Plow Project (ASP) (1999-2000)
The ASP system functions include lane position indication, lane departure warning, and forward collision warning. Lane position indication and lane departure warning were developed by PATH using their embedded magnetic reference marker system for lateral position indication within the lane.

Integrated Collision Warning System (2000)
Based on the foundation of the frontal and side collision warning systems, the Frontal Collision Warning System (FCWS) and Side Collision Warning System (SCWS) teams joined efforts to improve the collision warning algorithms. The objective of the ICWS Program is to study how frontal and side collision warning system might interface with each other, and to develop prototype ICWS systems on two buses, one at Samtrans and the other at PAT.

4.1.2 Colorado

Smart Truck Parking (Pre-Pass, Cellular and DSRC)
Using detection and cloud-based software that understands and can report available parking spots to truckers will improve:

- Truckers' time and fuel consumption;
- Excess wear and tear on Colorado's roadways; and
- Excess pollution.

The first phase of this project will integrate six existing parking facilities into the Smart Truck Parking System.

Smart 70 Project
Colorado Department of Transportation (CDOT) has partnered with an international mapping firm, HERE, to provide drivers the most real-time data possible to allow them to make better decisions when traveling through the mountains. The SMART 70 Project will establish a robust communication system along the I-70 Mountain Corridor to provide drivers, and ultimately self-driving vehicles, with real-time information about road conditions such as traffic delays, icy conditions and crashes. The initial phases of the Smart 70 project will focus on transforming vehicles commuting on I-70 into “connected vehicles” that can send and receive information to drivers about road conditions from other vehicles, CDOT systems and sensors installed along the roadway.

4.1.3 Florida

Driver Assisted Truck Platooning (DATP)
The Florida Department of Transportation’s Florida Turnpike Enterprise will be conducting the first state sponsored pilot test in the CV/AV realm in Florida in response to an opportunity established by the Florida House Bill 7027 (2016) to study the use and safe operation of the technology. The project includes a study and pilot test that will run truck platoons using proven and safe connected V2V technology in a 143-mile segment of the Turnpike Mainline (SR 91) from Orlando to Palm Beach. This segment is specifically selected as a proving ground to test the technology mainly because it serves as one of the segments of the Turnpike System with the largest movements of trucks. Medium and long-term goals for DATP is to expand testing to the interstate system in Florida and have a southeast multistate corridor. Areas of research include safety and fuel savings to prepare for a potential commercial deployment.

Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD)
The Central Florida received an $11.9 million grant from the Federal Highway Administration (FHWA) to advance several Transportation Systems Management and Operations (TSM&O) technologies aimed at improving safety and easing congestion. Combining the $11.9 million grant with local investments, CEOC is a $65 million project comprised of three interrelated programs that connect through an ongoing FDOT initiative, SunStore. Those three programs include PedSafe, GreenWay, and SmartCommunity.

This project sets the stage for implementation in the City of Orlando, throughout Central Florida, and around the country. This deployment can tie into Sunrail, LYNX, Juice, Uber, and Lyft for modal choice; autonomous shuttles in downtown; and existing city efforts in parking management.

PedSafe
PedSafe will connect advanced signal controller capability, use Connected Vehicle technologies, and existing communication capabilities to reduce the occurrence of pedestrian and bicycle crashes. The application will be easily transferable throughout the country. This system will also be tested in the Pine Hills, a community that has faced significant challenges with pedestrian safety.

GreenWay
GreenWay is designed to better utilize the multimodal transportation system by actively managing over 1,000 traffic signals within the region. This will make travel times more consistent and help reduce congestion.

GreenWay will use sensors and new traffic signal technology to help the transportation system quickly adapt to real-time traffic conditions. This is expected to make travel times more consistent and help reduce congestion. The project will connect Advance Sensor Technology, Conditional Transit Signal Priority, Adaptive Deployment Traffic Signal Interface with Track Positive Train Control (SunRail), Smart Parking Technology with Signal Performance Metrics, expand Integrated Corridor Management, and Signal Control Analytics and Visualization.

SmartCommunity
SmartCommunity is an integrated program that connects people to the places they need to go and provides them with the services they need to receive. This includes travel time information for driving, riding the bus, taking the train, or using rideshare and/or car share.

Through a Mobility on Demand framework, SmartCommunity leverages existing ridesharing and car sharing products to offer residents access to cars when required. SmartCommunity will allow travelers in the same area to share information and coordinate trips to destinations such as employment centers, education facilities, the grocery store, and medical treatment centers. SmartCommunity will have a benefit for low income and underserved populations in the area and help connect the community to the region.

I-75 Florida's Regional Advanced Mobility Elements (FRAME)
The I-75 FRAME (Florida's Regional Advanced Mobility Elements) project is located on the I-75 and US 301/441 corridors, connecting east-west Divideds between these two corridors. The purpose of this project is to reroute the I-75 traffic during emergencies and incident managements to US 301/441 using east to west Divideds as SR 500, SR 200 and SR 40. These efforts are part of the 2016 Central Office ATCMTD application to lessen the recurring and non-recurring congestion on I-75 between Gainesville and Wildwood/Ocala region. The project length comprises of FDOT Districts 2 and 5 jurisdictions where the northern and southern areas of this regional effort are located. Each District will lead the efforts of their areas which will deploy CV Technologies to better manage, operate, and maintain the multi-modal system and create an integrated corridor management solution. This includes the deployment of Automated Traffic Signal Performance Measures (ATSPM); RSUs and on-board units (OBUs); transit signal priority (TSP); pedestrian safety elements, and adding fiber optic cable on US 301/441 gaps. The emerging technologies proposed in this project are Automated Traffic Signal Performance Measures and Connected Vehicle technologies such as Roadside Units and On Board Units for effective traffic operations; Transit Signal Priority and Freight Signal Priority. The goal of the project is to disseminate real-time information to the motorists during freeway incidents.

AV/CV/ITS Freight Applications
This pilot project will follow a three-phase approach to measure, deploy and prioritize portions of the perishable-goods delivery supply chain. The perishable freight industry is a significant contributor to the economy of Miami-Dade County. Drayage trips of perishables from Miami International Airport (MIA) operate almost continuously 365 days per year. AV technologies can enhance safety and improve efficiencies of the movement of goods on these highly repetitious freight routes.

- During Phase 1, connected vehicle (CV) technologies will be deployed to allow fleet operators and FDOT to better understand vehicle progression throughout delivery corridors and where bottlenecks occur at traffic signals.

- During Phase 2, utilizing the same installed CV devices from Phase 1, the next phase will connect the freight vehicles to traffic signals through the back-end systems at the Miami-Dade County Traffic Management Center.
- During Phase 3, during non-peak congestion hours, traffic signal priority will be granted to study vehicles in the pilot to improve delivery performance by providing the freight vehicle with a green signal. A preliminary analysis showed that a vehicle leaving MIA, traveling along Northwest 25th Street, with a destination at 1500 NW 70th Ave., resulted in a total travel time of just over 30 minutes (2.5 miles). The same vehicle could make the same trip in 8.5 minutes if given additional green time along this corridor. Reduction in travel time directly results in better on-time delivery performance, as well as savings in fuel use and greenhouse gas emissions.

Bike and Pedestrian Safety

FDOT applied for the Federal Accelerated Innovation Deployment (AID) Demonstration program in April 2017 to pilot connected vehicle and pedestrian/bicyclist safety applications (active or passive) at 13 signalized intersections and seven mid-block crossings within the core of the University of Florida (UF) campus. The goal of this project is to reduce pedestrian and bicycle crashes and conflicts with vehicles and transit. The routes are SR 26 (University Avenue), US 441 (SW 13th Street), Museum Road, and Gale Lemerand Drive. The project will install at least 20 roadside units (RSU) and 20 passive pedestrian detection systems on these corridors for testing. The project will be led by UF and will consist of before and after analysis. The following will be tested during this project:

- Passive pedestrian/bicyclist detection at all locations via detection technologies
- Real-time notification to transit, motorists, and pedestrians/bicyclists
- Signal phase and timing data broadcasting with active pedestrian/bicyclist detection via RSUs

4.1.4 Maricopa County, Arizona.

Maricopa County DOT SMARTDrive Program
Maricopa County Department of Transportation (MCDOT) constructed a test bed in Anthem, Arizona to test the MCDOT SMARTDrive Program's vehicle prioritization technology in 2011. It was one of the first seven test beds in the country. The Arizona Connected Vehicle program has now expanded its testing to include new applications such as a pedestrian traffic signal crosswalk application, transit priority application and a trucking priority application. In the future, the Arizona Connected Vehicle Consortium hopes to expand its program even further by testing these applications in "real world" scenarios where residents and businesses in Maricopa County can participate.

The national Connected Vehicle Pooled Fund selected the Anthem Test Bed, along with the California Department of Transportation (CALTRANS) test bed, to deploy and test the USDOT MMITSS application. Connected vehicle systems are also being programmed into other projects including the recently awarded FHWA ATCMTD grant for the Loop 101 Integrated Smart Corridor project and the freight signal priority system on Maricopa County 85 Road (MC 85) that consists of nineteen signalized intersections.

The applications being tested include MMITSS. The roadside units (RSUs) in the test bed run the Multi-Modal Intelligent Traffic Signal System (MMITSS) that provides intelligent signal control (I-SIG), priority for emergency, transit, and freight vehicles (EVP, TSP, and FSP) and a pedestrian smartphone application (PED-SIG) that improves access to pedestrians, especially disadvantaged (blind) pedestrians. Each traffic signal broadcasts MAP and SPaT (signal phase and timing) messages and can provide priority for properly equipped vehicles. MMITSS has been developed and tested as part of the Connected Vehicle Pooled Fund study by a team lead by the University of Arizona. In addition, other vehicle-to-infrastructure (V21) applications have been developed and tested including vehicle-to-vehicle (V2V) emergency vehicle alert and roadside alerts- including work zone, incident and school zone alerts.

4.1.5 Michigan

Signal Phasing and Timing SPaT Operational
A total of 9 intersections along a 4.5 mile corridor serving as a testbed for SPaT, MAP, TIM and BSM related Connected and Automated Vehicle applications.

I-94 Truck Parking Information and Management System
Truck Parking Information and Management System (TPIMS) delivers real-time parking availability information to truck drivers along the I-94 corridor. Commercial traffic accounts for 23 to 30 percent of all traffic on I-94 in southwest Michigan, some of the highest commercial volumes in all of the Midwest. Drivers will be notified through dynamic roadside truck parking signs, websites, smartphone apps, and connected vehicle equipment.

Ann Arbor Connected Vehicle Test Environment
The information gathered from this study can be used for certain safety applications – such as collision warning systems – sustainability initiatives. Connected vehicle technology allows vehicles to communicate wirelessly with similarly equipped vehicles and with portions of the infrastructure – such as traffic signals. AACVTE is a $13 million, federally-funded project being conducted and operated by The University of Michigan Transportation Research Institute.

4.1.6 Minnesota

Connected Corridors - Snow Plow Signal Priority System
The Snow Plow Signal Priority (SPSP) system would provide plows the ability to request extended green or early green phases at traffic signals along snow plow routes via DSRC. Minnesota Department of Transportation (MnDOT) plans to deploy SPaT at approximately 20 traffic signals along corridors between I-494 and I-94. Two deployment locations have been elected, TH-55 and I-394, each offering a different scenario for application of the SPSP. Along TH-55, signal priority would be given to plows as they approach mainline signals. Deployment on I-394 would occur at interchange signals and ramp meters along the corridor, allowing plows clearing exit and entrance ramps to operate more efficiently. Related projects include:

- Connected Corridor V2I Design, Install, and Integrate
- Connected Corridor Evaluation
- Connected Corridor Security Credentials

Cooperative Intersection Collision Avoidance Systems (CICAS)
The CICAS initiative focuses on determining the optimal combination of infrastructure and in-vehicle systems needed to address a full range of intersection crash problems. CICAS integrates two types of intersection collision avoidance systems: infrastructure-based and vehicle-based. Infrastructure-vehicle cooperative systems, which comprise the bulk of the CICAS future research, unify infrastructure and in-vehicle systems to give drivers the best possible information to help avoid a collision.

Development and Demonstration of a Cost Effective In-Vehicle Lane Departure and Advanced Curve Speed Warning System
A goal of the study would determine how to appropriately capture the attention of potentially distracted drivers and reduce the speed of drivers approaching at dangerous speeds. Another priority would be to determine the distances ahead of the curves at which the warnings should be deployed to provide sufficient, but not pre-emptive, notice to allow drivers to safely reduce speeds. The work would complement other on-going work in Minnesota to develop a cloud-based Vehicle-to-Infrastructure repository of pertinent roadway information (e.g. work zone notifications and warnings), which could be communicated to drivers via their smartphones.

Use of Connected Vehicle Data in Road Weather Applications
Snow plows collect road weather information and transmit it to a server via DSRC as part of the Integrating Mobile Observations Phase 3 federally funded project.

University of Minnesota Eco-Driving Research
Uses a real drive train in a lab tied to a real vehicle in the field to measure benefits of connected vehicle eco-driving.

4.1.7 New York

Drivewyze Program
Drivewyze serves commercial drivers and fleets with innovative trucking apps such as Drivewyze PreClear, a weigh station bypass solution that's delivered through smartphones and tablets, as well as integrated into leading fleet mobility technology leaders such as Omnitracs, PeopleNet, Rand McNally and Zonar. Future Connected Vehicle Applications include:

- NYSDOT led an effort with Drivewyze to identify and geofence commercial vehicle rollover and crash hotspot location data in NYS
- NYSDOT also developed in-vehicle safety message design recommendations and presented to Drivewyze for eventual integration as driver warnings

New York State (NYS) Commercial Vehicle Screening Program
The commercial vehicle screen program deploys infrastructure technologies and vehicle technologies to perform tasks such as:

- License plate recognition and overview camera systems and 915 MHz and 5.9 GHz dedicated short range communications (DSRC) to uniquely identify the commercial vehicle
- Weight-in-Motion (WIM) devices to determine vehicle class, length, axle distances, axle weights and gross vehicle weight, capable of meeting Federal Highway Administration's (FHWA's) traffic monitoring data requirements
- Other technologies to supplement the above core components, depending on the location, including United States Department of Transportation (USDOT) number reader systems, over-height detection, and real-time traffic monitoring

Commercial Vehicle Infrastructure Integration
The Commercial Vehicle Infrastructure Integration (CVII) program focuses on developing, testing, and deploying connected vehicle technology for heavy vehicles. Since its inception, the CVII program has developed numerous vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications for trucks that leverage communication with roadside infrastructure and other light and heavy-duty vehicles to meet the objectives of the program.

Niagara International Transportation Technology Coalition: Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD)
Application developed by the Niagara International Transportation Technology Coalition using multiple communications technologies to alert truckers of border wait times and available parking to reduce congestion in the Buffalo-Niagara Region. The Niagara Frontier Transportation Authority received a $7.8 million grant from FHWA ATCMTD program to fund the project Connected Region: Moving Technological Innovations Forward in the Niagara International Transportation Technology Coalition (NITTEC) Region.

4.1.8 Pennsylvania

Smart Belt Coalition
A coalition formed between Pennsylvania, Michigan, and Ohio Department of Transportations and research institutions to develop and applications for commercial truck traffic. The coalition is developing its strategic plan which initially focuses on:

- Connected and automated applications in work zones, including uniform work-zone scenarios offering consistency for testers as well as technologies offering better information to motorists.
- Commercial freight opportunities in testing, including platooning (connecting more than one vehicle) and potential coordination on interstates.

- Incident management applications providing better information to and infrastructure for emergency responders and other agencies.

Connected Vehicles for Emergency Response Vehicles and Trucks
The Pennsylvania Department of Transportation and the National Operations Center of Excellence (NOCoE) participated in a demonstration on how Connected Vehicle technologies will benefit emergency responders. This demonstration, held at Penn State's Larson Institute test track featured two demonstrations: the Volvo Connected Truck and its automatic engine breaking system when approaching an incident scene, and Southwest Research Institute's Emergency Vehicle Alert application, installed on a rental car and ambulance.

I-76 Corridor Management Project
The first phase of the plan includes installing a series of Variable Speed Limit (VSL) and Queue Warning (QW) systems on I-76 in Montgomery County. The VSL systems will display regulatory speed limits that can change based on real-time expressway, traffic, and weather conditions to improve traffic flow and safety by warning drivers of changing travel conditions. The QW systems will be deployed to provide real-time displays of electronic warning messages to alert motorists of significant slowdowns ahead to reduce sudden stopping and the potential for rear-end crashes.

Technologies include Variable Speed Limits, Queue Detection/Warning, Dynamic Junction Control, Flex Lanes, and Ramp Metering. Multimodal improvements and proactive management of traffic signals along adjacent corridors are also part of the ICM Program.

4.1.9 Texas

Austin DSRC Pedestrian Pilot
In the state's capital city, a pilot will link pedestrians crossing a street to connected vehicles. If a pedestrian goes to a button to cross at the crosswalk, that button will be linked to the DSRC equipment and send a message to the approaching Capital Metro bus that a pedestrian is about to cross in the crosswalk.

The signalized corridors along the boundary of campus will be used to test vehicle-to-infrastructure (V2I) communications to promote the safety of not only drivers, but also the substantial populations of pedestrians, bicyclists, and transit riders.

4.1.10 Transport Canada

Cooperative Truck Platooning Systems (CTPS)
Four tractor-trailer combinations were used as part of the fuel-economy tests: the three identical test vehicles with the CACC control systems, and a control vehicle. Auxiliary fuel tanks were installed on the vehicles to permit direct measurement of the fuel use during each measurement run using a gravimetric fuel-weighing procedure. Phase I Track Testing includes:

- Examine impact of separation distances, speeds, weights and tractor configurations on fuel economy
- Prototype system tested based on Cooperative Adaptive Cruise Control between multiple vehicles using 5.9 GHz DSRC-based V2V and forward sensors to maintain constant distances between vehicles

Phase II Track Testing includes

- Measure effect of: non-platoon traffic (ambient and cut-ins); Canadian configurations (longer and heavier trucks); and separation distances (4 to 50m)

4.1.11 Virginia

Truck Platooning Cooperative Adaptive Cruise Control (CACC)
The Federal Highway Administration conducted the first of a two-day demonstration of three-truck platoons on I-66 in Centreville, Va., several miles outside the nation's capital. The results of a four-year research project to test the effectiveness of state-of-the-art driving and communications technologies were showcased at the event.

Virginia Connected Corridor (VCC) Open Cloud Computing Environment
The VCC Cloud Computing Environment provides a centralized system that supports the management of CV message traffic between research entities interacting on the corridor.

VCC Monitoring Application
The VCC Monitoring Application, is a Mission Control Function that provides situational awareness for monitoring corridor activity and events. The tool includes a map with detailed overlays that monitor and display the following information that are generated or used within the VCC environment include:

- RSE location and communication status
- Active Traveler Information Message postings
- CV/RSE DSRC interaction
- Vehicle speeds and brake state
- General traffic speeds (from Google)
- Dynamic Message Sign locations

Traveler Information Message Generator and Manager
The Traveler Information Message Generator interfaces within the Cloud Computing Environment and provides the ability to manually create and post Traveler Information Messages (TIMs). The TIMs are based on the J2735 SAE standard that is designed to enable the broadcast of messages to vehicles based on location and relevant traveler information.

VCC Mobile Application
A mobile application has been developed that can be downloaded on Android smartphones initially and is intended to exercise and test the capabilities of the VCC. The app can use both cellular and DSRC communications. Because it supports users with cellular service only (no access to DSRC), the basic capability works statewide. It is intended that the application will support TIM and custom messaging through a user interface that includes visual and audio indications. Initial functions include:

- Work Zone Details
- Weather Advisories
- Traffic Incidents
- Dynamic Message Sign Content (active messages)
- Driver Reported Issues

The mobile app is expected to be expanded to include multiple CV functional applications.

SmarterRoads.org Data Portal
This portal will support advances in V2V and V2I communications that promise to improve the safety and mobility of users of transportation systems.

4.1.12 Washington

WSDOT CAT Pilot Projects Winter Operations
Using various connected vehicle technologies, WSDOT shared data from snow plows and other data sources to inform motorists of road and adverse weather conditions.

WSDOT CAT Pilot Projects Traffic Signals (AASHTO SPaT Challenge)
Traffic signals testing how existing WSDOT signal systems can better communicate with vehicles to improve intersection safety and timing as well as overall traffic operations.
Initial locations planned for DSRC CV Technology Deployment 2 Locations along US 2 North the City of Spokane

5. Automated Vehicles

An assessment of the deployment state of automated vehicles (AV) in locations throughout North America is provided below.

5.1.1 Passenger Car

Automated passenger cars are being tested in a variety of states including:

- Arizona (AV vendors testing include Waymo);
- California (Agencies testing include City of San Diego, City of San Francisco, City of Sacramento [planned], City of Palo Alto, and AV vendors testing include Waymo, Lyft, Apple, Phantom Auto, Cruise Automation by GM, Nissan, Delphi, Bosch, BMW, Mercedes, Ford, Tesla, Honda, and Volkswagon);
- Colorado (AV vendors testing include Ford);
- Florida (Agencies testing include The Village; AV vendors testing include Voyage);
- Georgia (AV vendors testing include Waymo);
- Michigan (AV vendors testing include Waymo, Fiat Chrysler Automobiles (FCA), Ford, General Motors, Hyundai, Mercedes Benz, Nissan, Subaru, Toyota, and Uber);
- New Jersey (AV vendors testing include Nvidia-Uber [currently discontinued]);
- New York (AV vendors testing include Audi [currently halted], and Cruise Automation by GM [planned]);
- Texas (AV vendors testing include Waymo, Drive.ai, and Audi);
- Transport Canada (Agencies testing include City of Ottawa; AV vendors testing include Blackberry's QNX); and
- Washington (AV vendors testing include Waymo, and TORC Robotics).

5.1.2 Shuttle

Automated shuttle services are being tested in a variety of states including:

- California (Agencies testing include Contra Costa Transportation Authority, City of San Ramon, City of San Jose [planned], City of San Francisco, California Public Utilities Commission (Planned), and City of Concord; AV vendors testing include Easy Mile, and AutoX);
- Colorado (Agencies testing include Colorado DOT, and the City of Denver; AV vendors testing include Easy Mile);
- Connecticut (Agencies testing include Connecticut DOT);
- Florida (Agencies testing include Gainsville Autobus, and Downtown Tampa Autonomous Transit);
- Maryland (AV vendors testing include STEER Tech);
- Michigan (Agencies testing include University of Michigan, and the City of Ann Arbor; AV vendors testing include Navya, and May Mobility);
- Minnesota (Agencies testing include MnDOT; AV vendors testing include Easy Mile);
- Nevada (Agencies operating in Las Vegas)
- Pennsylvania (Agencies testing include the City of Pittsburgh);
- Tennessee (Agencies testing include City of Nashville [planned]; AV vendors testing include Olli);
- Texas (Agencies testing include City of Austin, Texas Innovation Alliance, City of Houston, City of San Antonio, City of Arlington, and City of Frisco; AV vendors testing include Easy Mile);
- Transport Canada (Agencies testing include City of Calgary, City of Edmonton, City of Montreal (planned), and City of Toronto (planned); AV vendors testing include Easy Mile);
- Washington (Agencies testing include Pierce County, City of SeaTac (planned), and City of Seattle (planned); AV vendors testing include Mighty AI); and

- Wisconsin (Agencies testing include University of Wisconsin–Madison; AV vendors testing include Navya).

5.1.3 Commercial Trucks

Automated commercial trucks are being tested in a variety of states including:

- Arizona (AV vendors testing include Waymo, TuSimple, Uber [currently discontinued]);
- Colorado (Agencies testing include Colorado DOT);
- Georgia (AV vendors testing include Waymo);
- Minnesota (Agencies testing include MnDOT); and
- Texas (Agencies testing include North Central Texas Council of Governments [NCTCOG]; AV vendors testing include Navistar).

6. State Specific AV Applications and Advancements

This section provides a review of known, specific CV applications and CV program advancements across North America.

6.1.1 California

Vehicle Assist and Automation (VAA) systems
Automated, predictable curb access enables transit buses to achieve rail-like quality of service and improve operational efficiencies through tighter scheduling. Vehicle Assist and Automation, or VAA, has been implemented onto Bus Rapid Transit, enabling buses to stop in fixed locations every time. Improved reliability and service make automatically guided buses a more attractive transit option for travelers of all types. The system is currently in field operational testing in Oregon and California.

Development of the Advanced Rotary Plow (ARP) for Snow Removal Operations (2006)
This project demonstrated an Advanced Rotary Plow (ARP) with automatic steering that allows the ARP to follow magnets embedded in the pavement. This project is one of the first real-world applications derived from PATH/Caltrans research in the area of automated vehicle control. A modified snowblower with add-on sensors, actuator, computer and driver interfaces was developed, and initial field tests were conducted along the 8 guardrail sections between Kingvale and Soda Springs on the shoulders of Interstate-80 near Donner Summit.

6.1.2 Colorado

Automated Truck Commercial Delivery
Colorado (Colorado Department of Transportation, Colorado State Patrol and Department of Revenue) partnered with Otto of Uber to demonstrate self-driving technology using advanced safety solutions for approximately 120-mile real-world environment of Colorado that will help Colorado move toward zero deaths on our roadways. Colorado is enthusiastic about working with Otto and others on:

- The long-term impacts and benefits of safely deploying this technology to enhance safety
- Improving environmental impacts of highway freight
- Foster the economic benefits advanced driving technologies are poised to bring to freight delivery and our state

Develop Communication Infrastructure for CV and AV to Share Road and Safety Data
The Colorado Department of Transportation (CDOT) has partnered with Panasonic to build an ecosystem for connected transportation where smart vehicles, self-driving vehicles, and infrastructure share instantaneous data and information about road and safety conditions, eventually reducing crashes by 80 percent, quadrupling the capacity of our highways, and dramatically improving travel time reliability. In fewer than 10 years, it's expected that up to 4 million vehicles in Colorado will be "talking" to each other and to the roadway infrastructure.

First and Last Mile Connection Pilot
The Colorado Department of Transportation, the City and County of Denver and the Regional Transit District are planning the deployment of EasyMile's autonomous shuttles in spring 2018. The driverless vehicle program will connect a light rail station to bus routes to provide a first- and last-mile solution for commuters.

Autonomous Vehicles to Improve Worker Safety
The Colorado Department of Transportation will use a self-driving Autonomous Impact Protection Vehicle (AIPV), as a barrier to protect highway workers. Crash protection vehicles are generally large lumbering garbage-truck-like vehicles equipped with bright yellow crash bumpers. They function as moving barriers to keep workers on the other side of them safe from careening cars. The AIPV, developed by Royal Truck & Equipment along with Kratos Defense and Security Solutions and Colas UK, takes the driver out of the truck, which is equipped with autonomous vehicle technology. The AIPVs are connected electronically to the human-driven lead truck. The autonomous system is accurate to within four inches, said DOT officials.

Autonomous Vehicle Lane
An autonomous vehicle lane and L.A.-style 10-lane stretches are among the ideas that CDOT is considering as part of a plan to address future congestion along C-470 through Morrison, US 6 thru Golden and along Colorado 93 between Golden and Boulder.

6.1.3 Florida

Assessing Advanced Driver Assistance Systems (District 7 – Tampa Bay Area)
The FDOT's Automated Vehicles Initiative is collaborating with FDOT District 7 to determine if the MobilEye technology provides value in preventing avoidable traffic accidents. The crux of the project includes the installation of MobilEye's Advanced Driver Assistant System (ADAS) on about 50 vehicles in the Tampa Bay area. Study vehicles in this pilot project include FDOT District 7 sedans and light trucks as well as buses, vans, and sedans operated by Hillsborough Area Regional Transit, Tampa Bay Area Regional Transit Agency, Pasco County Public Transportation , and the Pinellas Suncoast Transit Authority.

The MobilEye device includes one forward looking camera and a LED display to provide visual and audible warnings to the vehicle operator of eminent forward collisions, lane departure alerts, and pedestrian/bicycle detection. The MobilEye device does not utilize Global Positioning System (GPS) technology and does not track vehicle movement. A telematics system, provided by GeoTab, is installed on each vehicle to measure the effectiveness of MobilEye's safety enhancements. In order to provide a benchmark for performance measurement (comparative analysis), an additional 50 vehicles received only installation of the GeoTab device.

If the warnings provided by the MobilEye devices allow FDOT vehicle operators to prevent collisions, thereby reducing costs associated with collisions, ADAS systems may be recommended for wide-scale adoption by FDOT.

Driverless Taxi Services (Voyage) at The Villages
Voyage is starting to expand its driverless taxi service beyond a small test in the Villages, a gated community of about 4,000 residents where the average age is 76. Retirement communities, with their tightly controlled roads, can be an ideal proving ground for autonomous vehicles. In the Villages, there are 15 miles of roads where autonomous vehicles can learn how to navigate other cars, pedestrians, golf carts, animals, roundabouts and many other obstacles.

Voyage is bringing a door-to-door self-driving taxi service to the 750 miles of road at The Villages. When fully operational, all 125,000 residents will have the ability to summon a self-driving car to their doorstep using the Voyage mobile application, then travel anywhere within the bounds of the community fully autonomously.

Downtown Tampa Autonomous Transit
Marion Street is a north and south running roadway in the center of downtown Tampa. Between the hours of 6am and 7pm on weekdays, the corridor is for exclusive use of buses and emergency vehicles, and therefore offers an opportunity to operate a low-speed, autonomous last-mile shuttle service out of mixed traffic. The service would address mobility needs downtown by connecting the Marion Transit Center and parking to employment, and act as a catalyst for further autonomy in transportation throughout the Tampa Bay region.

Autobus Transit System
This project will deploy an autonomous transit system to connect the City of Gainesville Innovation District and downtown with the University of Florida campus and student housing by means of frequent transit service. The goal of the Gainesville Autonomous Transit Shuttle (Autobus) is to maintain a maximum headway of 10 minutes or less for the buses. Autobus routes include SW 4th Avenue, SW 13th Street, SW 2nd Avenue, and S Main Street. The project is anticipated to complete deployment by late 2018.

6.1.4 Georgia

Google (Waymo) Automated Freight Deployment in Atlanta
Waymo is testing a fleet of autonomous freight trucks in Atlanta that will take deliveries to Google's data centers.

City of Chamblee- Self-Driving Shuttle
As part of the Georgia Smart Communities Challenge, this project studies the feasibility and deployment of Shared Autonomous Vehicles (SAV), a cutting-edge approach to public transportation.

6.1.5 Maryland

STEER Tech Automated Vehicle Testing
STEER Tech's initial permits allowed testing at an MDOT State Highway Administration Park and Ride lot and an MDOT Maryland Transit Administration parking lot. The company has been continually testing since permit issuance and is now testing at the Baltimore-Washington International Thurgood Marshall Airport Parking Garage.

6.1.6 Michigan

Self-Driving Shuttles
Self-driving shuttles have been deployed in Mcity (the University of Michigan) and in downtown Detroit. The project, Mcity is examining how passengers react to the driverless shuttles, in an effort to measure consumer acceptance of the technology. The shuttles will transport Quicken Loans' employees in a circuit between their offices, parking sites and company events.

6.1.7 Minnesota

Automated Shuttle Bus Pilot Project
The vehicle underwent a series of winter weather conditions at MnDOT's MnROAD facility near Monticello from December 2017 through March 2018. This closed loop facility (not open to other traffic) allowed for safely testing the vehicle in snow, ice, cold weather and salt covered road conditions. MnDOT worked with 3M, Easy Mile and First Transit to operate and test the vehicle at MnROAD and other locations around the state.

Automated Truck Pilot Project
A RFI has been issued for an automated truck pilot project.

6.1.8 Pennsylvania

Autonomous Shuttle Network
Smart Pittsburgh (SmartPGH), partnering with U.S. Department of Transportation (USDOT), Carnegie Mellon University (CMU), and Uber, plans to connect neighborhoods through accessible, energy-efficient automated transportation. A new transit-only cartway will be built through Schenley Park, replacing and improving some of the city park's pedestrian and cyclists trails, and providing a unique solution to Greenfield and Hazelwood's frequently flooded infrastructure.

Smart Spine Corridors
SmartPGH, to connect Pittsburgh's dense employment areas, is deploying advanced technology like real-time adaptive traffic signals and vehicle-to-vehicle communication at key intersections. It provides the foundation for connectivity and automation that will improve mobility and make streets safer for pedestrians, cyclists, and motorists.

6.1.9 Texas

Texas Automated Vehicle Application Proving Ground Partnership (USDOT Designated Site)
Urban and freight automation applications are being tested in real-world environments at the following cities:

- Austin Area — Austin-Bergstrom International Airport and Riverside Drive corridor
- Houston Area — Texas Medical Center, Houston METRO HOV lanes, and Port of Houston
- Dallas/Fort Worth/Arlington Area — UTA campus, Arlington streets, I-30 corridor and Managed Lanes
- San Antonio Area — Fredericksburg Road/Medical Drive corridor and bus rapid transit system
- El Paso Area — Tornillo/Guadalupe Port of Entry

Texas A&M University System RELLIS Campus
At the RELLIS campus, automated vehicle and connected topics being researched include Truck Platooning Research, Autonomous Vehicle Safety, Unmanned Vehicle Systems (Federal Aviation Administration [FAA] designated unmanned vehicle system [UAS] test site). Texas A&M University is home to the Center for Autonomous Vehicle and Sensor Systems (CANVASS). CANVASS is the only center at a U.S. university that addresses all of autonomous underwater, ground, air, and space systems and their sensors. The strategic research goal of CANVASS is to establish trust in autonomous systems so that they interact with humans and their environment safely, reliably, and predictably to mutually accomplish desired missions and tasks.

Southwest Research Institute (SwRI)
For the past 10 years, SWRI has been testing AVs at its proving grounds in San Antonio. The institute has automated more than 15 different vehicles that have already been deployed in five countries on four continents, including vehicles outfitted for military applications that were deployed in Afghanistan. Core capabilities include:

- Vehicle system integration – partially or fully integrated actuation, sensors, computing, networking and other hardware into numerous vehicles.
- Vehicle control – custom control of one or both the steering and speed.
- Localization – hardware and software solutions to provide the required levels of accuracy and reliability for various automated driving applications.
- Perception – perception techniques for all of the common sensors found in AVs, including cameras, LIDAR, and radar.
- Path Planning – custom path planners for different applications that range from high precision and repeatable path following, to exploratory path planning in unconstrained environments.
- Tasking and Routing – software to allocate and schedule tasks for cooperative vehicles. This framework allows for customization to the needs of specific applications, such as automated trailer spotting.
- User Interface – User interfaces used on different kinds of devices (laptops, tablets, smart phones, etc.).

City of Austin and Capital Metro's Smart Mobility Roadmap
Austin Transportation and Capital Metro are preparing for a pilot of Direct Short Range Communications (DSRC), the current communication standard proposed by the federal government.

Austin Transportation, Capital Metro and the Rocky Mountain Institute (RMI) are also teaming up to pilot automated shuttles in the Austin area. A first effort will improve public awareness of the coming technologies and allow evaluation of its capabilities for use in multiple settings. The applications can range from first and last mile to support transit needs, to airport or large development transportation.

The Austin City Council recently approved the use of sidewalks for the priority of delivery bots. Pilots will test delivery robots in select neighborhoods to determine use rates and identify infrastructure issues. Vehicles tested include Taxibot, Driverless Shuttle, Deliverybot, and Freight.

Two-Truck Automated Platoon Test
Electronic component distributor TTI hosted a first-of-its-kind two-truck platooning technology demonstration at The Texas A&M University System RELLIS Campus. The system successfully executed all platooning scenarios planned for the demonstration.

Austin INRIX AV Road Rules
Austin is joining select cities and transportation agencies around the world to pilot a new autonomous vehicle deployment platform called INRIX AV Road Rules. Connected car services and transportation analytics provider INRIX announced the platform today as a foundation for cities and road authorities to communicate with operators for the safe and effective deployment of highly automated vehicles on public roads.

Drive.ai
Drive.ai, a self-driving startup based in California, is operating fully driverless vehicles without safety drivers on public roads in Frisco, a suburb outside Dallas-Forth Worth. With a push of a smartphone app, the approximately 10,000 employees who work at offices at Hall Park will be able to request a ride to shops and restaurants near The Star in Frisco. They'll be picked up by a self-driving car that will travel a little under a mile to their destination.

Easy Mile (Milo)
Milo operated until August 2018 on off-street trails in the Entertainment District, providing free rides to visitors and citizens at over 110 events. For $272,000, the city of Arlington leased two low-speed shuttles, each with a dozen seats and an operator who provides information and is a backup in case the shuttle has to go into manual mode. There is no steering wheel and the operator does not drive. The shuttles operated approximately one hour before and one hour after events in the Entertainment District. City officials plan to launch AVs on public streets this fall.

Capital Metro no-pilot shuttle pilot (Austin)
Capital Metro will run six electric driverless minibuses in an area between the Downtown Station and the Central Library. Capital Metro’s proposed pilot will feature shared-use vehicles capable of carrying up to 15 people. The vehicles are expected to be in service, picking up and dropping off customers, for a period of 12 months. During this time, the overall customer experience, safety and the public's reception and adoption of autonomous vehicles will be evaluated.

Marble
Marble, a San Francisco-based, logistics robotics delivery company, began mapping sections of north Arlington, Texas, sidewalks.

6.1.10 Transport Canada

Advance Connectivity and Automation in the Transportation System (ACATS)
Trade & Transportation Corridors Initiative (TTCI) TB Submission allocated funding for 5 years to support innovation, including:

- UAVs (Civil Aviation)
- CV/AV Regulatory Support Initiative (Motor Vehicle Safety)
- Advancing Readiness for Deployment of CV/AV (Programs Group)

Program activities include:

- Establishing a CV/AV community of practice to guide and support P/T technical, cybersecurity and regulatory readiness
- Providing Grant & Contribution funding to support
- Researching and studies to identify solutions to mitigate CV/AV technical, policy or regulatory issues
- Developing codes, standards, certifications and guidelines necessary to deploy CV/AV technologies in Canada
- Researching and testing activities to identify and begin to mitigate potential cybersecurity vulnerabilities

6.1.11 Virginia

Virginia Automated Corridor
The Virginia Automated Corridors is a partnership between Virginia Tech Transportation Institute (VTTI), VDOT, Transurban, and HERE Technologies. The Virginia Automated Corridors integrate multiple resources to test a variety of applications, including:

- Dedicated high-occupancy toll lanes managed by Transurban along I-495 and I-95
- High-definition mapping capabilities, real-time traffic and incidents, intelligent routing, and location cloud technology supported by HERE,
- Pavement markings maintained for completeness and retro-reflectivity
- Accurate localization via high-precision global navigation satellite systems
- CV capabilities using dedicated short-range communications and cellular technology; sophisticated and unobtrusive data acquisition systems
- Operations at higher speeds along a test track that features complex curves

6.1.12 Washington

Pierce County, Washington, Transit Deploys System to Help Buses Avoid Collisions with Pedestrians, Bicyclists
The agency outfit seven buses with vision sensors that notify drivers if a pedestrian or bicycle wanders into his or her blind spot.

WSDOT CAT Pilot Projects Automated work zone vehicles [Autonomous Truck Mounted Attenuator (TMA) Pilot
The WSDOT CAT pilot projects aim to improve safety by eliminating the need for a driver in some staging vehicles. Projects include:

- Pilot Truck and Autonomous Attenuator Vehicle
- 2018 Pilot with Other States
- Considering Low Speed Striping Operations

WSDOT Pilot Interests
Washington DOT is deploying automated projects including:

- Autonomous Shuttle - 1st Mile / Last Mile Connection to Transit through partnerships with rideshare companies.
- Continue automated pedestrian and bicycle detection pilots with the addition of automated braking and connection to traffic signals operations.

Certified Autonomous Vehicle Pilot Test
Private companies are testing automated vehicles in Washington. Google plans to test self-driving vehicles in Kirkland, Seattle, starting with one white Lexus RX450h SUV. Torc Robotics ended its successful cross-country trip in Washington. Torc Robotics, a spin-off company from Virginia Tech, safely drove its semi-autonomous vehicle across the country and through Washington state without incident.

Appendix A Acronyms

Acronym	Appendix
DSRC	Dedicated Short Range Communication
V2V	Vehicle to Vehicle
V2I	Vehicle to Infrastructure
V2X	Vehicle to Anything
RSE	Road Side Equipment
OBU	On Board Unit
SPaT	Signal Phase and Timing
MAP	Intersection Geometry
SSVW	Stop Sign Violation Warning
SSGA	Stop Sign Gap Assist
SWIW	Spot Weather Impact Warning
RWIS	Road Weather Information System
DMS	Dynamic Message Sign
WHWZ	Warnings about Hazards in a Work Zone
WUWZ	Warnings about Upcoming Work Zone
OVW	Oversize Vehicle Warning
RCVW	Railroad Crossing Violation Warning
RSZW/LC	Reduced Speed Zone Warning / Lane Closure
HOV	High Occupancy Vehicles
EEBL	Emergency Electronic Brake Lights
FCW	Forward Collision Warning
IMA	Intersection Movement Assist
BSW/LCW	Blind Spot/Lane Change Warning
VTRFTV	Vehicle Turning Right in Front of a Transit Vehicle
LTA	Left Turn Assist
DNPW	Do Not Pass Warning
CLW	Control Loss Warning
EVA	Emergency Vehicle Alert

Acronym	Appendix
PCA	Pre-crash Actions
SA	Situational Awareness
TA	Tailgating Advisory
FSP	Freight Signal Priority
HOT	High-Occupancy Toll
GHG	Greenhouse Gas
CACC	Cooperative Adaptive Cruise Control
Eco-CACC	Eco-Cooperative Adaptive Cruise Control
ACC	Adaptive Cruise Control
CCC	Conventional Cruise Control
AFV	Alternative Fuel Vehicle
ECO-ICM	Eco-Integrated Corridor Management
DSS	Decision Support System
ICM	Integrated Corridor Management
WxTINFO	Weather Response Traffic Information
MAW	Motorist Advisories and Warnings
VDT	Vehicle Data Translator
EMDSS	Enhanced Maintenance Decision Support Systems
WxDE	Weather Data Environment
ESS	Environmental Sensor Stations
VSL	Variable Speed Limits
I-SIG	Intelligent Traffic Signal System
TSP	Transit Signal Priority
PED-SIG	Pedestrian Signal System
PREEMPT	Emergency Vehicle Preemption
EVP	Emergency Vehicle Preemption
RESP-STG	Incident Scene Pre-Arrival Staging Guidance for Emergency Responders
SPD-HARM	Dynamic Speed Harmonization
Q-WARN	Queue Warning
INC-ZONE	Incident Scene Work Zone Alerts for Drivers and Workers
VDTO	Vehicle Data for Traffic Operations

Acronym	Appendix
EVAC	Emergency Communications and Evacuation
EOC	Emergency Operations Center
T-CONNECT	Connection Protection
IBL	Intermittent Bus Lane
RVI	Route ID for the Visually Impaired
CAD/AVL	Computer-Aided Dispatch/ Automated Vehicle Location
T-DISP	Dynamic Transit Operations
D-Ride	Dynamic Ridesharing
VMT	Vehicle Miles Traveled
CCOD	Container/Chassis Operating Data
GNSS	Global Navigation Satellite System
SRI	Smart Roadside Initiative
CMV	Commercial Motor Vehicle
MMITSS	Multimodal Intelligent Traffic Signal System
IDTO	Integrated Dynamic Transit Operations
EnableATIS	Enabling Advanced Traveler Information Systems
FRATIS	Freight Advanced Traveler Information Systems
DR-OPT	Drayage Optimization
INFLO	Intelligent Network Flow Optimization
R.E.S.C.U.M.E	Response, Emergency Staging and Communications, Uniform Management, and Evacuation
EVAC	Emergency Communications and Evacuation
SCM	Security and Credentials Management
ASP	Advanced Snowplow Project
DATP	Driver Assisted Truck Platooning
ATCMTD	Advanced Transportation and Congestion Management Technologies Deployment
TSM&O	Transportation Systems Management and Operations
FRAME	Florida’s Regional Advanced Mobility Elements
SPSP	Snow Plow Signal Priority
CICAS	Cooperative Intersection Collision Avoidance Systems
WIM	Weight-in-Motion
CVII	Commercial Vehicle Infrastructure Integration

Acronym	Appendix
ATCMTD	Advanced Transportation and Congestion Management Technologies Deployment
NOCoE	National Operations Center of Excellence
CTPS	Cooperative Truck Platooning Systems
VCC	Virginia Connected Corridor
VAA	Vehicle Assist and Automation
ARP	Advanced Rotary Plow
AIPV	Autonomous Impact Protection Vehicle
ADAS	Advanced Driver Assistant System
SAV	Shared Autonomous Vehicles
SmartPGH	Smart Pittsburgh
UVS	Unmanned Vehicle System
CANVASS	Center for Autonomous Vehicle and Sensor Systems
SwRI	Southwest Research Institute
ACATS	Advance Connectivity and Automation in the Transportation System
TMA	Autonomous Truck Mounted Attenuator

Appendix B References

Automotive Fleet Operations; Ford to Develop Connected Car Platform; 10 January 2018; https://www.automotive-fleet.com/143770/ford-to-develop-a-connected-car-platform

Iteris Connected Vehicle Reference Implementation Architecture; Connected Vehicle Applications; https://local.iteris.com/cvria/html/applications/applications.html

Michigan Department of Transportation; MDOT Connected Vehicles Overview; https://www.michigan.gov/mdot/0,4616,7-151-9621_11041_38217---,00.html

National Operations Center of Excellence; SPaT Challenge Overview; https://transportationops.org/spatchallenge

Siemens; Siemens Car2X Intelligent Infrastructure; 16 January 2015; https://www.siemens.com/press/en/feature/2014/mobility/2014-11-car2x.php

United States Department of Transportation; Intelligent Transportation Systems Joint Program Office; Connected Vehicle Benefits Database; https://www.itsbenefits.its.dot.gov/its/benecost.nsf/BenefitsHome

United States Department of Transportation; Intelligent Transportation Systems Joint Program Office; Connected Vehicle Benefits Brochure; 31 August 2016; https://www.its.dot.gov/factsheets/pdf/ConnectedVehicleBenefits.pdf

United States Department of Transportation; Intelligent Transportation Systems Joint Program Office; Connected Vehicle Costs Database; https://www.itscosts.its.dot.gov/its/benecost.nsf/CostHome

United States Department of Transportation; Intelligent Transportation Systems Joint Program Office; Estimated Benefits of Connected Vehicle Applications Report; August 2015; https://rosap.ntl.bts.gov/view/dot/3569/dot_3569_DS1.pdf

Volvo; Volvo Connected Car Program; Volvo Connected Cap Overview https://www.volvocars.com/us/own/connected-car