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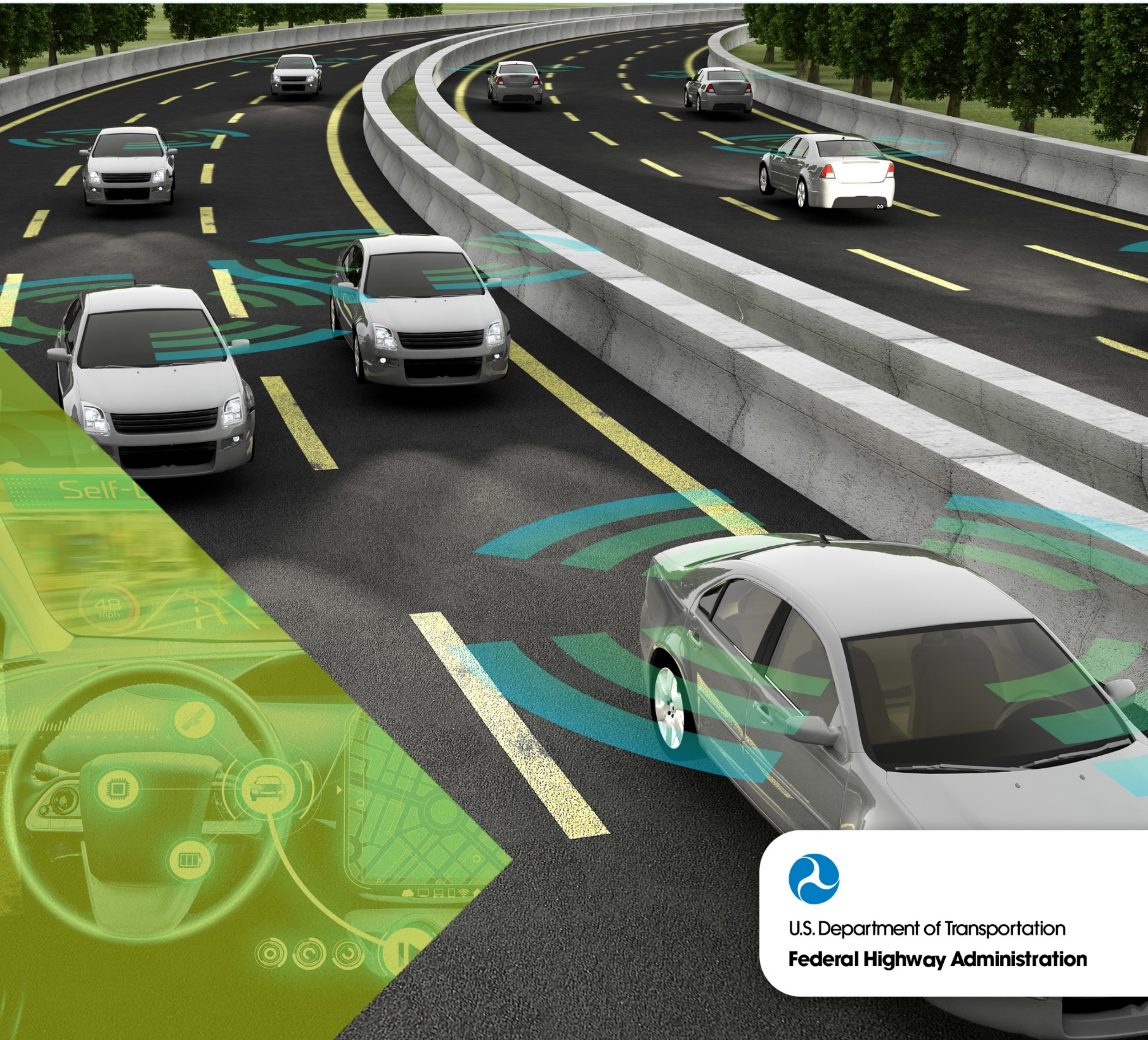
Effects on Intelligent Transportation Systems Planning and Deployment in a Connected Vehicle Environment



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16. Abstract

The objective of this document is to assess the impacts of Connected Vehicle (CV) technology on Intelligent Transportation Systems (ITS) planning processes and implementation. This report identifies and analyzes how CV technology may be considered in the ITS planning process and subsequent deployment; and investigates the need for new or enhanced tools, techniques, and data to support ITS planning and operations activities. The report covers ITS functions such as traveler information, freeway management and arterial management. It also includes functions that are currently peripheral to ITS practitioners but may, in the future, become more mainstream, such as Connected and Automated Vehicle (C/AV) technology and deployment and maintenance of roadside units to support security and data management. CV technology is anticipated to have significant impacts on traveler information, crash rates, and available traffic management strategies, and to drive a need for expanded data management and security as well as a need for new operational policies and practices. Agencies may choose to integrate CV into planning functions, engage with broader stakeholder groups, establish mechanisms for continued learning, outreach, and program evolution, and strengthen their communications networks.

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LIST OF ABBREVIATIONS AND SYMBOLS

ATMS	Advanced Traffic Management System
AV	Automated Vehicle
AVL	Automatic Vehicle Location
BSM	Basic Safety Message
CAD	Computer Aided Dispatch
C/AV	Connected and Automated Vehicle
CCTV	Closed Circuit Television
CSW	Curve Speed Warning
CV	Connected Vehicle
CVOP	Commercial Vehicle Operator Portal
DMS	Dynamic message signs
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communications
EV	Emergency response vehicles
EVAC	Emergency Communications and Evacuation
FHWA	Federal Highway Administration
GHz	Gigahertz
GPS	Global Positioning System
HAR	Highway Advisory Radio
HOT	High-Occupancy Tolled lane
HOV	High-Occupancy Vehicle lane
HRI	Highway-Rail Intersections
I2V	Infrastructure-to-Vehicle
INC-ZONE	Incident Scene Work Zone Alerts for Drivers and Workers
INFLO	Intelligent Network Flow Optimization
IPSEC	Internet Protocol Security
ISP	Information Service Provider
ITS	Intelligent Transportation System
JSON	JavaScript Object Notation
MAUTC	Mid-Atlantic University Transportation Center
MPO	Metropolitan Planning Organization
NHTSA	National Highway Traffic Safety Administration
OBU	On Board Unit
OEM	Original Equipment Manufacturers
OS	Operating System
PATH	Partners for Advanced Transit and Highways
PED-SIG	Mobile Accessible Pedestrian Signal System
PII	Personally Identifiable Information
PREEMPT	Emergency Vehicle Preemption
Q-WARN	Queue Warning
RAID	Redundant Array of Independent Disks
R.E.S.C.U.M.E.	Response, Emergency Staging and Communications, Uniform Management, and Evaluation

RESP-STG	Incident Scene Pre-Arrival Staging Guidance for Emergency Responders
REST	Representational State Transfer
RSU	Road Side Unit
SAE	Society of Automotive Engineers
SCMS	Security Credential Management System
SPaT	Signal Phase and Timing
SPD-HARM	Dynamic Speed Harmonization
SSL	Secured Socket Layer
TMC	Transportation Management Center
TSP	Transit Signal Priority
UAV	Unmanned Aerial Vehicles
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Anything
VMT	Vehicle Miles Traveled
VPN	Virtual Private Networks
WYDOT	Wyoming Department of Transportation

EXECUTIVE SUMMARY

Intelligent Transportation Systems (ITS) are defined by the U.S. Department of Transportation (U.S. DOT) as "the integration of advanced communication technologies into the transportation technologies and vehicles. Intelligent transportation systems encompass a broad range of wireless and wire line communications-based information and electronics technologies."[1]

ITS planning and deployment involves the design and implementation of this technology to provide better services to users and reduce environmental impacts. ITS technologies encompass all transportation modes, from pedestrian activities to freight movement. By implementing technologies over a region, the mobility and accessibility of the region can be enhanced, helping users go to where they want to go, when they want to, in a safer and more reliable manner.

Throughout the relatively short history of ITS, infrastructure procurements and operations planning have had to consider the impact of rapidly changing technology. Historically this has included areas such as video monitoring, introduction of advanced traffic signal controllers, and new communications technologies.

A Connected Vehicle (CV) environment enables wireless communications among vehicles (Vehicle-to-Vehicle, or V2V), infrastructure (Vehicle-to-Infrastructure, or V2I), and mobile devices (sometimes called nomadic devices). Vehicles include light vehicles, trucks, and transit vehicles. Pedestrians, bicyclists, or motorcyclists can carry mobile (nomadic) devices, allowing vehicles and infrastructure to communicate with other CV participants and vice versa (Vehicle-to-Anything, or V2X). The information shared through these communications may include the following:

- Presence, speed, location, and direction of travel.
- Road and traffic conditions.
- On-board vehicle data, such as emissions, braking, and windshield wiper activation. (The availability of on-board vehicle data for planning purposes is subject to Original Equipment Manufacturer's (OEM) support, privacy, and legal agreements.)

The main conclusion of the research is that connected vehicle technology may gradually change how roadway operations functions are carried out. Some of the identified trends are already relatively clear while others need to await greater market penetration of CV and Automated Vehicle (AV) devices.

CV technology may impact investment decisions related to transportation operations. Over time, Transportation Management Centers (TMCs) and ITS systems could change dramatically, with the timeframe largely dependent on the adoption of technology by private citizens and fleet operators.

[1] Definition obtained from the U.S. DOT Intelligent Transportation Systems Joint Program Office. https://www.its.dot.gov/about/faqs.htm.

Some examples of anticipated impacts (on both urban and rural transportation networks) include the:

- **Migration of Traveler Information Dissemination from Public to Private Sources—**The migration of traveler information dissemination from public to private sources is already well underway. Information increasingly tailored to individual vehicles can be sent directly into the vehicle via navigation systems, smartphone applications or emerging telematics systems which generally include both. CV technology may be a factor in this as well.
- **Reduction of Crash Rates—**Crash rates are anticipated to decrease over time, although this may be partially offset by the addition of new vehicles on the road. Resources may be needed to support safe operation of CV and AV vehicles. This could include communications and security systems, as well as infrastructure-related needs such as striping and lighting.
- **Enhancement of Traffic Management Strategies Related to Recurring Congestion—** Traffic management strategies related to recurring congestion, such as ramp metering and signal coordination, may be enhanced by CV technologies that could provide data from individual vehicles and communicate directly with roadside controllers.
- **Enhancement of Traffic Management Strategies Related to Non-Recurring Congestion—**Traffic management strategies related to non-recurring congestion, such as road weather, construction and special events, may also be enhanced by CV technology that could provide much richer data on real-time conditions via observations from individual vehicles.
- **Effect of Issues of Ownership, Security, and Privacy of the CV-Related Data—**Issues of ownership, security, and privacy related to CV data may impact some applications and their potential benefits.
- **Need for New Operational Policies and Practices—**New operational policies and practices will be needed to address the potential operational impacts of truck platooning, automated vehicles in mixed fleets, and closer headways among vehicles.

The following are actions that agencies may choose to take to prepare for CV impacts on ITS. These are loosely organized into short-term (zero to five years), medium-term (five to 15 years), and long-term (more than 15 years out).

In the **short-term:**

- Operating agencies may choose to reach out to and engage with a larger stakeholder audience, some of whom have not participated in the past. These new stakeholders may include vehicle and telematics manufacturers as well as cybersecurity firms. Several agencies have benefited from the formation of advisory panels, composed of multiple stakeholder public agencies as well as private sector stakeholders. Many agencies have found such panels to be relatively easy to develop and maintain given the cross-cutting energy and enthusiasm around the CV and AV topic.

- Agencies may choose to develop a Concept of Operations (ConOps) for their organization that describes the characteristics of the proposed system and identifies the roles, features, functions, and communications needed and addressed by advancing CV planning efforts.
- Agencies may choose to incorporate planned CV technology into their ITS architectures and strategic plans. This may include how modifications to their central systems, data collection, data archiving, and performance measures will occur.
- Agencies may choose to incorporate additional technology investments into their freeway management systems and software. Planning direction will be needed on timing, funding, and when technologies will potentially be phased out.
- As agencies collect CV data they likely will need support in the areas of data security and privacy. Even if private parties have the primary role, agencies will likely still need to understand and plan for the increased data quantities, security, and privacy.
- Agencies may choose to identify any existing regulatory and/or legal hurdles to CV investment and testing. To encourage innovative technology development, it is still critical to assess any existing regulatory and legal barriers that are not in line with an agency's vision for CV. The review of regulatory and legal hurdles would consider typical testing and deployment requirements.
- Innovations in CV are best accompanied with partnerships with neighboring and overlapping agencies/jurisdictions to support seamless interoperability. The level of partnerships can be determined by needs, ranging from simple communication of planned improvements and investments up to coordinated infrastructure purchase and deployment to ensure interoperability.

In the **medium-term:**

- Agencies may choose to adopt strict security policies and procedures for all systems and users of the CV systems and networks.
- Agencies can work with their preferred equipment vendors (traffic controllers) to develop the upgrades necessary to support the CV interface to support the Signal Phase and Timing (SPaT) message content and any data collection.
- Education of the public may be needed, although less with CV than with AV. Agencies may want to help alert the public to opportunities.
- As agencies begin to incorporate CV technology into the infrastructure, equipment maintenance costs and personnel requirements will need to be determined and budgeted. Concepts of operation may help to incorporate CV technology into operations and define thresholds for phasing out obsolete technology. These systems may also be incorporated into the Advanced Traffic Management System (ATMS) (in some cases) as well as asset management systems.

- While many agencies are well equipped to integrate CV technologies into existing ITS programs, as the technology evolves agencies will need to consider how agency and staff roles and responsibilities evolve in kind. A review of agency structure, organization, roles, and responsibilities can help agencies take the necessary steps to proactively adapt to achieve their vision, rather than relying on historical agency roles and responsibilities. This could include a vision for the creation of new agencies, mergers of existing agencies, or updating structures and responsibilities within agencies.
- Agencies may choose to develop data monitoring and feedback mechanisms to observe and understand the impacts existing CV deployments are having on performance and operations. As more active CV systems are deployed, agencies will gain knowledge on return on investment and performance impacts to shape future deployment and operation strategies.
- With rapid advance of technology, agencies will likely need new methods of keeping up with technical and institutional developments, and identifying information that is relevant to their planning and operations. Examples of potential activities include facilitation of an advisory panel, participation in pooled fund study groups, research panels, and industry conferences, and monitoring industry newsletters.

In the **long-term:**

- Agencies may choose to develop a communications master plan to support their traffic control systems and CV backhaul; this should be a complete communications architecture to support their video, traffic management, and CV needs, as well as the requirements of their other ITS devices. For the next decade, it is unlikely that CV technology will replace traditional ITS device deployment—but CV technology will likely place an added burden on the agency's IT security systems, network security, and communications networks.
- The concept of "technology" refreshment will become more significant; we have all observed that the "cell phone" has evolved to a powerful hand held computer—with additional features as they become practical in the product continuum. The implementation of CV technology is likely to require large scale upgrades or even equipment replacement as the communications technology evolves.
- Agencies likely will need to make major additions to their repair facilities to be able to assess the operation of their roadside communications units.

CHAPTER 1. INTRODUCTION

The objective of this project was to assess the impacts of connected vehicle technology on Intelligent Transportation Systems (ITS) planning processes and deployment. This report identifies and analyzes how connected vehicle technology could be considered in the ITS planning process and subsequent implementation; and investigates the need for new or enhanced tools, techniques, and data to support ITS planning and operations activities. This report also assesses the roles and responsibilities of stakeholders and needed organizational skills, expertise and capabilities to carry out ITS planning, deployment, management, operation, and maintenance in a connected vehicle environment. The results of this work include suggested activities to assist transportation agencies with better preparation for the potential impacts, operational and maintenance activities, and resource and system needs related to ITS planning in a Connected Vehicle (CV) environment, as well as with better decisionmaking for the replacement of current ITS assets and investments in future ITS assets.

REPORT OVERVIEW

Chapter 2 of this reports defines and provides a brief overview of the ITS services covered in this report. The categories follow those used in the Literature Review Report prepared for this project[2] and include basic ITS functions such as traveler information, freeway management, and arterial management as well as functions that are currently peripheral to ITS practitioners but may, in the future, become more mainstream. These might involve CV and Automated Vehicle (AV) technology and include, for example, deployment and maintenance of roadside units to support security and data management. Chapter 3 summarizes potential impacts of CV technology on the basic functions while chapter 4 includes a similar analysis for peripheral functions. Chapter 5 summarizes recommendations for ITS practitioners to address the impacts identified in the report.

DEFINITION OF INTELLIGENT TRANSPORTATION SYSTEMS

ITS is defined by the U.S. Department of Transportation (U.S. DOT) as “the integration of advanced communication technologies into the transportation technologies and vehicles. Intelligent transportation systems encompass a broad range of wireless and wire line communications-based information and electronics technologies.”[3]

ITS planning and deployment involve the design and implementation of this technology to provide better services to users and reduce negative impacts on the environment. ITS technologies encompass all transportation modes, from pedestrian activities to freight movement. By implementing technologies over a region, the mobility and accessibility of the region can be enhanced, helping users go to where they want to go, when they want to, in a safer and more reliable manner.

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[2] *Effects on Intelligent Transportation Systems Planning and Deployment in a Connected Vehicle Environment,* Literature Search Report, prepared by Cambridge Systematics for FHWA, January 2017.

[3] Definition obtained from the U.S. DOT Intelligent Transportation Systems Joint Program Office. https://www.its.dot.gov/about/faqs.htm.

FHWA requires all States and Metropolitan Planning Organizations (MPO) wishing to use Federal funding for ITS to have an ITS architecture (23 CFR 940[4]). An ITS architecture is a structured guideline to plan, define, and integrate ITS technology in a region or a State. Architecture development involves participation from a range of stakeholders including Federal agencies, State and regional agencies, local municipalities, and advocacy groups. The structured framework of an ITS architecture allows communication across regions and smoother incremental ITS deployment. ITS architectures include a hierarchy of functions under which there are sub-functions and specific technologies. Freeway management systems, for example, include a range of activities that involve facilities such as Traffic Management Centers, specific functions such as ramp metering, and supporting technologies such as fiber optic communications. ITS architectures can provide a good organizational structure for addressing the impacts of CV technology on ITS.

CONNECTED VEHICLE TECHNOLOGY

A CV environment enables wireless communications among vehicles (vehicle-to-vehicle, or V2V), infrastructure (vehicle-to-infrastructure, or V2I), and mobile devices (sometimes called nomadic devices). Vehicles include light vehicles, trucks, motorcycles, and transit vehicles. Pedestrians or bicyclists can carry mobile (nomadic) devices, allowing vehicles and infrastructure to communicate with other CV participants and vice versa (vehicle-to-anything, or V2X). The information shared through these communications may include the following:

- Presence, speed, location, and direction of travel.
- Road and traffic conditions.
- On-board vehicle data, such as emissions, braking, and windshield wiper activation. (The availability of on-board vehicle data for planning purposes is subject to OEM’s support, privacy, and legal agreements that have not yet been established.)

The U.S. DOT has been active in CV research over the past several years. A major demonstration project was conducted in Ann Arbor, Michigan that involved nearly 3,000 V2V-equipped vehicles and a number of infrastructure deployments. The focus of that project was on the communication of safety messages between vehicles and between vehicles and the infrastructure. The project has been expanded into a larger demonstration which is now underway.[5] In addition, the U.S. DOT has funded three pilot sites—in New York City, NY; Tampa, FL; and the State of Wyoming—that will further test Connected Vehicle deployment. These demonstrations will expand beyond the testing of technology to specific applications related to signal control, non-motorized user safety, emergency response, traveler information and weather information, among others. The first lessons from the demonstrations are beginning to come in, but these mainly focus on the development and implementation process.[6] The results of actual deployment will be very helpful to ITS and operating agencies in the evaluation and deployment of supporting CV technology. Information on the benefits of different applications

[4] FHWA Rule 940 www.fhwa.dot.gov/legsregs/directives/fapg/cfr0940.htm.
[5] http://www.its.dot.gov/research_archives/safety/aacvte.htm.
[6] http://www.its.dot.gov/pilots/pdf/CVP_LessonsLearned_v7.pdf.

and the costs and actions required to implement them will provide important guidance. These projects are due to be deployed during 2018 and will be in operation for 18 months thereafter collecting data to evaluate the benefits and costs.

AUTOMATED VEHICLE TECHNOLOGY

AVs are vehicles in which at least some aspect of a safety-critical control function (e.g., steering, throttle, or braking) occurs without direct driver input. Although it is expected that both CV and AV technologies will provide the vehicle and the driver with a greater awareness of their surroundings, they are different in that AVs, unlike CVs, rely on on-board sensors to collect information about the vehicle's surroundings and to operate the vehicle. While AV technology can be implemented without the ability to communicate with other vehicles or roadway infrastructure, higher levels of automation will likely need CV technology to achieve their full potential. Thus, when discussing connected/automated vehicles (C/AV), this report refers to automated functions that fuse the data from on-board sensors with the data stream from CV technologies.

AV technology, with its access to vehicle control functions, will be controlled by vehicle manufacturers rather than by public agencies and State DOTs; however, public agencies will influence the operations of AVs on public roads (e.g., licensing, insurance requirements, and permitted conditions for testing). While AV deployment may occur without significant involvement by the public sector, vehicle manufacturers are working towards a convergent solution, with CV systems playing an important role in enabling AVs.

A transportation system consisting primarily of highly automated vehicles may be decades away, but partially automated solutions assisted by V2V and V2I applications will be available sooner. For example, V2I systems can provide information on real-time traffic conditions, queue warnings, and Signal Phase and Timing (SPaT) to enable proactive responses by AVs. The National Highway Traffic Safety Administration (NHTSA) has accepted the Society of Automotive Engineers (SAE) defined six levels of vehicle automation, building off of current driver assistance technologies such as adaptive cruise control, lane departure warning, and left turn assist. The descriptions of the six levels are listed below with additional graphics included in the SAE's summary (https://www.sae.org/news/press-room/2014/10/sae-international-technical-standard-provides-terminology-for-motor-vehicle-automated-driving-systems). Various combinations of levels 0, 1, and 2 are operating on the road today.

- **Level 0: No Automation—**The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems.
- **Level 1: Driver Assistance—**The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.
- **Level 2: Partial Automation—**The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information

about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.

- **Level 3: Conditional Automation—**The driving mode-specific performance by an Automated Driving System of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene.
- **Level 4: High Automation—**The driving mode-specific performance by an Automated Driving System of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene.
- **Level 5: Full Automation—**The full-time performance by an Automated Driving System of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver.

The transportation community has issued widely varying timelines as to when users can expect the remaining levels of automation. In 2016, Serbjeet Kohli and Luis Willumsen presented the results of a Delphi survey on the field of AV transportation.[7] The results show that on average, transportation experts expect that AV technology will be available in the U.S. by 2021 (with a two-year standard deviation), and that there will be a 20 percent penetration rate in the U.S. market by 2033 (with a six-year standard deviation).

OVERVIEW OF METHODOLOGY

This research identified and analyzed how CV technology could be considered in the ITS planning process and subsequent deployment. It also assessed the need for new or enhanced tools, techniques, and data to support ITS planning and operations activities while reviewing the roles and responsibilities of stakeholders. These studies included detailing the organizational skills, expertise and capabilities needed to carry out ITS planning, deployment, management, operation and maintenance in a connected vehicle environment. A roadmap and guidance are provided to aid transportation agencies with better preparation for the potential impacts; operational and maintenance activities; resources and potential system needs; and decisionmaking for the replacement of current ITS assets as well as investments on future ITS resources.

This research relies on information collected through a literature search and outreach to the Transportation Management Center Pooled Fund Study committee members. Generally speaking, CV technologies may impact ITS and operations by:

- Enhancing current ITS services in the short-term by providing additional channels of communication, more targeted information, and more sophisticated operational strategies.
- Replacing ITS services/providing new services in the long-term.
- Providing new and more detailed data on traffic volume and flow, as well as travel patterns.

[7] https://www.linkedin.com/pulse/delphi-poll-sheds-some-light-role-future-autonomous-willumsen/.

- Strengthening the linkage between the operations and planning of ITS by potentially involving a wider array of stakeholders.
- Changing the role of operations agencies and their personnel, possibly including:
  - Less emphasis on real-time data collection as this information is gained instead from probe vehicles and third-party sources.
  - More emphasis on traffic management strategies, which can become more sophisticated as a result of improved communication between vehicles and the infrastructure and richer data.
  - Development and implementation of operational strategies to accommodate new capabilities such as vehicle platooning and dynamic pricing.
  - Analysis and input to investment strategies that may change as technologies are adopted.
  - Monitoring and management of infrastructure assets that are required for the safe operation of connected and automated vehicles.
  - Coordination with new stakeholders such as communication service providers and Original Equipment Manufacturers (OEM).

Throughout the relatively short history of ITS, infrastructure procurements and operations planning have had to consider the impact of rapidly changing technology. Historically this has included areas such as video monitoring, introduction of advanced traffic signal controllers, and new communications technologies. An important consideration moving forward is that CV technology may impact investment decisions related to transportation operations. Over time, Transportation Management Centers (TMC) and ITS systems could change dramatically, with the timeframe largely dependent on the adoption of technology by private citizens and fleet operators.

CHAPTER 2. INTELLIGENT TRANSPORTATION SYSTEM CATEGORIES AND SERVICES

The project identified Intelligent Transportation Systems (ITS) categories as defined by the U.S. Department of Transportation (U.S. DOT) for the development of ITS architectures. Additional categories were considered to include a broad spectrum of ITS categories and address developments. Each category contains a number of services that were examined in detail. The U.S. DOT Intelligent Transportation Systems Joint Program Office (ITS JPO) webpage was consulted to provide commonly used definitions of the services considered.[8] The following categories are detailed in this chapter:

- Traveler information.
- Freeway management.
- Arterial management.
- Archived data management.
- Public transportation.
- Emergency management strategies.
- Construction and maintenance management strategies.
- Other traffic management.
- Vehicle safety.
- Connected vehicle technology.

TRAVELER INFORMATION

Traveler information systems refer to strategies designed to inform transportation users of various aspects important for their trip. Traveler information systems encompass a wide variety of transportation modes and types of users, providing descriptive data of the transportation system, which could assist the user to select their mode of travel, route, trip time, or destination. These systems may provide static data, such as maps and touristic information; or dynamic data, often relying in road surveillance equipment or information from probe vehicles. Different media is used to publish and distribute such information, from roadside equipment to personal communication devices. Traveler information systems include the following services:

- **Broadcast Travel Information—**This service includes information provided using broadcasting technology, such as radio broadcasts, cellular data, and Internet Web casts.
- **Interactive Traveler Information—**This service includes information provided to users based on a user-selected request.

[8] https://www.its.dot.gov/.

- **Autonomous Route Guidance—**This service includes information on route planning and guidance based on static stored information.
- **Dynamic Route Guidance—**This service includes information consisting of advanced route planning and guidance responsive to real-time conditions.
- **ISP-Based Trip Planning and Route Guidance—**Trip planning and route guidance information provided by the Information Service Provider (ISP), which may include a variety of modes and transportation services.
- **Transportation Operations Data Sharing—**This service makes real-time transportation operations data available to transportation system operators.
- **Traveler Service Information and Reservation—**This service provides information and allows users to plan and reserve transportation services.
- **Dynamic Ridesharing—**This service enables dynamic ride sharing and ride matching services to users.
- **In-Vehicle Guidance—**This service augments regulatory, warning, and informational signs and signals by providing information directly to drivers through in-vehicle devices.

FREEWAY MANAGEMENT AND ARTERIAL MANAGEMENT

Freeway management includes systems and services designed to optimize traffic flow and safety on limited access roadways. ITS resources are the focus of this and include Closed Circuit Television (CCTV) cameras, vehicle detection systems, ramp meters, service patrols and traffic management staff and software. Arterial management strategies are designed to improve traffic flow and safety along arterial roadways. In some areas, major arterials may be linked to the freeway management system and be equipped with CCTVs and Dynamic Message Signs (DMS). Specific services reviewed for this project include:

- **Traffic Probe Surveillance—**This service includes the collection of data from vehicles in order to determine vehicle speeds and to detect incidents.
- **Ramp Metering—**This service uses signals at freeway ramp entrances to control flow on to the roadway.
- **High-Occupancy Vehicle (HOV) Lane Management—**This service includes lanes dedicated, usually at peak hours, to high-occupancy vehicles that include carpools, vanpools, buses and taxis, and in some areas electric vehicles. High-Occupancy Tolled (HOT) lanes allow single-occupancy vehicles to use HOV lanes if they pay a toll.
- **Traveler information Dissemination—**This service uses DMS, Highway Advisory Radio (HAR) and 511 telephone services provide current information on travel conditions to freeway users. In-vehicle navigation and smartphone applications now provide an increasing amount of this information to users.
- **Traffic Incident Management—**This service includes surveillance and traffic detection technology, along with Traffic Management Center (TMC) operators, and software to quickly detect incidents. There is close coordination with first responders through

communications sharing or co-location of traffic operations and first responder personnel. Service patrols support first responders in responding to incidents and restoring traffic flow, reducing congestion and secondary crashes.

- **Reversible Lane Management—**ITS technologies are used to manage reversible lanes that are used to expedite traffic flow where peak hour traffic is highly directional.
- **Speed Warning and Enforcement—**This service includes warning systems that can detect vehicles entering a curve or sensitive area (school zone) at too high a speed and warn motorists to slow down. Automated enforcement is not as widely adopted due to privacy concerns.
- **Dynamic Roadway Warnings—**This service includes systems similar to speed warnings but refer to unanticipated events such as roadway obstacles or incidents. Connected Vehicle (CV) technology provides a method of passing information upstream from one vehicle to another, rather than relying on broadcast or signing. This technology is still under development in the standards arena.
- **Variable Speed Limits—**This service uses dynamic roadside or overhead signs as a way to smooth traffic flow and slow traffic down during bad weather or construction. Signs now used along the roadway to accomplish this could be replaced with CV technology, providing the ability to target vehicle speeds more specifically.
- **Dynamic Lane Management and Shoulder Use—**Dynamic lane management and shoulder use are methods of increasing freeway capacity without major capital investment. Agencies often limit these strategies to peak hours. CV technology provides the potential for managing these.
- **Vehicle Miles Traveled (VMT) Road User Payment—**This service seeks to facilitate charging 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). This strategy would help reduce congestion by charging users of a congested network a price close to the real cost of using it, which includes environmental and other externalities implied in the use of the network during congested periods.
- **Mixed Use Warning Systems—**This service supports the sensing and warning systems used to interact with pedestrians, bicyclists, and other vehicles that operate on the main vehicle roadways, or on pathways which intersect the main vehicle roadways. These systems could allow automated warning or active protection for this class of users.
- **Network Surveillance—**This service refers to the use of information from traffic surveillance equipment, like traffic detectors or other surveillance equipment. This information enables TMCs to monitor traffic and road conditions, manage incidents, and optimize network operations.
- **Traffic Signal Control—**This service refers to the operation of traffic control equipment in signalized intersections, including monitoring equipment and communication solutions. All control strategies are also considered in this ITS solution, from fixed signal timings to dynamic responsive [adaptive] systems.

- **Regional Traffic Management—**Regional traffic management refers to the process of data sharing among traffic management centers in a region, to optimize network operations along local jurisdictions, and often considers the integration of freeway operations and corridor signal controls. The overall goal of this strategy is to further enhance traffic operations at a larger geographic scale, often resulting in better traffic conditions systemwide. This is widely used during major incidents, special events, and extreme weather conditions.
- **Transportation Decision Support and Demand Management—**This service considers different operational strategies and response plans based on real-time network performance. Incident response and congestion management recommendations often consider the integration of transit, parking, and toll strategies. More advanced versions of this may include predictive analysis of traffic conditions to manage the roadway network and to optimize the incident response and track its effects.
- **Emissions Monitoring and Management—**This service refers to monitoring activities of air quality and emissions through distributed sensors. The information collected can be used to implement a specific demand management strategy, or promote environmentally sensitive policies and regulations.
- **Roadway Closures Management—**This service refers to roadway closures due to maintenance, unsafe traffic conditions, or other scenarios [e.g. weather] where traffic must be prohibited. There is a close relation with Traveler Information Systems, as these are often used to alert users of closures and provide alternatives for travel.

ARCHIVED DATA MANAGEMENT

Archived data management systems refer to infrastructure and system architecture that enables transportation agencies to collect, archive, query, and share transportation data. With a growing number of data sources available, data management has become a growing ITS category among transportation management agencies. Furthermore, with the advent of CV, the ability to collect and use real-time data increases significantly. The services described are considered for this project. It should be noted that FHWA does not endorse any specific products, services, or enterprises. Products and manufacturers' names appear in this document because they are considered essential to the objective of the report. They are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

- **ITS Data Mart—**This service focuses on data collection by a single agency, private sector provider, or other related organization. The data collected often focuses on data exclusive for a single transportation mode.
- **ITS Data Warehouse—**This service refers to the management of integrated data sources and agencies, providing accessibility to data across modes and jurisdictions. This service often handles a large amount of data, which could include the utilization of shared servers and storage facilities. The data warehouse is often managed by a lead agency, supervising that data is being integrated according to the expected format and quality, and controlling accessibility to the information.

- **ITS Virtual Data Warehouse—**This service relates to similar services provided by ITS Data Warehouses, but provides this access using enhanced interoperability between physically distributed ITS archives that are each locally managed. The U.S. DOT is developing a Situation Data Warehouse for CV collected data (such as basic safety messages, or BSM), and dynamic data distribution services for the real-time distribution of CV collected data. These are being developed by the U.S. DOT and will be used by the Wyoming and Tampa pilot programs.

PUBLIC TRANSPORTATION

This ITS category encompasses ITS solutions for public transportation services.

- **Transit Vehicle Tracking—**This service refers to the monitoring of transit vehicle location, often through Automatic Vehicle Location (AVL) technology. Vehicle position may be determined through Global Positioning System (GPS) equipment or through beacons and equipment along the transit routes. Location data can be very useful for transit agencies, as they can use it to optimize schedule operations and provide reliable information to users.
- **Transit Fixed-Route Operations—**This service refers to the management of transit operations, often through Computer Aided Dispatch (CAD) technology, which relies on vehicle location data and enables communication between transit dispatch and operators. This solution allows the optimization of scheduling activities including the creation of schedules, blocks and runs, as well as operator assignments. Traveler information can also be provided, allowing users to have accurate and reliable trip information.
- **Demand Response Transit Operations—**This service enables the operation of flexible-route transit, or paratransit services, which are dispatched based on demand needs. This package monitors the current status of the transit fleet and supports allocation of these fleet resources to incoming requests for paratransit service while also considering traffic conditions.
- **Transit Fare Collection Management—**This service manages transit fare collection on-board transit vehicles and at transit stops using electronic means. It allows transit users to use a traveler card or other electronic payment device.
- **Transit Security—**This service refers to the operation of equipment and sensors for monitoring and surveillance of transit passengers' safety. The surveillance equipment includes video and/or audio systems. The sensor equipment includes threat sensors and object detection sensors as described above as well as, intrusion or motion detection sensors and infrastructure integrity monitoring.
- **Transit Fleet Management—**This service supports automatic transit maintenance scheduling and monitoring. On-board condition sensors monitor system status and transmit critical status information to the transit agency, enabling preventative and corrective maintenance scheduling.

- **Multimodal Coordination—**This service enables communication between multiple transit and traffic agencies, often seeking to improve operation efficiencies for users, making services more reliable.
- **Transit Traveler Information—**This service allows transit users at stops and on vehicles to access transit information. The information provided includes transit stop annunciation, imminent arrival signs, and real-time transit schedule. Systems that provide custom transit trip itineraries and other tailored transit information are also represented in this service.
- **Transit Signal Priority—**This service enables the communication between transit vehicles and traffic control operations, to give them priority when they reach the intersection. The coordination between traffic and transit agencies seeks to improve on-time performance of the transit system to the extent that this can be accommodated without degrading overall performance of the traffic network.
- **Passenger Counting—**This ITS solution seeks to count the number of passengers entering and exiting a transit vehicle using sensors mounted on the vehicle and communicates the collected passenger data back to the operations center.
- **Multimodal Connection Protection—**This service package supports the coordination of multimodal services to optimize the travel time of travelers as they move from mode to mode (or to different routes within a single mode).

EMERGENCY MANAGEMENT STRATEGIES

This ITS category focuses on using ITS solutions to allow the application of response plans to emergency events. The following services were considered for this project:

- **Emergency Call-Taking and Dispatch—**This service provides basic public safety call-taking and dispatch services. It includes emergency vehicle equipment, equipment used to receive and route emergency calls, and wireless communications that enable safe and rapid deployment of appropriate resources to an emergency.
- **Emergency Routing—**This service enables more efficient emergency strategies by incorporating automated vehicle location and dynamic routing of emergency vehicles to enhance emergency vehicle routing. Integration with control strategies can also be included to improve the safety and time-efficiency of responding vehicle travel on the selected routes.
- **Mayday and Alarms Support—**This service allows all type of users to initiate a request for emergency assistance and allows the agency responsible for emergency management to gather information about the incident, and determine the appropriate response. The request for assistance may be manually initiated or automated and linked to vehicle sensors.
- **Roadway Service Patrols—**This service supports roadway service patrol vehicles that monitor roads that aid motorists, offering rapid response to minor incidents (flat tire, incidents, out of gas) to minimize disruption to the traffic stream.

- **Transportation Infrastructure Protection—**This service includes the monitoring of transportation infrastructure (e.g., bridges, tunnels and management centers) for potential threats using sensors and surveillance equipment, seeking to mitigate the impact of an incident if it occurs. Threats considered include natural incidents (e.g., hurricanes, earthquakes), terrorist attacks, or other incidents causing damage to the infrastructure (e.g., stray barge hitting a bridge support.)
- **Wide-Area Alert—**This service uses ITS to alert the public in emergency situations such as child abductions, severe weather events, civil emergencies, and other situations that pose a threat to life and property. The alert includes information and instructions for transportation system operators and the traveling public, improving public safety and enlisting the public's help in some scenarios.
- **Early Warning System—**This ITS service monitors and detects potential, looming, and actual disasters including natural disasters (hurricanes, earthquakes, floods, winter storms, tsunamis, etc.) and technological and man-made disasters (hazardous materials incidents, nuclear power plant accidents, and acts of terrorism including nuclear, chemical, biological, and radiological weapons attacks).
- **Disaster Response and Recovery—**This service enhances the ability of the surface transportation system to respond to and recover from disasters. It addresses the most severe incidents that require an extraordinary response from outside the local community.
- **Evacuation and Reentry Management—**This service supports evacuation of the general public from a disaster area and manages subsequent reentry to the area. This solution addresses evacuations for all types of disasters, including disasters like hurricanes that are anticipated and occur slowly, allowing a well-planned orderly evacuation, as well as disasters like terrorist acts that occur rapidly, without warning, and allow little or no time for preparation or public warning.
- **Disaster Traveler Information—**This service uses ITS to provide disaster-related traveler information to the general public, including evacuation and reentry messages and other information concerning the operation of the transportation system during a disaster. This solution collects information from multiple sources including traffic, transit, public safety, emergency management, shelters, and travel service organizations. The collected information is processed and the public is equipped with real-time disaster and evacuation awareness using ITS traveler information systems.

CONSTRUCTION AND MAINTENANCE MANAGEMENT STRATEGIES

This category relates to strategies and operation changes agencies need to consider for construction and maintenance activities. The following services were considered for this project:

- **Maintenance and Construction Vehicle and Equipment Tracking—**This service tracks the location of maintenance and construction vehicles and other equipment to ascertain the progress of their activities. These activities can include ensuring the correct roads are being plowed and work activity is being performed at the correct locations.

- **Maintenance and Construction Vehicle Maintenance—**This service performs vehicle maintenance scheduling and manages both routine and corrective maintenance activities on vehicles and other maintenance and construction equipment. Data to develop these schedules include on-board equipment and sensors.
- **Road Weather Data Collection—**This service collects current road and weather conditions through environmental sensors deployed on and about the roadway or transportation network considered. Data is collected via fixed sensor stations at the roadside or equipped vehicles.
- **Weather Information Processing and Distribution—**This service uses the environmental data collected to detect environmental hazards such as icy road conditions, high winds, dense fog, so system operators and decision support systems can make decision on corrective actions to take.
- **Roadway Automated Treatment—**This service automatically treats a roadway section based on environmental or atmospheric conditions. Treatments include fog dispersion and anti-icing chemicals.
- **Winter Maintenance—**This service relates to winter road maintenance including snow plow operations, roadway treatments (e.g., salt spraying and other anti-icing material applications), and other snow and ice control activities.
- **Roadway Maintenance and Construction—**This service supports numerous services for scheduled and unscheduled maintenance and construction on a roadway system or right-of-way.
- **Work Zone Management—**This service manages work zones, controlling traffic in areas of the roadway where maintenance, construction, and utility work activities are underway. This service provides control of field equipment in all maintenance and construction areas, including fixed, portable, and truck-mounted devices supporting both stationary and mobile work zones.
- **Work Zone Safety Monitoring—**This service includes systems that improve work crew safety and reduce collisions between the motoring public and maintenance and construction vehicles. The service detects vehicle intrusions in work zones and warns crew workers and drivers of imminent encroachment or other potential safety hazards.
- **Maintenance and Construction Activity Coordination—**This service supports the dissemination of maintenance and construction activity to centers that can utilize it as part of their operations.
- **Environmental Probe Surveillance—**This service collects data from vehicles in the road network that can be used to directly measure or infer current environmental conditions. It leverages vehicle on-board systems that measure temperature, sense current weather conditions (rain and sun sensors) and also can monitor aspects of the vehicle operational status (e.g., use of headlights, wipers, and traction control system) to gather information about local environmental conditions.

- **Infrastructure Monitoring—**This service package monitors the condition of pavement, bridges, tunnels, associated hardware, and other transportation-related infrastructure (e.g., culverts) using both fixed and vehicle-based infrastructure monitoring sensors.

OTHER TRAFFIC MANAGEMENT

This category seeks to include some ITS services that can be considered in multiple or other categories, and which have an important effect on transportation networks. The following services were considered for this category:

- **Electronic Toll Collection—**This service provides 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.
- **Roadside Lighting System Control—**This service includes systems that manage electrical lighting systems by monitoring operational conditions and using the lighting controls to vary the amount of light provided along the roadside.
- **Standard Railroad Grade Crossing—**This service manages highway traffic at Highway-Rail Intersections (HRI) where operational requirements do not dictate more advanced features (e.g., where rail operational speeds are less than 80 miles per hour).
- **Advanced Railroad Grade Crossing—**This service manages highway traffic at HRIs where operational requirements demand advanced features (e.g., where rail operational speeds are greater than 80 miles per hour).
- **Railroad Operations Coordination—**This service provides an additional level of strategic coordination between freight rail operations and traffic management centers. Rail operations provide train schedules, maintenance schedules, and any other forecast events that will result in HRI closures. This information is used in advanced traffic control strategies or to enhance the quality of traveler information.
- **Parking Facility Management—**This service provides enhanced monitoring and management of parking facilities. It assists in the management of parking operations, coordinates with transportation authorities, and supports the electronic collection of parking fees.
- **Regional Parking Management—**This service supports communication and coordination between equipped parking facilities and also supports the regional coordination between parking facilities and traffic and transit management systems.
- **Drawbridge Management—**This service supports systems that manage drawbridges at rivers and canals and other multimodal crossings (other than railroad grade crossings). The equipment managed by this service includes control devices (e.g., gates, warning lights, dynamic message signs) at the drawbridge as well as the information systems that are used to keep travelers apprised of current and forecasted drawbridge status.

VEHICLE SAFETY

This category refers to on-board vehicle ITS solutions that seek to enhance safety and vehicle control for better driving. The following services were considered for this project:

- **Vehicle Safety Monitoring—**This service provides a diagnosis of critical components of the vehicle and warn the driver of potential dangers. On-board sensors determine the vehicle's condition, performance, on-board safety data, and display information.
- **Driver Safety Monitoring—**Similar to vehicle safety monitoring, but for drivers, this service will determine the driver's condition, and warn the driver of potential dangers. On-board sensors determine the driver's condition, performance, on-board safety data, and display information.
- **Longitudinal Safety Warning—**This service utilizes safety sensors and collision sensors to monitor the areas in front of and behind the vehicle and present warnings to the driver about potential threats/hazards.
- **Lateral Safety Warning—**This service utilizes safety sensors and collision sensors to monitor the areas to the sides of the vehicle and present warnings to the driver about potential threats/hazards.
- **Intersection Safety Warning—**This service monitors vehicles approaching an intersection and warns drivers when hazardous conditions are detected. Among the hazards detected are impending violations (e.g., red-light violations) and potential conflicts between vehicles occupying or approaching the intersection. When a potentially hazardous condition is detected, a warning is communicated to the involved vehicles using short range communications and/or signs/signals in the intersection.
- **Pre-Crash Restraint Deployment—**This service uses in-vehicle sensors and on-board communications to monitor the vehicle's local environment, determine collision probability and deploy a pre-crash safety system. It will exchange messages with other equipped vehicles to determine the precise location of surrounding vehicles and deploy a pre-crash safety system when a crash is imminent.
- **Driver Visibility Improvement—**This service seeks to enhance driver visibility using an enhanced vision system.
- **Advanced Vehicle Longitudinal Control—**This service automates the speed and headway control functions on board the vehicle. It utilizes safety sensors and collision sensors combined with vehicle dynamics processing to control the throttle and brakes. It requires on-board sensors to measure longitudinal gaps and a processor for controlling the vehicle speed.
- **Advance Vehicle Lateral Control—**This service automates the steering control on board the vehicle. It utilizes safety sensors and collision sensors combined with vehicle dynamics processing to control the steering. It requires on-board sensors to measure lane position and lateral deviations and a processor for controlling the vehicle steering.

- **Intersection Collision Avoidance—**This service determines the probability of an intersection collision and provides timely warnings to approaching vehicles so that avoidance actions can be taken. Information from in-vehicle sensors and roadside equipment is used to develop control actions which alter the vehicle's speed and steering control and potentially activate its pre-crash safety system.
- **Automated Vehicle Operations—**This service enables “hands-off” operation of the vehicle on automated portions of the highway system. Implementation requires lateral lane holding, vehicle speed and steering control. Communications between vehicles and between the vehicles and supporting infrastructure equipment supports cooperative check-in to the automated portion of the system and transition to automated mode, coordination of maneuvers between vehicles in automated mode, and checkout from the automated system as the driver resumes control of the vehicle.
- **Cooperative Vehicle Safety Systems—**This service enhances the on-board longitudinal and lateral warning stand-alone systems by exchanging messages with other surrounding vehicles and roadside equipment. Vehicles send out information concerning their location, speed, and direction to surrounding vehicles. The roadside equipment provides information about potential safety hazards in the vehicle path such as stalled (unequipped) vehicles, wrong-way drivers, debris, or water hazards. The on-board systems can then process this information and present warnings to the driver including headway warnings, merge warnings, unsafe passing warnings, and warnings about hazards detected in the vehicle path. Special messages from approaching emergency vehicles may also be received and processed.

CONNECTED VEHICLE TECHNOLOGY

The final category includes topics found in research related to complimentary ITS applications intrinsic to CV technology. CV has the potential to transform ITS operations in other modes of transportation, like powered two-wheeled vehicles and pedestrians, as well as enhance ITS solutions based on technology interoperability. The following services were included among research terms analyzed for this purpose:

- **Traffic Operations—**This service focuses on determining further impacts CV may present to traffic operation in general. Among the services considered were traffic monitoring, road pricing systems, speed harmonization, queue warning, eco-friendly signal operations, traffic enforcement, and even on-demand lighting.
- **Cooperation/Automation—**This service relates to the interconnectivity between CV and Automated Vehicle (AV). Research in this area has focused on determining how CV capabilities can benefit AV through enhanced communication, such as dynamic routing; collaborative merging strategies; effects of autonomous vehicles on traffic signals; and cooperative and adaptive speed harmonization.
- **Other Modes of Transportation—**This service focuses on the impact of CV on other modes of transportation, particularly for commercial vehicles, powered two-wheelers, pedestrians and bicycles.

- **Connectivity and Modeling—**An area that has been the focus of significant research is the connectivity issues among CV. This service relates to technical-specific issues in current research, seeking to determine shared use of the 5.9 GHz spectrum transmission interference levels through test-beds and simulators.
- **Other Technologies Related to CV—**This service seeks to analyze the research made relating to the application of technology to enable CV. Communication technologies include radio connectivity, dedicated short-range communications (DSRC), Wi-Fi, infrared, radar, Bluetooth, fourth-generation (4G), and fifth-generation (5G) connectivity.
- **Safety Enhancements—**This service seeks to describe CV capabilities that can improve safety significantly. The services considered with the potential to enhance safety include: collision avoidance systems (such as in-vehicle crash warning systems), improved alert notifications (focusing on minimizing possible driver distraction), and enhanced awareness of roadside vulnerable users (like roadway workers or pedestrians).
- **ITS Interoperability—**CV capabilities were not only found related to safety, but to a variety of ITS applications. Articles were found discussing the interoperability of ITS applications with CV, ultimately enhancing their performance. Among the technologies analyzed include vehicle location, electronic toll collection, and payment systems.
- **Information Collection and Dissemination—**Another recurrent topic found was the ability to collect and send data through CV technologies. The service considered for this topic focuses on deciding the frameworks used to collect a vehicle's trip information (like origins and destinations), as well as receiving information (like speed warnings and pre-defined routes), primarily through in-vehicle devices. The availability of data is subject to high levels of privacy controls and will require secure systems for transfer, use, and retention.
- **Planning and Regulation—**This service considers impacts on agencies' planning and regulation procedures. Transportation planning efforts will increasingly need to anticipate and address the impacts of CV. CV will likely be a part of a wide variety of planning functions including long-range plans, improvement programs and capital plans, asset management plans, operations, safety plans, and a variety of modal planning. Among the services considered include strategies that can be implemented at different geographic levels.
- **Funding—**Another source of support may be public/private partnerships, including relationships with data service providers and commercial application developers. State agencies may be able to charge for private use arrangements, which are subject to 23 U.S.C. 156.

CHAPTER 3. CONNECTED VEHICLE IMPACTS ON CORE INTELLIGENT TRANSPORTATION SYSTEM FUNCTIONS

This chapter discusses potential Connected Vehicle (CV) impacts on core Intelligent Transportation Systems (ITS) functions. For each ITS category considered, the research discusses:

- **Current Services and Trends—**Summarizes the current state of the practice and the results of the literature search.
- **CV Technology Opportunities—**Identifies ways CV technology may be incorporated into ITS and operations.
- **Impacts on ITS Planning and Deployment—**Identifies the potential impacts of CV technology on ITS planning and deployment.
- **Impacts on Data—**Identifies the potential impacts of CV technology on data.
- **Impacts on Operations—**Identifies the potential impacts of CV technology on data.
- **Roles and Responsibilities—**Identifies key roles and responsibilities.
- **Challenges and Uncertainties—**Lists issues that need to be resolved and issues that may influence the implementation of CV technology.

Following the discussion of the topics identified above, a relevant case study on agency examples in incorporating connected vehicle technology into ITS planning, programming, deployment and operations is presented.

TRAVELER INFORMATION

Traveler information systems refer to strategies designed to inform transportation users of various aspects important for their trip. Traveler information services have evolved from television and radio reports (which are still heavily used) to public sources such as 511 to numerous smartphone and telematics applications that provide not only real-time data but predictive estimates of travel times.

Current Services and Trends

With proliferating data sources that can be used in combination by ITS and operations personnel, data sharing frameworks are of great interest. The goal of these is to provide a structure for enhancing data transferability while addressing security concerns. In general, there is a pervasive sentiment that traveler information can improve mobility as data accessibility increases. There seems to be a growing acceptance of private information sources, as these sources of information could offer mobility information at a greater level of detail than public ones. Furthermore, as accessibility to data increases, research has been able to focus on specific transportation issues, such as ridesharing services, or location specific traveler information. However, research continues to highlight the importance of security and data privacy, the need for which has been tackled in a variety of different ways in pilot projects.

Connected Vehicle Technology Opportunities

Vehicle-based data may potentially offer more specific and detailed information. CV technology may be able to provide a wealth of detailed data to support traveler information services including vehicle speeds, weather-related roadway condition information (wet or icy pavement) and even information on crashes. Until a larger portion of the fleet is outfitted with the technology other means of collecting traffic volume data will be needed. It is also unclear whether data generated from vehicles would be made available for traveler information purposes.

Tailored information could be provided directly to the vehicle. In-vehicle telematics offer the potential to provide tailored messages to individual vehicles or groups of vehicles based on their speed and location. Some of this is currently done through smartphone apps but could be enhanced with CV related data. For example, very detailed data on icy spots could be broadcast to individual vehicles approaching that location.

Site-specific warning signs such as those on curves or in school zones may be supplemented by virtual or targeted data. Warnings could be sent to specific vehicles that are approaching these zones at too fast a speed. General warning signs could potentially be removed if CV technology reaches full deployment.

Impacts on Intelligent Transportation Systems Planning and Deployment

Traveler information has been increasingly migrating to the private sector in recent years and likely will continue to do so. The ability to access vehicle data for traveler information purposes remains unclear. However, it is likely that there will be a market for data from both private and public sources. Private parties, which already collect data from navigation devices and smartphones and process it for use by consumers, will continue to refine and enhance products. Agency understanding of and partnership with private sector providers will become increasingly important as part of this shift. CV-related data and products are likely to expand their current role as a source of information for companies and organizations in the market for data and traveler information.

Information delivery is evolving as more in-vehicle communications are harnessed as the delivery source to travelers. Sources such as Dynamic Message Signs (DMS), Highway Advisory Radio (HAR) and 511 are less needed and are likely to become obsolete in the short- and mid-term as private sources take over and are able to provide more detailed, targeted information. Even for emergency situations, agencies may find it more efficient to use private sources rather than to support legacy systems.

The use of CV technology to deliver messages directly into the vehicle will provide the opportunity to tailor messages more directly based on vehicle location and possibly speed, and eventually allow the phasing out of current information services such as 511 and DMS. Fixed asset DMSs may ultimately be replaced, but more slowly, as in-vehicle penetration of CVs needs to grow to a higher level before DMS can be fully removed. If shorter lives are anticipated for certain fixed assets, rather than invest in full DMS replacements, agencies may look at less expensive options; for example roadside or portable signs.

Public agency goals on topics like social equity will likely not perfectly align with private sector operations. Agencies will need to work to ensure traveler information is reaching as many transportation system users as possible, not merely those with the newest technology available.

Impacts on Data

It is anticipated that agencies will continue to collect data but become less involved in providing information. CV-related data will be useful to public agencies in areas such as system management and collection of system condition data. However, dissemination of information is likely to migrate to targeted in-vehicle systems, and private sector sources are likely to grow. Use of in-vehicle systems and probe data will likely mean a larger role for the private sector, and the need to develop partnerships that serve the needs of all parties.

Agencies will need to ensure the security and privacy of data. Current pilot projects have dealt with this in a variety of ways, but generally find it to be a challenge.

Impacts on Operations

As CV technology penetration grows, agencies will find greater opportunities for more complex and tailored traveler information applications. Agencies will have the opportunity to expand their service offerings but will need to develop new standards and guidance on how and when to employ traveler information functions and how to facilitate capacity development and experimentation without endangering the public or investing in inefficient outcomes.

Agencies can potentially increase active traffic management with better real-time speed data and more opportunity to engage and reroute traffic.

Roles and Responsibilities

Public sector agencies have a major role in setting a course for traveler information, managing traveler information applications, setting guidance and standards, and ensuring equity. They would likely benefit from working with private sector partners in developing and sharing data and gaining access to distribution networks.

Challenges and Uncertainties

The timing of CV and Automated Vehicle (AV) market penetration is uncertain. Agencies will need to closely track private sector developments in order to make sound decisions regarding changes to legacy ITS traveler information systems. While it appears that systems such as 511 and HAR could potentially be phased out, DMS and systems related to emergencies and hazardous conditions must be more carefully considered.

Ownership and use of CV-related data is an issue that will impact traveler information services. This is an area where agencies and private vendors of traveler information will likely want to work together to make sure that this information is available to serve the public while protecting the privacy of individual drivers.

Case Study on Virtual Dynamic Message Signs

DMS, also known as variable message signs, are installed on highways so that the traffic management center can provide current information to the traveling public about matters such as crashes, detours, and weather warnings. These traditional DMS systems are expensive to deploy and require ongoing maintenance. Aside from the sign itself, agencies also need to invest in supporting structures and communications. Although DMSs provide valuable information to the traveling public, limitations such as legibility distance and language barriers can cause comprehension issues and excessive braking.[9]

The Mid-Atlantic Universities Transportation Center (MAUTC) has studied the potential benefits and costs to utilize CV technology to provide a virtual DMS system.[10] They found that CV technology could provide a more cost effective and flexible solution through virtual DMS. The messages may be received through an in-vehicle system using CV communications. Messages could be made audible and/or converted to a different language.

To illustrate the costs of deploying a virtual DMS project in comparison to a traditional DMS project, an average traditional DMS project and a hypothetical virtual DMS project were envisioned in order to itemize the costs. For these example projects, capital costs of traditional and virtual DMS systems are compared at a high level. The traditional DMS system project consists of two DMSs for each side of the freeway, related supporting structures and controllers, and a half-mile of fiber-optic communication. The virtual DMS project consists of two Road Side Units (RSU) for each side of the freeway and backhaul communications for each site.

Table 1 lists and compares the capital costs of a traditional infrastructure-based and CV-based, virtual DMS system. The total average cost of the traditional DMS system is approximately $560,000 and total high-end cost of the CV-based virtual DMS system is approximately $122,000. As this hypothetical example shows, the CV-based system can potentially cost much less because of the lower asset requirements and labor costs. For example, while a traditional DMS needs to be mounted across the highway so that it is in line of sight for drivers, an RSU can be installed along the road since messages are received inside the vehicle. In addition to being less expensive, the RSU may be a more versatile investment, as it can be utilized for other in-vehicle messages such as work zone and queue warnings, as well as for data collection.

[9] Federal Highway Administration, Connected Vehicle Impacts on Transportation Planning: Primer (FHWA-JPO-16-420), June 2016, page 30.
[10] http://www.matsutc.org/wp-content/uploads/2015/07/Alona-Green-Paper.pdf.

Table 1. Preliminary capital cost comparison of traditional and virtual dynamic message signs.

Traditional DMS Item[1]	**Traditional DMS Total Average Cost**[1]	**CV-Based Virtual DMS Item**	**CV-Based Virtual DMS Total Maximum Cost**[2]
DMS (2)	$217,000	RSU (2)	$42,400
Support Structures (2)	$231,400	–	–
Communications and Power (0.5 mile)	$67,500	Backhaul Communications (2)	$80,000
Controller and Other (2)	$43,800	–	–
Total	**$559,700**	**Total**	**$122,400**

(Source: Federal Highway Administration, *Connected Vehicle Impacts on Transportation Planning: Primer* (FHWA-JPO-16-420), June 2016, page 30.)

[1] http://www.matsutc.org/wp-content/uploads/2015/07/Green-Final-Presentation.pdf, slide 12.

[2] Preliminary estimates have large ranges. The maximum value is presented here.

In order to receive and display messages from the RSU, the traveling public would need to be in compatible CV-equipped vehicles. In the short term, the traveling public would be responsible for investing in an aftermarket On Board Unit (OBU) (similar to toll transponders). Given that current DMS systems provide information to the public at no cost, it would be difficult to motivate voluntary investment if this were the only benefit. Agencies may consider providing incentives or offering to install aftermarket units in order to pilot the virtual DMS system and introduce it to the traveling public.

As market penetration of CV-enabled passenger vehicles matures, and as traditional DMSs reach the end of life, agencies may consider investment and transition to a CV-based virtual DMS. During the transition to market maturity, agencies may need to operate in a mixed environment with both traditional and virtual DMS systems.

FREEWAY MANAGEMENT

Freeway management includes systems and services designed to optimize traffic flow and safety on limited access roadways. Related ITS resources include Closed Circuit Television (CCTV) cameras, vehicle detection systems, ramp meters, service patrols and traffic management staff and software.

Current Services and Trends

Current research is focused on how CV can improve information dissemination; from investigating how roadside equipment can evolve to incorporate CV to experimenting with new innovative ways to disseminate freeway information to users, like smartphone applications and on-board equipment. Research is also currently focusing on ways to enhance data collection and freeway surveillance using CV technology, ultimately improving traffic operation strategies, like more efficient speed harmonization strategies and dynamic lane management.

Connected Vehicle Technology Opportunities

An important opportunity presented by CV technology is that it may allow agencies to have enhanced data on traffic conditions on freeways with a potential lower cost than with current strategies.

CV technology could advance the shift from reactive to proactive traffic management. Having reliable real-time data could enable traffic agencies to consider new operational strategies, shifting from fixed reactive strategies, to more dynamic operations that incorporate the unique conditions of each event.

Data from CV has the potential to improve freeway operations significantly, at a low cost. This premise will likely depend on many factors, like CV penetration rates, data ownership, management, and integration. Best-practices will likely define data management frameworks as research continues to develop in this area.

CV technology offers an opportunity to reduce freeway impacts of traffic incidents. With a more efficient Traffic Information Dissemination system, agencies would be able to alert users of traffic condition changes with greater precision and timelier information, ultimately reducing congestion on freeways due to traffic incidents.

The CV technology used for freeway management may also evolve to support asset management activities. Pavement and some bridge condition information could potentially be collected from the vehicle.

Impacts on Intelligent Transportation Systems Planning and Deployment

Over time, the combination of CV and AV technologies is expected to reduce freeway crashes significantly. This would free up resources currently used for incident management to support other needs, such as the communications and security infrastructure needed to support these systems. These changes would in turn impact the mix of personnel requirements for ITS and operations agencies.

A relatively small market penetration of CV technology may allow agencies to reduce costs currently incurred in specialized data collection activities for asset management.

Impacts on Data

CV market penetration may lead to better real-time data resources and more opportunity for benefits from active management of freeway corridors, even those without heavy ITS instrumentation. As with other ITS functions discussed, there would need to be a mechanism in place for the collection, analysis, and storage of new CV data streams. This mechanism should allow for partnership and coordination with the private sector to optimize efficiency.

Impacts on Operations

As noted earlier, CV technology could potentially advance the shift from reactive to proactive traffic management. Having reliable real-time data could enable traffic agencies to consider new operational strategies, shifting from fixed reactive strategies, to more dynamic operations that incorporate the unique conditions of each event.

Roles and Responsibilities

Public sector agencies have led—and will likely continue leading—investment in freeway management infrastructure and applications, as well as the establishment of standards and goals for the utilization of this infrastructure. As CV technology advances, public agencies would likely benefit from working more with private sector partners in developing and sharing data and gaining access to distribution networks.

Challenges and Uncertainties

To incorporate CV technology, traffic management agencies will likely need to upgrade current data management and security systems, seeking to incorporate data from CV technology. This may result in significant investments in infrastructure (like larger data servers and roadside equipment), and personnel training (accounting for analysis of large quantities of data and more dynamic freeway operation strategies).

As vehicular technology evolves, there is uncertainty on the effect it will have on traffic safety. Although CV technology has the potential to improve safety, there are still many questions on how information can be disseminated to drivers without increasing distraction. Furthermore, there are still questions regarding the impact of CV technology on the current fleet of vehicles, specifically about whether aftermarket products can be safely incorporated into currently non-equipped vehicles.

Case Study on Curve Speed Warning Systems

CV technology promises the opportunity to reduce physical infrastructure and to communicate and tailor safety warnings to individual vehicles or groups of vehicles.

Current Curve Speed Warning (CSW) systems use DMS and radar that display warnings to drivers when their travel speeds exceed safety thresholds. CV technology can potentially integrate data from the infrastructure (e.g., slippery road surface condition) and vehicle to deliver more accurate and robust warnings to drivers through an in-vehicle display. U.S. DOT has released a Concept of Operations on CSW (and other V2I safety applications) describing the user needs, benefits, and operational scenario in detail.[11]

California Partners for Advanced Transit and Highways (PATH) have conducted preliminary tests on a prototype CSW application. Results showed that the system was able to integrate

[11] https://rosap.ntl.bts.gov/view/dot/26496.

vehicle sensor, digital map, and Global Positioning System (GPS) information and provide appropriate warnings when speeds were too high.[12]

To illustrate the costs of deploying a C/AV CSW pilot system, table 2 presents a high-level estimate of the capital costs to deploy C/AV infrastructure, equipment, and CV CSW in a hypothetical CSW pilot project. In this hypothetical project, RSUs would be installed along 10 curves with high crash rates and aftermarket OBUs would be installed on 30 agency vehicles. The total cost of the project would be an estimated $461,000 to $1.1 million.

Table 2. Preliminary cost estimates for connected vehicle curve speed warning.

Item	Quantity	Per Unit Cost	Total Costs
RSU	10 curves	$13,100-$21,200	$131,000-$212,000
Backhaul Communications	10 curves	$3,000-$40,000	$30,000-$400,000
Light Vehicle Aftermarket OBU	30 vehicles	$1,000-$10,000	$300,000
C/AV Project Total			**$461,000-$1,073,000**

(Source: Adapted from: Federal Highway Administration, *Connected Vehicle Impacts on Transportation Planning: Primer* (FHWA-JPO-16-420), June 2016, page 44.)

When piloting the CV CSW application, the project timeframe should ideally be long enough to allow an adequate sample of data to be collected and analyzed. Then the CV CSW data could be compared with conventional CSW data to gauge its ability to provide accurate information in a timely manner and motivate speed compliance.

In the short term, CV may supplement current static and radar-based signs. In the medium to long term, as CV technology reaches higher market penetration, the traveling public may receive in-vehicle warnings, which has the long-range potential of making physical signs obsolete. Infrastructure deployed during this transition should continue to support the safety needs of unequipped vehicles. Furthermore, as AV technology improves over the medium to long term, fully automated vehicles may utilize both on-board sensors and CV technology to adjust the vehicle speed accordingly.

ARTERIAL MANAGEMENT

Arterial management strategies are designed to improve traffic flow and safety along arterial roadways. They are focused heavily on improving the efficiency of traffic signal operations but may also include ITS elements common to freeway management.

Current Services and Trends

Researchers are investigating the best approach to incorporate CV technology into arterial management strategies, seeking to improve mobility systemwide with the use of data from CV. It is expected that arterial management could be enhanced by having more dynamic control

[12] https://merritt.cdlib.org/d/ark:%252F13030%252Fm52n5403/2/producer%252FPRR-2010-26.pdf.

strategies, at a potentially lower cost. Specifically, FHWA's CV pilot program is testing the communications between CV-equipped vehicle and signal controllers to determine how dissemination of Signal Phase and Timing (SPaT) information can enhance arterial flow and safety. Furthermore, as with freeway management, researchers are evaluating possibilities to enhance current network surveillance and regional traffic management systems, looking at strategies that would reduce congestion and its environmental externalities across the network, moving from corridor analysis to systemwide solutions.

CV Technology Opportunities

One of the most important opportunities presented by CV technology is to communicate with infrastructure to provide more efficient network mobility. Transmitting SPaT information (and MAP or intersection geometric information) to the vehicles can enable them to reduce the number of stops. Feeding vehicle information back to dynamic control systems can potentially mitigate both congestion and its environmental impacts.

CV technology presents an opportunity to improve safety-related strategies. CV technology can be used to warn drivers if their trajectory is likely to result in a traffic signal violation, and could extend the green if a potential violation is imminent, thereby reducing the risk of a conflict. It could also be used to provide in-vehicle warnings regarding approaching emergency vehicles including their location and direction.

Better and more reliable network operation data may be available through CV data. As for freeway management systems, CV technology could allow agencies to have reliable data to characterize traffic conditions that cause non-recurring congestion on arterial networks, including identification of weather conditions and temporary lane blockages.

CV technology presents an opportunity to improve safety for non-motorized users. There has been significant work in the development of CV technology that can be incorporated into smartphones. This would allow pedestrians and cyclists to communicate their location and movement to vehicles, providing advanced warning of their presence. Warnings could be sent back from the vehicles to non-motorized users. Safeguards could also be brought into the infrastructure; for example, controller based CV technology could detect a vehicle about to run a red light and defer the pedestrian phase of the signal.

The CV technology used for arterial management may also evolve to support asset management activities (as noted in the freeway management discussion). Pavement and some bridge condition information could potentially be collected from the vehicle and collected through roadside infrastructure.

CV technology also allows a better "picture" of the vehicles approaching the intersection including queue locations for side street and main street which can be used to optimize the signal timing.

CV technology can provide an alternative method using communications and standardized message sets to request transit signal priority and emergency vehicle preemption (PREEMPT).

Impacts on Intelligent Transportation Systems Planning and Deployment

CV technology combined with improved control software could provide opportunities to automate real-time operations and improve upon the adaptive control systems that exist today. Ultimately fewer resources could be expended on signal operations and retiming.

Impacts on Data

Data from CV has the potential to improve arterial operations significantly, at a low cost. This premise will depend on many factors, like CV penetration rates, data ownership, management, and integration. Best-practices will likely define data management frameworks as research continues to develop in this area.

A relatively small market penetration of CV technology may allow agencies to reduce costs currently incurred in specialized data collection activities for asset management.

Impacts on Operations

Reduced crash rates would help first responder agencies stretch their resources and reduce the amount required to replace or repair infrastructure that is often damaged in crashes such as signal supports, signs and streetlights.

CV technology could advance the shift from reactive to proactive traffic management even on arterials with limited ITS infrastructure in place. Having reliable real-time data could enable traffic agencies to consider new operational strategies, shifting from fixed reactive approaches, to more dynamic operations that incorporate the unique conditions of each event.

Roles and Responsibilities

Public sector agencies lead investment in arterial management infrastructure and applications and determine the standards and goals for their utilization. Agencies will need to work with private sector partners in developing and sharing data and gaining access to distribution networks.

Challenges and Uncertainties

Opportunities exist to incorporate the needs of non-motorized users, as noted above. However, there are challenges in providing access; many non-motorized users, for example, may not have the latest smartphone technology. There is also concern that more efficient signal operations may result in increased arterial speeds, increasing the risk to non-motorized users. Further, current cellphone and nomadic device technology does not provide location information accurate enough for most vehicle warning systems. However, if this aspect can be overcome—then pedestrian devices could provide a benefit to the visually challenged and other special needs populations.

Current institutional management of many arterial systems presents a significant challenge. Arterial systems are managed at the State and local level, sometimes both. Arterial corridors may go through multiple jurisdictions with different levels of resources and operating philosophies. Signal equipment is supplied by a variety of manufacturers and there are systems in the field of different vintage. These factors present a challenge in incorporating CV into arterial corridors and realizing the potential benefits.

Today's traffic control systems (including adaptive) largely rely on volume and occupancy—derived from either road loops or the equivalent using out of pavement technology. CV monitoring cannot provide accurate volumes or occupancy—so today's control algorithms need to determine how to use such parameters as travel times and spot speeds to improve traffic flow.

Case Study on Mobile Pedestrian Signal Systems

Installing CV technology on arterial infrastructure and integrating it into traffic signal control could potentially enhance the safety of pedestrians and cyclists. Integration of SPaT/MAP[13] data with advanced vehicle safety systems could potentially help to reduce incidents, protect pedestrians and cyclists as well as smooth the path of emergency vehicles.[14]

The mobile pedestrian (and bicyclist) signal system (PED-SIG) application allows users to broadcast his/her location and request extend walk (green) time. Users interface with infrastructure through an application on a CV-enabled smartphone. The use case for pedestrians is for senior citizens and the disabled who need more time to cross the intersection. The application also can provide visual and haptic feedback to help visually impaired users. The use case for bicyclists is at actuated intersections where bicycle detection and travel time is not sufficient. The application also can collect data and inform authorities of traffic signals that should be adjusted to better accommodate bicyclists.

Several agencies and companies are working to develop and test PED-SIG technology. The Arizona Test Bed in Maricopa County currently is testing various applications, including a pedestrian mobility application.[15] The Savari SmartCross is an example of an application to aid visually impaired stakeholders.[16] (PED-SIG is the generic application name, while SmartCross is a specific application developed by Savari.) Finally, the NY Connected Vehicle Pilot Project is equipping 100 visually impaired pedestrians and plans to develop a navigation and crossing aid to assist this population using the SPaT and MAP messages being broadcast on DSRC.

To illustrate the costs of deploying a pilot mobile pedestrian signal system project, a hypothetical project focused on a pedestrian and bicyclist mobility application helps to explore the costs and benefits of PED-SIG. In this hypothetical project and PED-SIG

[13] The SPaT message provides information regarding the signal phase displayed (permitted movements) and the time for each such maneuver—i.e., when the movement will no longer be permitted. The MAP message is required in order for the vehicle to assess its position and determine which signal display (signal group) "controls" the lane the vehicle is occupying.

[14] Federal Highway Administration, *Connected Vehicle Impacts on Transportation Planning: Primer* (FHWA-JPO-16-420), June 2016, page 44.).

[15] http://itsmd.org/wp-content/uploads/Faisal-Saleem-Vehicles-Test-Bed-Deployment-and-Lessons-Learned.pdf.

[16] http://savari.net/solutions/smart-phone/.

application, a bicyclist or pedestrian broadcasts his or her location information and makes an extension request to the RSU. The user would receive a response if the request was successful. The RSU processes the request and interfaces with the traffic signal controller.

Table 3 presents a high-level estimate of capital costs to deploy CV infrastructure, equipment, and the PED-SIG application associated with this hypothetical project. RSUs would be installed at each of the 10 intersections and pedestrians/bicyclists would be equipped with a CV-enabled smartphone. Each intersection would require a signal controller and backhaul upgrade. While there are separate applications with various mobility and safety features, creating a comprehensive application would require more software development costs. The total budget of this project ranges from $412,000 to $1.1 million.

Table 3. Preliminary cost estimate for mobile accessible pedestrian signal system.

Item	Quantity	Per Unit Cost	Total Costs
RSU	10 intersections	$4,100-$21,200	$41,000-$212,000
Signal Controller Upgrade	10 intersections	$3,200	$32,000
Backhaul Communications	10 intersections	$3,000-$40,000	$30,000-$400,000
Mobile Application Development	1	$300,000	$300,000
Mobile Smartphone Upgrade	30 units	$300	$9,000
C/AV Project Total			**$412,000-$1,114,000**

(Source: Adapted from: Federal Highway Administration, *Connected Vehicle Impacts on Transportation Planning: Primer* (FHWA-JPO-16-420), June 2016, page 44.)

In deploying PED-SIG projects, agencies should take precautions to provide consistent and intuitive information for the safety of all users. For example, if the extended walk time is being granted, the walk countdown and traffic signals need to be coordinated.

Along with the data collected from the mobile applications, surveys also should ideally be conducted to assess both the actual and perceived impact. A secondary performance measure of level of service for motor vehicle traffic also may be useful.

In the short term, CV technology introduces a novel way for road infrastructure to respond to the needs of vulnerable users. Over the medium to long term, as market penetration of CV-enabled smartphones and passenger vehicles increases, the benefits of a connected vehicle environment may be fully realized.

ARCHIVED DATA MANAGEMENT

One of the most important premises of CV is the ability to have better transportation system data that can be analyzed and used to improve real-time system operation.

Current Services and Trends

Current deployment of CV technology is limited to demonstration projects. Recent pilot deployments in Southeast Michigan have provided large amounts of detailed data regarding the performance of CV communication between both vehicle and the infrastructure. However, this data was collected using on-board flash memory chips necessitating the physical access to the vehicles on a periodic basis—which is not practical for a largescale deployment.

Current FHWA-sponsored pilot projects in New York City, Tampa and Wyoming are building on those findings. The NY and Wyoming projects are collecting this data via the CV communications mechanism and are working out the techniques for accomplishing this. State DOTs are now deploying CV infrastructure in some of their major corridors. At present, there is little information on how these technologies will impact ITS and operating strategies, but agencies can expect new findings over the next several years.

Connected Vehicle Technology Opportunities

CV technology provides a major opportunity to increase the amount and quality of data used for real-time operations, research and evaluation. Combined with data analytics, more scenarios can be evaluated and incorporated into increasingly-sophisticated decision support systems.

CV data can be used to enhance current services and over time replace existing services more cost-effectively. However, CV will produce extremely large quantities of data that will need to be reduced, managed and analyzed in order to provide useful information. There are also issues with privacy and security that need to be addressed.

Impacts on Intelligent Transportation Systems Planning and Deployment

As connected and automated vehicle technologies evolve, it is likely that a mixed-fleet of vehicles including AVs, CVs, and traditional vehicles will share the roadway. Such mixed-fleets could present challenges in terms of real-time operations and infrastructure investments. Here, archived data management would be key to provide insights on the road usage and trends of this mixed-fleet. This information can be used to populate models that help determine the timing and feasibility of important decisions; for example, when is it feasible to set aside an AV-only lane and what reduction can be made in its width?

Impacts on Data

CV-enhanced data streams promise the ability to integrate and utilize real-time data for different agencies' activities and operations. For this to happen, a data management framework needs to be designed, allowing real-time data integration from different data sources (automobiles, transit vehicles, trucks, mobile devices, and infrastructure) and communication channels (Wi-Fi, 5G, DSRC, and other radio communications). Furthermore, processes need to be defined to ensure high-quality information, efficient data processing, and secure data-sharing procedures.

There is a need to enhance system security to prevent hacking and data tampering, as security concerns continue to increase. Furthermore, the data management system needs to protect users' privacy, promoting safety among the multiple stakeholders involved. Data ownership and usage limitations may impact data availability and usage.

There is a need to define data management standards, allowing agencies to incorporate CV data in their current system architectures. This process will likely be defined in detail as CV technology continues to roll out.

Impacts on Operations

With this enhanced data, agencies may be able to deploy enhanced weather applications, enable real-time signal priority, broadcast reliable traveler information, enhance fleet management applications, and develop safety advisory systems.

More detailed information on traffic impacts of adverse weather, or queueing patterns behind incidents would provide opportunities to improve operating and response strategies. Responder after-action reports regarding incidents or other non-recurring events may be greatly improved with the use of CV data.

Roles and Responsibilities

Public sector agencies are likely to be the primary data managers for ITS applications, though that role may evolve in partnership with the private sector. Current and future agencies' data managers will need to update their skills to efficiently use new real-time data sources and improve the agencies' operations.

Challenges and Uncertainties

Data ownership and use will depend on agreements made through the collection and sharing processes. Public agencies and private stakeholders will need to work together on mutually beneficial agreements regarding data that also protect the data rights and privacy of travelers.

Critical to this aspect of CV deployment will be the cooperation between all parties as to how "probe data" will be supported and what data can and will be collected. While R&D project managers and researchers may sometimes desire to "collect everything," this is not practical due to backhaul limitations, storage limitations, and privacy concerns. Both public agency and private CV stakeholders may benefit from an overall data collection plan which pushes "edge computing" to the field devices and Transportation Management Center (TMC) systems and distributes useful information that can be analyzed to improve the operation and measure the benefits.

Case Study on the U.S. DOT Connected Vehicle Pilot in Wyoming

CV data may be used to enhance current traffic management services, and, over time, potentially change the way certain services are performed. However, CVs will likely produce extremely large quantities of data that will need to be condensed, stored, secured and analyzed in order to provide useful information and measure performance. The three CV Pilot Deployment Programs in Wyoming, Tampa, and New York City have released Data Management Plans and Data Privacy Plans in order to provide a framework that addresses these issues and can be adopted by other agencies looking to pursue CV deployments.

The program led by Wyoming Department of Transportation (WYDOT) is intended to develop a suite of applications that utilize vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication technology to enable overall improvements in WYDOT's traffic management and traveler information practices to reduce the impact of adverse weather on travel in the I-80 corridor. These applications support a flexible range of services from advisories, roadside alerts, parking notifications and dynamic travel guidance. Information from these applications is made available directly to the equipped fleets or through data connections to fleet management centers (that will then communicate information to their trucks using their own systems). The pilot includes the deployment of approximately 75 RSUs and 400 OBUs.

The following is a summary of WYDOT's CV data protection and security concept:[17]

- WYDOT hosts a relational database management system responsible for the storage and distribution of all CV data. This system uses persistent identifiers that are available throughout the lifecycle of the data. CV data placed in this data warehouse will be retained for the period of the pilot. WYDOT has adequate online storage so that archiving will not be necessary during the pilot.
- All server systems within the data center, including the systems that support the relational database management system, will have an operating system (OS) and application patches applied on a regular basis. Additionally, critical patches are installed as soon as practical. These servers have physical data protection implemented with RAID (Redundant Array of Independent Disks) 5 and a hot spare drive. A Secure Network Monitoring Protocol tracks and notifies WYDOT maintenance staff of drive failures.
- Critical systems are maintained in geographically separate cities for redundancy and to ensure systems can be recovered in the event of a disaster.
- Backups will be performed on a daily basis and stored in a fireproof locked vault/safe. All information on backup media will be encrypted, whether the backup media is part of WYDOT's rotation or a cloud hosted service. Media retention is planned to be a minimum of three months.
- Database backups are currently maintained for several weeks and include a combination of internal binary-level backups and exports.
- Data administration for the data warehouse is controlled by the data warehouse administrator. Developers who access the database must have a reason to access the data and sign a Computer Environment Access and Non-Disclosure Agreement with

[17] Federal Highway Administration. *Connected Vehicle Pilot Deployment Program Phase 2: Data Management Plan—Wyoming.* Report No. FHWA-JPO-17-470. April 2017.

WYDOT. Developers and consultants will be assigned unique database accounts with appropriately restricted access to information.

- The relational database management system will implement data encryption and audit logging for Personally Identifiable Information (PII) related information.

The Wyoming CV Pilot data that will be collected to support performance measurement and evaluation are grouped into the following four categories (detailed data elements, source, and frequency are listed in the Data Management Plan):

- **System Data—**Data collected from vehicle systems and CV Pilot systems.
- **Non-System Data—**Data collected from external systems and databases necessary to support performance measurement.
- **Survey and Interview Data—**Data collected through electronic surveys of commercial vehicle fleet managers and truck drivers. Additionally, data that may be collected through in-person interviews of WYDOT personnel and other stakeholders.
- **Modeling and Simulation Data—**Data supportive of modeling/simulation activities during performance measurement and evaluation.

The approach to developing the data storage estimates needed to support future evaluation of the pilot program (listed in table 4) was based on initial analysis of likely frequency of certain events happening. These estimates represent a total data storage size estimate for all 75 RSUs and 400 equipped fleet vehicles and commercial trucks over the 18-month demonstration period.

Table 4. Wyoming Department of Transportation connected vehicle pilot deployment program preliminary data size requirements.

Data Category	Total Data	Assumptions/Comments
Sent basic safety messages (BSM) stored on vehicles	200GB	BSM JavaScript Object Notation (JSON) compressed option
RSUs collection of stored BSMs	3TB	All 75 RSUs
Interactions between CVs	20-50TB	Dependent on CVs traveling within range of each other and sharing information
Environmental sensor data	25GB	Estimated 50 vehicles with sensors
Traffic management data	15GB	TMC inputs and outputs
Pikalert data[1]	30GB	Forecasts and Motorist Alerts and Warnings
Traveler information messages	5GB	Sent from TMC
WYDOT TMC systems	20GB	Includes some non-system data
Speed and crash data	10GB	Supporting safety evaluation

(Source: Federal Highway Administration. *Connected Vehicle Pilot Deployment Program Phase 2: Data Management Plan—Wyoming*. Report No. FHWA-JPO-17-470. April 2017.)

[1] The Pikalert System supports the integration and fusion of CV and non-CV weather data to develop alerts and advisories regarding adverse weather conditions along I-80.

The evaluation efforts will measure the level of success of the CV applications deployed in Wyoming through these main performance measures of interest:

- Improved road weather condition reports received into the TMC.
- Improved ability of the TMC to issue general alerts and advisories.
- More effective dissemination and receipt of Infrastructure-to-Vehicle (I2V) and V2I alert/advisory messages from the TMC.
- Improved information to CV fleet managers.
- More effectively transmit and receive V2V messages.
- Automated emergency notifications of a crash.
- Improved speed adherence and reduced speed variability.
- Reduced vehicle crashes.

The data in motion is protected by Security Credential Management System (SCMS) signing for all CV wireless communications and encryption for non-broadcast communications. The data that connects third parties to the WYDOT data center will be transmitted over encrypted Secured Socket Layer (SSL) tunnels. This will provide access to the Commercial Vehicle Operator Portal (CVOP), REST (Representational State Transfer) service end points and other Web sites that need protection (not for general public access). For back haul connections from RSUs and traditional ITS equipment, data will be protected with Internet Protocol Security (IPSEC) Virtual Private Networks (VPN) or private networks. WYDOT will host a relational database management system responsible for the storage and distribution of all CV data. For the CV Pilot program an analysis of each data field will be performed. If it is determined that the field could contain sensitive, proprietary, or PII, the field will be marked and any data added or stored to the field will be required to be encrypted.[18]

PUBLIC TRANSPORTATION

Current CV-related research in this ITS category focuses primarily on enhancing current ITS services in public transportation with CV capabilities.

Current Services and Trends

The transit-focused services that will likely be impacted by CV technologies the most include Computer Aided Dispatch (CAD) and Automatic Vehicle Location (AVL). Although these services are currently being provided as an integrated solution for transit services, it is expected that CV capabilities would allow agencies to enhance such services. Transit Signal Priority (TSP) is being implemented in many cities, particularly where Bus Rapid Transit or exclusive lanes are being provided. Implementation of CV technology on these routes could potentially enhance TSP capabilities. Transit agencies are beginning to test automated and semi-automated

[18] Federal Highway Administration. *Connected Vehicle Pilot Deployment Program Phase 2: Data Privacy Plan, Version 2—Wyoming.* Report No. FHWA-JPO-17-469. April 2017.

systems in confined areas such as campus settings or airports. If these tests are successful, these technologies may be used more in regular service, potentially requiring additional infrastructure support.

Connected Vehicle Technology Opportunities

Since the number of vehicles in any transit fleet is limited and under central control, full market penetration can likely be achieved quickly and major transit routes could receive priority for installation of CV infrastructure.

CV technology could enhance current operations and safety through communication with roadside units and other vehicles. This could improve the effectiveness of TSP operations and also help identify potential safety hazards such as obstacles in a bus lane or pedestrians in crosswalks. Specific CV applications are being developed through U.S. DOT for transit safety including forward collision warnings and curve speed warnings. Other safety applications are designed to detect vulnerable users including bicyclists and pedestrians in crosswalks.

Agencies are beginning to use ridesharing services for first mile/last mile applications. Installation of CV technology at key transfer locations could improve coordination and provide passengers with more accurate wait time information.

CV-enabled transit services will likely be an important data source for transportation agencies. They can serve as effective probe vehicles for both transit and roadway operations since they are continuously on the road.

Impacts on Intelligent Transportation Systems Planning and Deployment

By adopting CV technology, transit agencies could potentially improve service reliability through the integration of their services with other transportation alternatives, such as ridesharing, ultimately making public transportation more attractive to a wider range of users.

Overall agency costs may be reduced if CV technology allows functions such as vehicle tracking and dispatch and TSP to be implemented and operated more cheaply. Greater operational efficiency could also reduce resource requirements.

Impacts on Data

Enhanced AVL and other real-time location and speed data on fleet vehicles will likely support better routing and operations. Enhanced data streams would need to be collected, managed, and archived. Data could be shared with the public to enhance service. Over time, data may be able to support more rigorous operational analysis.

Impacts on Operations

Transit agencies may have the opportunity for more active service management using enhanced real-time location and congestion data. Vehicles could potentially be rerouted more easily with the updated traveler information immediately and widely disseminated to the public.

Transit agencies may have greater opportunity to interface with other agencies involved in active roadway management such as TMCs. This would support event planning and emergency operations.

Roles and Responsibilities

Transit agencies have the potential to lead the deployment of CV equipment on fleet vehicles and design of data collection, management, and analysis processes. In some cases, transit agencies may deploy ITS infrastructure with CV capabilities. In other instances, transit agencies may partner with roadway owners and operators to ensure interoperability. The private sector will continue to play a major role in transit data aggregation, distribution, and supply.

Challenges and Uncertainties

Some of the safety applications being developed will likely require a high market penetration of CV technology among other roadway users. This will take time, and current technologies may become obsolete in the meantime. This is a significant challenge for agencies considering these investments.

Decisions on which parts of the infrastructure are prioritized for CV technology deployment should be coordinated with roadway operations agencies.

Many transit agencies are limited in their ability to procure new technology, by either low-bid requirements or specifications that have not incorporated these technologies.

Case Study on Transit Signal Priority

Many transit agencies use TSP as a way to improve on-time performance and reliability. Transit buses use emitters to send a request to traffic signal controller boxes for signal priority; these process the request and modify the signal cycle accordingly. Typically, TSP logic is to temporarily extend or provide an early start of the original green time. The decision to grant priority and which logic to follow is based on various inputs such as schedule adherence, traffic conditions, bus location, etc.; however, inaccurate and outdated data results in underutilized green times and unnecessary adverse impacts on side streets.[19]

CV technology can potentially introduce a more integrated means to request and grant TSP. The traffic signal system will have more accurate data and enhanced awareness of existing conditions

[19] Federal Highway Administration, *Connected Vehicle Impacts on Transportation Planning: Primer* (FHWA-JPO-16-420), June 2016, page 50.)

(e.g., traffic volume). CV technology has the potential to allow messages to be sent with low latency 10 times per second; those messages can include other data such as vehicle speeds and brake status. Furthermore, CV technology could enable traffic controllers to better handle multiple TSP requests. To enhance safety, emergency vehicle preemption may be integrated on the same communication platform.

Mid-Atlantic University Transportation Center (MAUTC) is active in researching CV-based TSP. A study that evaluated new TSP strategies based on CV technology found in simulations significant improvements in reducing bus delay while minimizing side street impacts. Ongoing research at MAUTC will continue to develop these concepts, including by performing an operational field test.[20] The CV Test Bed in Arizona's Maricopa County has concluded from preliminary results that CV technology is a viable medium for traffic signal priority.[21]

To illustrate the costs of deploying a pilot CV-based TSP project, a hypothetical TSP project helps to explore the costs and benefits of this technology. In this hypothetical TSP application, a transit vehicle OBU would send a request for extended greenlight to an RSU. The RSU would then process the request and interface with the traffic signal controller.[22]

Table 5 presents a high-level estimate of the capital costs to deploy C/AV infrastructure, equipment, and the CV TSP application associated with this hypothetical TSP project. RSUs would be installed at each of the 10 intersections, while aftermarket OBUs would be installed on each of the five transit vehicles. Each intersection would require a signal controller and backhaul upgrade. The total budget of this project would range from $243,000 to $694,000.

Table 5. Preliminary cost estimates for connected vehicle transit signal priority.

Item	Quantity	Per Unit Cost	Total Costs
RSU	10 intersections	$13,100-$21,200	$131,000-$212,000
Signal controller upgrade	10 intersections	$3,200	$32,000
Backhaul communications	10 intersections	$3,000-$40,000	$30,000-$400,000
Transit Vehicle OBU	5 vehicles	$10,000	$50,000
C/AV Project Total			**$243,000-$694,000**

(Source: Adapted from: Federal Highway Administration, *Connected Vehicle Impacts on Transportation Planning: Primer* (FHWA-JPO-16-420), June 2016, page 50.)

In the short term, CV TSP could provide similar functionality as current TSP systems.

20 http://www.mautc.psu.edu/docs/UVA-2012-04.pdf.

21 http://itsmd.org/wp-content/uploads/Faisal-Saleem-Vehicles-Test-Bed-Deployment-and-Lessons-Learned.pdf.

22 http://local.iteris.com/cvria/html/applications/app79.html#tab-3.

EMERGENCY MANAGEMENT STRATEGIES

One of the categories that is not usually mentioned while discussing potential CV impacts is its effect on emergency management systems. CV may have the potential to improve how transportation agencies respond to different emergencies, potentially enhancing the transportation system resiliency and reducing the emergency impact.

Current Services and Trends

Close coordination between emergency managers and transportation management centers, along with advances in communications, has enabled emergency situations to be addressed more effectively. TMCs, for example, have taken a larger role in supporting evacuations with their detection and surveillance capabilities. New technologies are already beginning to work their way into this area, with Unmanned Aerial Vehicles (UAVs) being considered to provide surveillance of areas that are not reachable due to disasters such as floods, earthquakes or landslides.

Connected Vehicle Technology Opportunities

CV technology may help improve the level of information provided to transportation and emergency managers during emergencies. Evacuation routes may not have detection or CCTV, but the combination of V2I and V2V technologies could be used to collect information on evacuation routes and to provide tailored information back to vehicles. For example, CV-enabled vehicles could be guided to shelters with capacity based on their location during an emergency (although there are limitations on existing CV technologies and issues related to private and subscriber-based information dissemination networks that would need to be overcome in this example).

CV technologies could also support the adjustment of evacuation routes and the repositioning of emergency resources "on the fly" by providing more detailed information on traffic conditions. If a key evacuation route freeway fills up for example, traffic could be re-routed to a parallel arterial and signal timing adjusted based on anticipated flows.

In cases of truck accidents or potentially hazardous spills, emergency personnel could obtain information from the vehicle to identify what substances are involved and what resources are needed to respond.

Impacts on Intelligent Transportation Systems Planning and Deployment

Agencies may want to consider the role of CV in emergency planning and ITS deployment along critical evacuation corridors.

Impacts on Data

CV may increase the amount of data that can be collected from the field remotely and also allow communications directly into vehicles. This may reduce the amount of resources required in the field and allow these resources to be dedicated to faster recovery and restoration of infrastructure.

Archived CV data may be valuable in after-action reports and ongoing efforts to improve emergency response plans.

Impacts on Operations

Transportation and first responder personnel already work together closely in emergency situations, but the availability of richer data sources may allow them to combine resources even more effectively, thus reducing cost of response.

Agencies need to ensure the protocols and operational capacity are available to use CV-enhancements in the event of an emergency.

Roles and Responsibilities

Public sector agencies will likely continue to be the focal point of emergency management, though increased partnership with private sector entities can support widespread and valuable data sharing during emergency situations.

Challenges and Uncertainties

In emergency situations, priority needs to go to response. If strategies are to be enhanced by CV, additional resources may be needed to compile and review the additional information that will be coming from the field as well as to implement optimal strategies.

Deployment of CV technology along evacuation routes may have to compete for resources with deployments on roads that experience more severe and recurring congestion. Maintenance of infrastructure that is only used on rare occasions could be a resource challenge as well.

As with most CV and AV applications, privacy and data ownership issues could impact the ability of public agencies to make use of the data. Agencies need to stay involved in the ongoing resolution of these issues.

Case Study on Emergency Vehicle Preemption

Emergency response vehicles (EV), including police vehicles, ambulances, and fire trucks, provide visual and audio alerts of their presence (e.g., sirens and flashing lights) to prompt surrounding vehicles to clear a path. Unfortunately, the effectiveness of these alerts is limited by background and in-vehicle noise, with drivers sometimes having difficulty determining the source and path of the EV. This confusion has resulted in collisions, creating concerns about both safety and mobility.[23]

Traffic signal controllers enable signal preemption by detecting oncoming EVs and changing the desired direction to green, while stopping traffic on all other approaches. EVs are equipped with

[23] Federal Highway Administration, *Connected Vehicle Impacts on Transportation Planning: Primer* (FHWA-JPO-16-420), June 2016, page 26.)

emitters that provide one-way communication requesting preemption. Unfortunately, conflicting requests from multiple EVs needing preemption have resulted in collisions.

A recent study supported by U.S. DOT researched CV-based strategies that could improve safety and response times for EVs in congested urban environments. Through V2V and V2I communication, an EV can broadcast its location, route, and final destination to vehicles and infrastructure in its path. This information can be processed to provide directions that clear a safe path for EVs to their destination. Traffic signals along this path can be optimized to clear downstream intersections.[24] Preliminary results from Arizona's Test Bed in Maricopa County have concluded that DSRC is a viable medium for traffic signal priority.[25]

To help illustrate the costs of an EV preemption pilot project, a hypothetical project in which a Metropolitan Planning Organization (MPO) is implementing the Emergency Vehicle Preemption (PREEMPT) application and related infrastructure is summarized below. Table 6 presents a high-level preliminary estimate of the capital costs to deploy and pilot C/AV infrastructure, equipment, and the PREEMPT application associated with this hypothetical project. The pilot would be on part of the corridor, a 10-mile urban arterial section. There would be about one-half-mile spacing between intersections, totaling 20 intersections. There would be RSUs installed at all intersections and aftermarket OBUs installed on 10 emergency vehicles. The total budget for the initial deployment and testing of the C/AV strategy would range from $433,000 to $1.7 million. There would be other costs not captured here, such as annual operations and maintenance costs.

Table 6. Preliminary cost estimates for emergency vehicle preemption.

Item	Quantity	Per Unit Cost	Total Costs
RSU	20 intersections	$13,100-$21,200	$262,000-$424,000
Signal controller upgrade	20 intersections	$3,200	$64,000
Backhaul communications	20 intersections	$3,000-$40,000	$60,000-$800,000
Light Vehicle OBU with additional features	10 vehicles	$4,700	$47,000
C/AV Project Total			**$433,000-$1,657,000**

(Source: Adapted from: Federal Highway Administration, *Connected Vehicle Impacts on Transportation Planning: Primer* (FHWA-JPO-16-420), June 2016, page 26.)

CONSTRUCTION AND MAINTENANCE MANAGEMENT STRATEGIES

CV technology has the potential to enhance construction and maintenance management systems. Research found for this category focused particularly in two topics: determining complementary and alternative solutions to enhance road weather data collection services, and enhancing safety in work zones.

[24] https://trid.trb.org/view.aspx?id=1329805.
[25] http://itsmd.org/wp-content/uploads/Faisal-Saleem-Vehicles-Test-Bed-Deployment-and-Lessons-Learned.pdf.

Current Services and Trends

U.S. DOT's CV program is involved in the development of applications to support work zone management and maintenance activities, including winter maintenance and other tasks that reduce roadway capacity. CV technology on maintenance vehicles can be used as probes to provide information on roadway conditions. CV technology also provides an opportunity to provide targeted information to motorists, for example, if there is a snow plow ahead but out of sight. There are already efforts underway to implement CV technology in work zones such as in Arizona. These systems will help provide warnings as CV market penetration increases and in the shorter-term can be used to enhance worker safety.

Connected Vehicle Technology Opportunities

Many agencies are starting to bring back detailed weather and roadway condition information from winter maintenance vehicles. Various means of communications are used, including satellite and cell technology. CV technologies provide an opportunity to enhance these efforts; for example, providing warnings and condition information to upstream vehicles via V2I or V2V technology (a function which is currently in the standards development phase).

Temporary CV technology installations could be used to monitor traffic conditions and queues in and around work zones. Movement of construction vehicles and personnel could be monitored to enhance both worker and motorist safety with messages provided to both vulnerable workers and vehicles approaching the zone.

Ultimately some of the more dangerous activities involved with both construction and maintenance may be accomplished with AV. Warnings to approaching traffic would still be required, but these may eventually be transmitted directly to the vehicle. CV technology can work together with advanced traffic management strategies, such as Variable Speed Limits, to enhance work zone safety.

Impacts on Intelligent Transportation Systems Planning and Deployment

CV technologies, through V2I or V2V communications, may allow automatic generation of warnings reducing the workload on TMC operators and field personnel.

CV technology, in a long-run, full penetration scenario, could reduce the need for signs and other field equipment by transmitting warnings and relevant information directly into the vehicle.

Impacts on Data

CV technology presents opportunities for better real-time data on work zone and near work zone facilities. Data resources may support targeted traveler information and active management.

Impacts on Operations

CV technologies have the potential to improve safety through applications of advanced traffic management strategies.

Roles and Responsibilities

Work zone management is largely a public sector role, though partnership with construction firms to ensure interoperability and two-way data flows will be needed for some of the higher level, more active work zone management strategies discussed.

Challenges and Uncertainties

Additional contract requirements to incorporate CV technology may add cost to construction and maintenance activities. Over time, these increases may be offset by reductions in other costs such as temporary signing, but this will require a high market penetration for CV technology.

In providing information on winter conditions, great accuracy is needed especially when there is precipitation and temperatures around freezing. Greater confidence is required in the weather observations coming off vehicles before disseminating traveler information based on the data.

As work zones and maintenance activities are constantly moving, portability of the technology is required and is an important challenge that needs to be addressed. Vendors have been successful in building ITS capabilities into portable installations and will need to do the same in implementing CV technology.

Case Study on Connected Vehicle Work Zone Safety Applications

Work zones disrupt regular traffic flow and can be especially hazardous when drivers are unprepared to respond quickly to temporary traffic control measures. Rear-end crashes (running into the rear of a slowing or stopping vehicle) are the most common type of work zone crash, with the majority of fatal work zone crashes occurring on roads with speed limits greater than 50 mph. U.S. DOT has developed several CV-based strategies to improve safety in these situations, such as Queue Warning (Q-WARN) and Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE).

The Q-WARN system provides drivers with a warning of downstream queue backup to allow drivers to adapt, slow down, and prepare to brake. The traffic data used for queue determination may originate from the vehicles, travelers or roadside infrastructure. Vehicles would broadcast their status when certain parameters are triggered such as rapid deceleration and/or low speed relative to the posted speed limit. Traffic data from vehicles can be broadcast using vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) to upstream vehicles and centrally to a TMC respectively. Q-WARN is part of the Intelligent Network Flow Optimization (INFLO) bundle that aims to improve roadway throughput and reduce crashes through the use of frequently collected and rapidly disseminated data drawn from connected vehicles, travelers, and infrastructure. Q-WARN can be used in conjunction with the INFLO Dynamic Speed

Harmonization (SPD-HARM) application, in which the vehicle operator can adhere to the dynamically recommended vehicle speed for downstream congestion, incidents, and weather or road conditions in order to maximize traffic throughput while reducing crashes.

A small-scale demonstration of the INFLO prototype system was deployed in Seattle, Washington in 2015. A smartphone graphical display mounted on the dashboard of each CV-equipped vehicle provided drivers with two types of Q-WARN messages: a Queue Ahead message that displayed the distance to the back of the queue, and an In-Queue message that displayed the distance and estimated time to the end of the queue. Drivers could expect to receive messages at least a mile in advance of the back of the queue. Participants in the demonstration saw immediate value in both queue warning message types, stating that the messages allowed them to take action in advance of congestion, reducing the need to slow down or stop suddenly.[26]

INC-ZONE is part of the Response, Emergency Staging and Communications, Uniform Management, and Evaluation (R.E.S.C.U.M.E.) bundle that aims to transform the processes associated with incident management. The CV applications included in this bundle (Incident Scene Pre-Arrival Staging Guidance for Emergency Responders or RESP-STG, INC-ZONE, and Emergency Communications and Evacuation or EVAC) seek to quickly detect and assess incidents and their effects on traffic flow, model the evacuation flow, push information to evacuees, and help responders identify the best available resources and ways to allocate them in the timeliest manner. The INC-ZONE application bundle has two components, one that warns drivers that are approaching temporary work zones at unsafe speeds, and or trajectory; and another that warns public safety personnel and other officials working in the zone through an audible warning system.

The INC-ZONE prototype was developed and demonstrated first in Columbus, Ohio and then at the Maryland Police and Correctional Training Commission’s Driver Training Facility in Sykesville, Maryland, both in 2014. The INC-ZONE prototype consisted of an in-vehicle messaging system that provides drivers with merging and speed guidance as they approach an incident zone. The system sends warning messages to drivers if they are arriving at the incident location at an unsafe speed or trajectory, as well as warning messages to on-scene workers.

While demonstration participants believed in the effectiveness of the INC-ZONE application to save lives of first and second responders, as well as motorists, one of the challenges of this demonstration was placing the connected vehicle applications on the responder and oncoming vehicles. Implementing CV messaging between responder and oncoming vehicles to support threat and imminent crash warnings also presented issues. Another challenge and potential improvement area was the implementation of lane-level mapping and an accurate GPS positioning system. The INC-ZONE application needs to be compatible and incorporated into existing responder portable laptops and existing consumer smartphones while using the existing public safety communications equipment to be effective.[27]

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[26] http://www.itsknowledgeresources.its.dot.gov/its/bcllupdate/CVMobility/.

[27] Federal Highway Administration. *Estimated Benefit of Connected Vehicles: Dynamic Mobility Applications*, AERIS, V2I Safety, and Road Weather Management Applications. Final Report. Report No. FHWA-JPO-15-255. August 2015.

CHAPTER 4. CONNECTED VEHICLE IMPACTS OF PERIPHERAL INTELLIGENT TRANSPORTATION SYSTEM FUNCTIONS

This chapter presents findings for the more peripheral Intelligent Transportation Systems (ITS) functions defined in the research. These areas are either broader in scope or less directly relevant to ITS operations. There is greater uncertainty in what these technologies will look like and what role ITS will play in them. As a result, these areas include more generalized descriptions than those for the core ITS functions.

OTHER TRAFFIC MANAGEMENT STRATEGIES

There are some ITS services that can be considered in multiple or other categories, and which have an important effect on transportation networks.

- The first service considered is electronic toll collection. Connected Vehicle (CV) technologies could enhance electronic toll collection significantly through communication with infrastructure devices. This solution could significantly enhance freeway management strategies—enabling a simpler and more efficient operation of toll lanes or congestion pricing schemes.
- Truck parking information systems may also benefit from proliferation of CV technology.
- CV technology could also potentially enhance implementation of more sophisticated ITS strategies such as Integrated Corridor Management and Dynamic Traffic Management.

For the most part, these strategies combine elements of the basic functions identified in chapter 3 under Freeway Management Systems. Other solutions considered in this category include possible enhancements to roadside lighting systems and railroad grade crossings. Research on these topics continues to explore possibilities in these areas, but CV may be a factor that enhances their effectiveness, and thus their adoption—although not a major driver in CV deployment.

VEHICLE SAFETY

Perhaps the most important impact of CV relates to enhancements in vehicle safety. Although these capabilities may not directly impact agencies’ operations, their implementation may have a significant effect on traffic safety, ultimately enhancing traffic safety and improving general mobility conditions. ITS Architectures consider a number of market packages in this category, including collision warnings, lateral and longitudinal control, emergency braking, and vehicle monitoring, among other services, all of which can be potentially enhanced with CV capabilities. For the most part, these technologies would likely be implemented by manufacturers and vehicle fleet owners through purchase of new vehicles or retrofitting of older vehicles. It is anticipated that early adopters of these technologies will be vehicle fleets, including large trucks, delivery vehicles, taxis/rideshare vehicles and rental cars. With consumer options in these areas increasing, however, the pace of adoption among various sectors is not clear. Some of the significant impacts on ITS are described in chapter 3 and include:

- The ability to send targeted messages directly into vehicles could reduce and ultimately eliminate the need for traveler information services such as 511, Highway Advisory Radio (HAR) and Dynamic Message Signs (DMS).
- Roadway infrastructure required for CV and Automated Vehicle (AV) security, as well as communications, could constitute a new responsibility for ITS and operations personnel.
- Truck platooning has the potential for early adoption. This may require new operating policies (i.e., number of trucks allowed in platoon, minimum headway requirements for changing lanes or exiting freeways).
- As CV- and AV-equipped vehicles increase their market penetration, agencies may consider the implementation of exclusive lanes. These lanes could be reduced in width but would require technology to assure that only properly-equipped vehicles are allowed in. This may be a new operating responsibility for ITS and operations personnel.

CONNECTED VEHICLE TECHNOLOGY

The final category analyzed includes topics found in research related to complementary ITS applications intrinsic to CV technology. CV has the potential to enhance ITS operations in other modes of transportation, like powered two-wheeled vehicles and pedestrians. CV capabilities could enhance ITS interoperability as well. As vehicle safety technology continues to roll-out, and adds CV communications capabilities, Vehicle-to-Vehicle (V2V) communication has potential for many applications. An example of this capability could include in-vehicle collision warning alerts shared with downstream vehicles, further enhancing safety conditions on the road. The same capabilities are currently being researched regarding data collection and dissemination. As CV may provide an important source for traffic information, it has the potential to further enhance data collected by collecting trip origin-destination information, assuming agencies can resolve data privacy issues, which could be valuable to planning agencies.

The link between CV and AV is also significant. CV has the potential to enhance vehicle cooperative mobility, which can be seen in truck platooning capabilities. This capability can also be envisioned with automobiles, as researchers discuss potential capabilities for vehicle platooning, adaptive speed harmonization, and collaborative merging strategies. CV could be the gateway for such features, which could be part of future vehicle technologies like AV.

CHAPTER 5. KEY FINDINGS AND RECOMMENDATIONS

This chapter contains a summary of key findings across the Intelligent Transportation Systems (ITS) categories analyzed and a series of activities for short-term, medium-term, and long-term steps forward.

The key findings, and some of the most critical impacts, that will impact both rural and urban transportation networks, include:

- **Migration of Traveler Information Dissemination from Public to Private Sources—** The migration of traveler information dissemination from public to private sources is already well underway. Information increasingly tailored to individual vehicles can be sent directly into the vehicle via navigation systems, smartphone applications or emerging telematics systems which generally include both. Connected Vehicle (CV) technology may be a factor in this as well.
- **Reduction of Crash Rates—**Crash rates are anticipated to decrease overtime, although this may be partially offset by the addition of new vehicles on the road. If these reductions occur, fewer resources can be dedicated to incident management. Some of these funds may be needed to support safe operation of CV and Automated Vehicle (AV) vehicles. This could include communications and security systems, as well as infrastructure related needs such as striping and lighting.
- **Enhancement of Traffic Management Strategies Related to Recurring Congestion—** Traffic management strategies related to recurring congestion, such as ramp metering and signal coordination, will likely be enhanced by CV technologies that will provide data from individual vehicles and communicate directly with roadside controllers.
- **Enhancement of Traffic Management Strategies Related to Non-Recurring Congestion—**Traffic management strategies related to non-recurring congestion, such as road weather, construction and special events, will also likely be enhanced by CV technology that will provide much richer data on real-time conditions via observations from individual vehicles.
- **Resolution of Issues of Ownership, Security, and Privacy of the CV-Related Data—** Issues of ownership, security, and privacy related to CV data that will support ITS functions will need to be resolved before the benefits can be realized.
- **Need for New Operational Policies and Practices—**New operational policies and practices will be needed to address the potential operational impacts of truck platooning, automated vehicles in mixed fleets, and closer headways among vehicles.

The following are actions that agencies may choose to take to prepare for CV impacts on ITS. These are loosely organized into short-term (zero to five years), medium-term (five to 15 years), and long-term (more than 15 years out).

In the **short-term:**

- Operating agencies may choose to conduct outreach to and engage with a larger stakeholder audience, some of whom have not participated in the past. These new stakeholders may include vehicle and telematics manufacturers as well as cybersecurity firms. Several agencies have benefited from the formation of advisory panels, composed of multiple stakeholder public agencies as well as private sector stakeholders. Many agencies have found such panels to be relatively easy to develop and maintain given the cross-cutting energy and enthusiasm around the CV and AV topic.
- Agencies may choose to develop a Concept of Operations (ConOps) for their organization that describes the characteristics of the proposed system and identifies the roles, features, functions, and communications needed and addressed by advancing CV planning efforts.
- Agencies may choose to incorporate planned CV technology into their ITS Architectures and Strategic plans. This may include how modifications to their central systems, data collection, data archiving, and performance measures will occur.
- Agencies may choose to incorporate additional technology investments into their Traffic Management Systems and software. Planning direction will likely be needed on timing, funding, and when technologies will potentially be phased out.
- As agencies collect CV data they will likely need support in the areas of data security and privacy. Even if private parties have the primary role, agencies will likely still need to understand and plan for the increased data quantities, security, and privacy.
- Agencies may choose to identify any existing regulatory and/or legal hurdles to CV investment and testing. To encourage innovative technology development, it is still critical to assess any existing regulatory and legal barriers that are not in line with an agency’s vision for CV. The review of regulatory and legal hurdles would consider typical testing and deployment requirements.
- Innovations in CV would benefit from partnerships with neighboring and overlapping agencies/jurisdictions to support seamless interoperability. The level of partnerships can be determined by needs, ranging from simple communication of planned improvements and investments up to coordinated infrastructure purchase and deployment to ensure interoperability.

In the **medium-term:**

- Operating agencies may choose to adopt strict security policies and procedures for all systems and users of the CV systems and networks.
- Agencies may want to work with their preferred equipment vendors (traffic controllers) to develop the upgrades necessary to support the CV interface to support the Signal Phase and Timing (SPaT) message content and any data collection.
- Education of the public may be needed, although less with CV than with AV. Agencies may want to help alert the public to opportunities.

- As agencies begin to incorporate CV technology into the infrastructure, equipment maintenance costs and personnel requirements will need to be determined and budgeted. Concepts of operation may help to incorporate CV technology into operations and define thresholds for phasing out obsolete technology. These systems may also have to be incorporated into Advanced Traffic Management System (ATMS) (in some cases) as well as asset management systems.
- While many agencies are well equipped to integrate CV technologies into existing ITS programs, as the technology evolves agencies may want to consider how agency and staff roles and responsibilities evolve in kind. A review of agency structure, organization, roles, and responsibilities may help to ensure that agencies are taking the necessary steps to proactively evolve to achieve their vision, rather than relying on historical agency roles and responsibilities. This could include a vision for creation of new agencies, mergers of existing agencies, or evolving structures and responsibilities within agencies.
- Agencies will likely need to develop data monitoring and feedback mechanisms to observe and understand the impacts existing CV deployments are having on performance and operations. As more active CV systems are deployed, agencies will gain knowledge on return on investment and performance impacts to shape future deployment and operation strategies.
- With rapid advance of technology, agencies will likely need new methods of keeping up with technical and institutional developments, and identifying information that is relevant to their planning and operations. Examples of potential activities include facilitation of an advisory panel, participation in pooled fund study groups, research panels, and industry conferences, and monitoring industry newsletters.

In the **long-term:**

- Agencies may choose to develop a communications master plan to support their traffic control systems and CV backhaul; this should be a complete communications architecture to support their video needs, traffic management needs, CV needs, and the needs of their other ITS devices. For the next decade, it is unlikely that CV technology will replace traditional ITS device deployment—but CV technology is likely to place an added burden on the agency's IT security systems, network security, and communications networks.
- The concept of "technology" refreshment will likely become more significant; we have all observed that the "cell phone" has evolved to a powerful hand held computer—with additional features as they become practical in the product continuum. The implementation of CV technology is likely to require large scale upgrades or even equipment replacement as the communications technology evolves.
- Agencies will likely need to make major additions to their repair facilities to be able to assess the operation of the roadside communication units.

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