

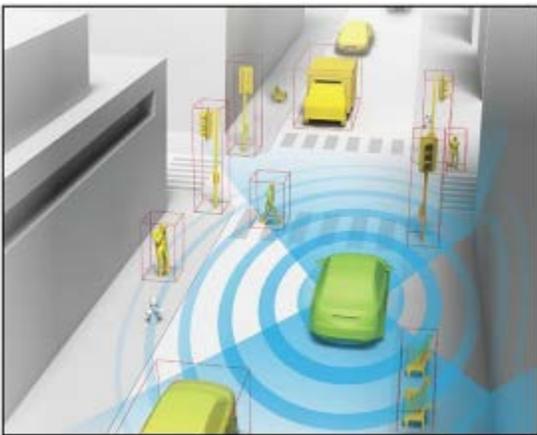
# Connected Vehicle Impacts on Transportation Planning

## Primer

[www.its.dot.gov/index.htm](http://www.its.dot.gov/index.htm)

Final Report—June 2016

FHWA-JPO-16-420



U.S. Department of Transportation

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<b>16. Abstract</b> The principal objective of this project, "Connected Vehicle Impacts on Transportation Planning," is to comprehensively assess how connected vehicles should be considered across the range of transportation planning processes and products developed by States, metropolitan planning organizations (MPO), and local agencies throughout the country. This report summarizes the results of the findings and recommendations of the study and provides planners with a primer on how to begin to address the impacts of connected and automated vehicle (C/AV) technology in their work. The first section includes a summary description of the technologies and potential impacts. The following section includes a summary of potential impacts on planning goals, objectives, products, tools, and data. Impacts are identified as short-term (0 to 5 years), medium-term (5 to 20 years), or long-term (over 20 years). Impacts are then further examined in a series of case studies designed to help planners incorporate these technologies into their planning products. Eleven case studies are presented, each of which focuses on a planning activity. Impacts and suggested strategies are provided at each key step of product development along with sample applications. Case studies included are: 1) Transportation Improvement Program; 2) Statewide Intelligent Transportation Systems (ITS) Architecture; 3) Bicycle and Pedestrian Plan; 4) Long-Range Metropolitan Transportation Plan; 5) Transportation Asset Management Plan; 6) Strategic Highway Safety Plan; 7) State Implementation Plan; 8) Transit Development Plan; 9) Public Involvement Plan; 10) Freight Plan; and 11) Financial Plan. The following section summarizes research and recommendations on the tools, techniques, and data required to evaluate C/AV-related investments. Gaps in current models and data are identified and a proposed research program for addressing these needs is presented. The final chapter includes a summary of current C/AV training programs and documents the stakeholder outreach that was used to help identify training and skill needs related to planning. Recommendations are included for new and enhanced training programs oriented toward planners, including content, audiences, and delivery methods.					
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## SI\* (MODERN METRIC) CONVERSION FACTORS

<b>APPROXIMATE CONVERSIONS TO SI UNITS</b>				
SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
<b>LENGTH</b>				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	645.2	square millimeters	mm <sup>2</sup>
ft <sup>2</sup>	square feet	0.093	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yard	0.836	square meters	m <sup>2</sup>
ac	acres	0.405	hectares	ha
mi <sup>2</sup>	square miles	2.59	square kilometers	km <sup>2</sup>
<b>VOLUME</b>				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft <sup>3</sup>	cubic feet	0.028	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	cubic meters	m <sup>3</sup>
NOTE: volumes greater than 1000 L shall be shown in m <sup>3</sup>				
<b>MASS</b>				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
<b>TEMPERATURE (exact degrees)</b>				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
<b>ILLUMINATION</b>				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m <sup>2</sup>	cd/m <sup>2</sup>
<b>FORCE and PRESSURE or STRESS</b>				
lbf	poundforce	4.45	newtons	N
lbf/in <sup>2</sup>	poundforce per square inch	6.89	kilopascals	kPa
<b>APPROXIMATE CONVERSIONS FROM SI UNITS</b>				
SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
<b>LENGTH</b>				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
<b>AREA</b>				
mm <sup>2</sup>	square millimeters	0.0016	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	10.764	square feet	ft <sup>2</sup>
m <sup>2</sup>	square meters	1.195	square yards	yd <sup>2</sup>
ha	hectares	2.47	acres	ac
km <sup>2</sup>	square kilometers	0.386	square miles	mi <sup>2</sup>
<b>VOLUME</b>				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m <sup>3</sup>	cubic meters	35.314	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.307	cubic yards	yd <sup>3</sup>
<b>MASS</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
<b>TEMPERATURE (exact degrees)</b>				
°C	Celsius	1.8C+32	Fahrenheit	°F
<b>ILLUMINATION</b>				
lx	lux	0.0929	foot-candles	fc
cd/m <sup>2</sup>	candela/m <sup>2</sup>	0.2919	foot-Lamberts	fl
<b>FORCE and PRESSURE or STRESS</b>				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in <sup>2</sup>

\* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003).

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# Executive Summary

The principal objective of this project, “Connected Vehicle Impacts on Transportation Planning,” is to comprehensively assess how connected vehicles should be considered across the range of transportation planning processes and products developed by States, Metropolitan Planning Organizations (MPO), and local agencies throughout the country. While the focus is primarily on connected vehicle (CV) technology, it is clear that, to incorporate the full range of planning products and activities, automated vehicle (AV) technology should be considered as well; thus, the subject of this effort is referred to as connected/automated vehicle (C/AV) technology in the document. The consideration of AV impacts is especially important in longer range plans and, ultimately, CV and AV may merge into one general technology.

The project conducted four distinct types of analysis, as identified by the United States Department of Transportation (U.S. DOT) to comprehensively assess the impact of C/AV technology on transportation planning:

1. Identified how C/AV technology should be considered in transportation planning processes and products under a variety of circumstances;
2. Developed a number of illustrative scenarios of C/AV planning, based on real-world planning environments, that highlight the various ways that C/AVs can be addressed in planning processes and products;
3. Identified new or enhanced tools, techniques, and data to support various C/AV planning activities and approaches for how to develop them;
4. Identified the roles and responsibilities of stakeholders and organizational and workforce skills, expertise, and capabilities needed to carry out C/AV planning.

Connected and automated vehicle technologies are advancing rapidly, with large investments in the private sectors and accelerating competition in the marketplace. New alliances between automotive companies, major technology companies, and start-ups are being formed on almost a weekly basis. The arena is international, with all major automotive companies in the process of developing and implementing these technologies. Once they are more widespread additional economic disruption can be expected in a wide range of industries including freight, warehousing, real estate, construction, and insurance. The rapid growth of carsharing and ridesharing services provides an indication of the economic disruption which could occur. Potential benefits, documented in this report, are dramatic with the promise of elimination of most crashes and new mobility options for those who cannot drive an automobile. Operational strategies will need to be developed to accommodate a long period of mixed operation, when the fleet consists of both C/AV-equipped vehicles and nonequipped vehicles.

Transportation planners need to keep abreast of these developments and be able to incorporate them into their activities. The changes described above are likely to come but the timing is unknown and the rate of change will determine how plans and related investment policies are impacted. As market penetration of these technologies increases, investment decisions related to safety and mobility will change, along with the tools, techniques and data required to evaluate these investments. While a

higher level of uncertainty will increase the challenges involved in forecasting the future, these technologies have the potential to provide much richer and more complete data for planning. New skills and training will be needed to adapt the changes in planning techniques and take full advantage of new data sources.

A wide range of issues relevant to planners have been identified in the documents prepared for this project. Some of these issues are specific to planning activities or products, while others apply to multiple activities or products. A high-level list of key findings that planners should take away from these documents include:

- In the short term, C/AV deployment will likely take the form of small-scale pilot projects that planning agencies will need to incorporate into their Transportation Improvement Plans. Agencies will need a level of technical knowledge adequate to evaluate these investments and will need to educate their board members and stakeholders on the benefits and costs of the technology.
- In the medium to long term, C/AV deployments are likely to become a standard strategy, with large-scale investments over multiple funding cycles. It is important to note that for both the initial C/AV pilots and longer-term investments, ongoing maintenance and operations funding should be provided if the project is to continue after initial funds run out.
- C/AV technologies provide a great opportunity for agencies to enrich their sources of planning data, particularly in the areas of traffic and asset management. This may require new skills in data science; and the development of relationships with new stakeholders may be required to address issues of privacy and data ownership.
- C/AV technologies provide opportunities to enhance the mobility and safety of nonautomobile users, including transit riders, bicyclists, and pedestrians by providing improved information and enhancing motorist awareness of vulnerable users. Planning agencies will want to identify these opportunities, evaluate their effectiveness and facilitate implementation where beneficial.
- New C/AV data will be available for use in long-range Metropolitan Transportation Plan alternatives analyses and will help to better understand new land use, transportation facility use, socio-economic impacts that result from C/AV. For instance, widespread adoption of automation by the commercial vehicle industry is expected to shift the economics of the industry and may result in significant shifts in location of warehouse and manufacturing employment. Alternative land use and economic scenarios thus become an important element of the long-range analysis.

It should be noted that implementation of these new technologies will require both private and public sector stakeholders to overcome issues related to privacy, liability, data ownership, and motor vehicle regulation. There is already significant effort from the private sector, trade organizations, U.S. DOT, and State transportation agencies in addressing these issues. It is important that planners proceed on the assumption that these technologies will take hold, and begin to incorporate their impacts into day-to-day activities. This report is designed to provide guidance in accomplishing that goal.

# Introduction

The principal objective of this project, “Connected Vehicle Impacts on Transportation Planning,” is to comprehensively assess how connected vehicles should be considered across the range of transportation planning processes and products developed by States, Metropolitan Planning Organizations (MPO), and local agencies throughout the country. While the focus is primarily on connected vehicle (CV) technology, it is clear that, to incorporate the full range of planning products and activities, automated vehicle (AV) technology should be considered as well; thus, the subject of this effort is referred to as connected/automated vehicle (C/AV) technology in the document. The consideration of AV impacts is especially important in longer range plans and, ultimately, CV and AV may merge into one general technology.

The project conducted four distinct types of analysis, as identified by the United States Department of Transportation (U.S. DOT) to comprehensively assess the impact of C/AV technology on transportation planning:

- 1. Impact Typology.** This analysis identified how C/AV technology can be considered in transportation planning processes and products under a variety of circumstances. From this, the project developed a typology of C/AV impacts on transportation planning as a framework for considering these impacts. The full results of this analysis are detailed in the project's associated reports: *Technical Memorandum #1: Framework for Connected Vehicle Planning Typology and Technical and Memorandum #2: Connected Vehicle Planning Processes and Products and Stakeholder Roles and Responsibilities*. (Technical Memorandum #1 was an interim document that was incorporated into Technical Memorandum #2.)
- 2. Case Studies.** The case studies developed a number of illustrative scenarios of C/AV in transportation planning, based on real-world planning products and environments. They highlight the various ways that C/AV can be addressed in planning processes and products. The full results of this analysis are detailed in the project's associated report: *Technical Memorandum #5: Case Studies*. (Technical Memorandum #4 was an interim document that was incorporated into Technical Memorandum #5.)
- 3. Analytical Tools and Techniques.** The objective of this analysis was to identify new or enhanced tools, techniques, and data required to support various C/AV planning activities, as well as approaches for how to develop them. The full results of this analysis are detailed in the project's associated report: *Technical Memorandum #3: Analysis of the Need for New and Enhanced Analysis Tools, Techniques, and Data*.
- 4. Workforce Skills and Training.** This analysis researched and described C/AV training programs to build the skills, expertise, and organizational capabilities needed to carry out C/AV planning. The full results of this analysis are detailed in the project's associated report: *Technical Memorandum #6: Skills and Expertise Required to Incorporate Connected Vehicles into Transportation Planning*.

# Technology Summary

This section provides a brief summary of the background and context of connected/automated vehicle (C/AV) technology needed to best understand the expected impacts on transportation planning. The technology summary covers five main topics: connected vehicle technology, automated vehicle technology, the key potential benefits of C/AV technology, potential C/AV applications across all benefit categories in the short and long term, and key issues for transportation planners. Additionally, this section discusses resources that can be used to obtain further information on C/AV technology and development.

## Connected Vehicles

A connected vehicle (CV) environment enables wireless communications among vehicles (vehicle-to-vehicle, or V2V), infrastructure (vehicle-to-infrastructure, or V2I), and mobile devices. Vehicles include light vehicles, trucks, and transit vehicles. Pedestrians, bicyclists, or motorcyclists can carry mobile 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 privacy and legal agreements that have not yet been established.)

Connected vehicle communications types include Dedicated Short-Range Communications (DSRC), cellular, and Wi-Fi:

- DSRC operates over the 75 megahertz (MHz) of spectrum in the 5.9 gigahertz (GHz) band, allocated for transportation safety purposes by the Federal Communications Commission (FCC) in 1999. This dedicated network provides a low-latency, short- to medium-range wireless communications medium that permits very fast and reliable data transmissions critical for safety applications.
- Cellular technology uses fourth-generation (4G) and third-generation (3G) mobile networks provided by private carriers such as Verizon and AT&T. Cellular communications currently do not consistently provide the low latency required for critical safety applications, but this medium can carry longer-range communications for transfer of data that support some mobility and environmental applications, along with supporting data disseminated/collected by transportation agencies, such as traffic and pavement data.

- Wi-Fi communications are typically short range and are not as reliable as DSRC for communications with moving vehicles. Wi-Fi can carry large data transfers in areas where vehicles may be stationary for extended periods of time.

## Automated Vehicles

Automated vehicles (AV) 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 fundamentally 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 strictly controlled by vehicle manufacturers rather than by public agencies and Departments of Transportation (DOT); however, public agencies will provide a regulatory or supervisory role regarding 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 defined five levels of vehicle automation, building off of current driver assistance technologies such as adaptive cruise control, lane departure warning, and left turn assist (figure 1). ([The Society of Automotive Engineers \(SAE\)](#) has defined a slightly different scale with 6 levels of automation.) Various combinations of levels 0, 1, and 2 are operating on the road today.

LEVEL	DESCRIPTION	EXAMPLES	
<b>Driver Warning Systems</b> <b>0</b>	Provides guidance to the driver, but makes no decisions and does not take away control.	<ul style="list-style-type: none"> <li>Forward collision warning</li> <li>Lane departure warning</li> <li>Blind spot monitoring</li> </ul>	
<b>Automation of Isolated Driver Functions</b> <b>1</b>	Manages individual driver functions, but requires a human driver to continue performing other essential functions.	<ul style="list-style-type: none"> <li>Adaptive cruise control</li> <li>Dynamic brake support</li> <li>Lane Keeping Assist</li> </ul>	
<b>Automation of Several Driver Functions</b> <b>2</b>	Manages several driver functions simultaneously, but still requires a human driver to handle some essential functions.	<ul style="list-style-type: none"> <li>Combinations of items from (1) above.</li> </ul>	
<b>Limited Self-Driving Capability</b> <b>3</b>	Limited autonomous operation in certain environments, with supervision from human driver to handle complex situations.	<ul style="list-style-type: none"> <li>Handling inclement weather</li> <li>Interpreting traffic signals</li> <li>Reacting properly to pedestrians</li> <li>Handling railroad crossings</li> </ul>	
<b>Fully Autonomous Operation</b> <b>4</b>	Capable of handling more advanced driving situations and environments, for fully autonomous operation from origin to destination.	<ul style="list-style-type: none"> <li>Interpreting and avoiding animals/obstacles</li> <li>Obeying instructions from flaggers and peace officers</li> <li>Reacting properly to bicyclists</li> </ul>	

**Figure 1. Diagram. The National Highway Traffic Safety Administration's five levels of vehicle automation.**

(Source: [National Highway Traffic Safety Administration](https://www.nhtsa.gov/autonomous-vehicles).)

## Benefits

C/AV technologies have the potential to provide a broad range of benefits to the transportation system and its users, whether they be drivers, passengers, pedestrians, or bicyclists. There are four main categories of C/AV benefits:

- Safety.** The injuries and fatalities of both vehicle occupants and vulnerable road users will be reduced and mitigated as C/AV reduces crash rates. Users will share information such as speed, location, and direction or travel information, allowing drivers/vehicles to take preemptive actions to avoid and/or mitigate crashes.
- Mobility.** The information about travel conditions and options for both system users and operators will be increased and improved, allowing for capacity increases in current systems with no new right-of-way (ROW) required. Users will be able to make decisions in real time and operators will be able to manage road network performance in real time.

- **Environment.** The impact of vehicle travel will be reduced by promoting greener transportation choices and driver/vehicle behavior. Vehicles will be able to communicate with infrastructure to enhance fuel efficiency by avoiding unnecessary stops or excessive idling.
- **Data.** There will be new cost effective data sources and collection methods introduce that will improve asset management, network operations, just-in-time maintenance, and incident response, among other functions.

The greatest benefits will come from deploying connected and automated vehicle technologies together. Additionally, it is expected that C/AV will produce significant economic benefits in many industries, possibly starting with freight where cost savings from applications such as C/AV-enabled truck platooning to increase travel time and fuel efficiency has high potential.

The development of C/AV and its benefits currently is focused on light vehicles, freight, and transit, with limited applications under development for motorcyclists, bicyclists, and pedestrians. The safety and mobility of those not participating in the CV environment should be considered in planning and deployment activities. For example, the private sector has tested C/AV safety applications with after-market modifications to smartphones, but it is not possible to estimate how many users will adopt this technology until more information is available regarding cost and impact on performance.

## Potential Applications

This report focuses on C/AV applications that are practical for agencies to deploy in the short term and medium to long term. In the short term, the market penetration of connected vehicles and the availability of automated capabilities will both be limited. As a result, short-term benefits will most likely be realized from V2I applications that provide driver alerts. In the medium to long term, as market penetration grows and automated capabilities are expanded, V2V applications and AV responses will become more practical. While the benefits delivered by CV infrastructure are greater with both V2V and V2I applications in place, the development of V2V and V2I applications can occur independently.

The rest of this section describes short-term (0 to 5 years), medium-term (5 to 20 years) and long-term (20+ years) applications under each of the benefit categories described above. This report refers to applications using the names developed by the U.S. DOT Connected Vehicle Pilot Deployment Program; however, these names are subject to change over time as C/AV technology and research evolves. The defined timeframes are established solely for the purposes of evaluating impacts on planning and are linked to estimated deployment timelines. The applications within each timeframe can be generally defined as follows:

- The short term will focus on pilot deployments, other demonstration projects and early technology adopters.
- The medium term will introduce CV-equipped vehicles with increasingly automated functions to the market, transition pilot deployments, and field operations. It is likely that during this phase, connected and automated technologies will become linked together.
- The long term will result in the market maturity of CV-equipped vehicles with fully automated capabilities and field maturity of CV-enabled infrastructure.

## Safety

**Short Term:** Drivers will be provided with warnings based on information regarding relatively static conditions such as SPaT, work zones, and sharp curves. Examples of short-term applications include the following:

- **Red Light Violation Warning (RLVW).** SPaT information from a signal controller, along with vehicle position and speed, is used to determine if a warning to the driver is needed.
- **Reduce Speed/Work Zone Warning (RSWZW).** Information is provided to the vehicle to enable alerts or warnings relating to the specific situation, such as warning drivers to reduce speed, change lanes, or come to a stop within or approaching work zones.
- **Pedestrian in Signalized Crosswalk (PSCW).** An application that warns vehicles of a potential conflict with pedestrians that are within the crosswalk of signalized intersection.
- **Curve Speed Warning (CSW).** Geometric information is provided to the vehicle to enable a warning that the speed of the vehicle is too high to safely negotiate the curve.

C/AV applications are expected to offer some of the most promising opportunities for crash reduction. Research conducted by the National Transportation Systems Center for the National Highway Traffic Safety Administration (NHTSA) estimates that V2I and V2V systems can potentially address up to 81 percent of vehicle crashes.

**Longer Term:** In addition to providing warnings, vehicle-based applications may determine if automated braking or steering is required.

## Mobility

**Short Term:** Benefits include increased operating efficiency for transit/truck vehicles and access to more accurate traffic information for system users. Examples of short-term applications include the following:

- **Emergency Vehicle Preemption (PREEMPT).** Traffic signal controllers detect oncoming emergency vehicles and change desired direction to green.
- **Transit Signal Priority (TSP).** Transit vehicles request an extended green from traffic signals.
- **Freight-specific Dynamic Planning and Performance (FSDPP).** Applications provide enhanced freight-related travel information, such as wait times at ports, road closures, work zones, and route restrictions.
- **Mobile Accessible Pedestrian Signal System (PED-SIG).** An application that allows for an automated call from the smartphone of a visually impaired pedestrian to the traffic signal, as well as audio cues to safely navigate the cross.

**Longer Term:** Vehicles traveling at closer headways can increase operating capacity, and the availability of real-time traffic data allows for active traffic management by system operators.

## Environment

**Short Term:** Applications provide drivers with signal timing information to promote eco-friendly behavior. Short-term applications include the following:

- **Eco-Approach and Departure at Signalized Intersections (EADSI).** SPaT information is used to provide speed advice, allowing the driver to adapt in order to pass the next signal on green or to decelerate to a stop in the most eco-friendly manner.

**Longer Term:** Sufficient environmental data allows for larger portions of the system to be optimized and made more eco-friendly.

## Agency Data

All applications in the other categories have a data component. The agency data category captures applications that primarily focus on improved data collection and may have secondary impacts on safety, mobility, or environment categories.

**Short Term:** New data sources and collection methods will supplement current sources and methods. Short-term applications include the following:

- **Probe-based Pavement Maintenance (PBPM).** This technology detects vertical wheel movement and/or body acceleration to measure road quality, such as pothole location and size and surface roughness.

**Longer Term:** New data sources and collection methods can allow agencies to reduce or phase out more expensive traffic monitoring methods such as loop detectors and cameras.

## Key Issues for Planning

Planners will not need to know all of the technical details behind C/AVs, but it will be important for planners to track developments in these technologies. C/AV technology will advance quickly, causing the impacts, opportunities, stakeholders, relationships, and roles of planners to change as well. Key issues for planners to keep to mind during the evolution of the C/AV include:

- Timeframes for the implementation of C/AV-supporting infrastructure and programs (e.g., V2I).
- Funding sources for C/AV-supporting infrastructure and programs.
- Societal and organizational impacts, as well as ways to adapt to disruption in the private and public sectors.
- C/AV data outputs to support planning needs.

## Resources and Research

The U.S. DOT Intelligent Transportation Systems ITS Joint Program Office (JPO) Web site on ITS research is the main resource for planners to learn about and stay up to date on C/AV topics and research. Planners can sign up for the email newsletter and get news updates on policy, technology, and pilot progress, along with notice of upcoming guidance documents and webinars. Furthermore, the site serves as a repository of other resources and links—most of the resources cited in this report also can be found on the Web site.

The American Association of State Highway and Transportation Officials (AASHTO) and U.S. DOT are collaborating on efforts to identify and define a vehicle-to-infrastructure (V2I) program and provide guidelines to States, MPOs, and local agencies for implementation. One of the more important document referenced throughout this report is the [National Connected Vehicle Field Infrastructure Footprint Analysis](#), developed by AASHTO, with support by U.S. DOT and Transport Canada. The Footprint describes the value of current research about connected vehicle deployments, along with applications analysis, deployment concepts, and a preliminary cost estimation.

A particularly relevant example of federally funded connected vehicle research that planners can learn more about on the ITS JPO Web site is the U.S. DOT Connected Vehicle Safety Pilot Program. Research Track 1 of the Connected Vehicle Safety Pilot Program included several driver clinics at six different test sites across the United States between August 2011 and January 2012. The purpose of these clinics, each with over 100 drivers performing behind-the-wheel tests, was to gauge driver acceptance and response to various connected vehicle technology interfaces and systems. Results from these clinics are already available, and the responses provide insight into which technologies and C/AV technologies drivers are most interested in seeing deployed. For example, intersection movement assist scored the highest on several dimensions including usefulness and desirability. Questions regarding cost acceptance and motivation for adoption were also asked of the respondents, with over half of the respondents indicating that they would pay at least \$250 for V2V technology in their vehicles.

Research Track 3 of the Connected Vehicle Safety Pilot Program involved the deployment of approximately 3,000 vehicles with CV technology on public streets in Ann Arbor, Michigan, to determine the effectiveness of such technology at reducing crashes. This one-year program sponsored by U.S. DOT and led by the University of Michigan Transportation Research Institute (UMTRI) took place between 2012 and 2013 with the intent of yielding real-world data on DSRC communications in the context of connected vehicles and examining the potential safety benefits of CV technology through field-based testing and evaluation. In addition to safety applications, the pilot deployment was also designed to highlight other strategies that can be informed, improved, or made possible by V2V and V2I technology, including the following:

- Transit vehicle signal priority and emergency vehicle signal preemption.
- Pavement maintenance data collection.
- Pedestrian traffic density data.
- Traffic signal timing applications.

Research Track 2 was concerned with determining specifications for devices and establishment of a qualified products list. It did not produce any C/AV data that would be directly relevant to this analysis

of the need for new and enhanced planning tools, techniques, and data. U.S. DOT currently is sponsoring the [CV Pilots Deployment Program](#), which has recently awarded three locations (New York City, Tampa, and Wyoming) to pilot connected vehicle technologies in the field and provide insight into the real-world outcomes. More details on the pilot program and ongoing progress can be found on the [U.S. DOT CV Pilots Web site](#).

# Impact Typology

This analysis identified how connected/automated vehicle (C/AV) technology should be considered in transportation planning processes and products under a variety of circumstances. From this, it developed a typology of C/AV impacts on transportation planning as a framework for planners to consider C/AV.

## Typology Structure

The C/AV impact typology addresses changes to different planning processes and products, roles and responsibilities, and planning contexts. How and when changes occur will be a function of the nature of technologies, their rate of adoption, and the level of transformation that occurs in both the private and public transportation sectors. The newness of C/AV technology and the rapid pace of change present significant challenges in identifying what impacts will occur and in developing a structure to look at those impacts. A number of elements could be included in a C/AV impact typology. The following elements, however, are key to a typology of C/AV impacts in transportation planning:

- **Products.** Planning agencies produce a range of products that vary in purpose, timing, and content. These range from short-term studies that focus on an area as small as a single intersection to those that investigate a major regional or statewide transportation corridor. Standard documents produced by planning agencies include Transportation Improvement Plans (TIP) at the Metropolitan Planning Organization (MPO) or State level, long-range plans, State highway safety plans and Intelligent Transportation Systems (ITS) Architecture documents.
- **Goal Areas.** Goal areas can be a useful way to categorize impacts since planning agencies generally have similar goals. Common goals are generally related to mobility, safety, environmental protection, economic development, system preservation, and equity.
- **Demographic/Economic Characteristics.** Impacts of C/AV technology may vary, particularly in the short- and medium-term, by type of area. Some methods of stratifying geographic areas include region of the country, metropolitan area population, population density, and characteristics of transportation network (multimodal, highway oriented).
- **Projects.** Planning agencies conduct specific projects within a category of product. Many projects revolve around specific subregions, corridors, or intersections and focus on capital or operational improvements. Projects may focus on specific modes, including studies of specific transit lines or nonmotorized facilities.
- **Processes, Tools, and Methods.** Planning agencies use a variety of tools, methods, and processes in their development of projects and products. Forecasting models, traffic analysis software, and various databases fall into this category.

Planning agencies also must understand the new and emerging requirements of these processes and tools in the context of advancing C/AV technology.

Any or all of these elements could be used as the basis for the typology; for example, products, goal areas, and projects were all options for categorizing the impacts. After some discussion, project partners agreed that focusing initially on products and processes would be the best way to provide a typology matrix that reflects the way planning agencies approach their work. Table 1, which combine the elements described above, provide an overview of the elements required in the typology, categorized by planning products. The tables also document the process for categorizing impacts and building case studies. The second column identifies the geographic scope of the planning agency, which may be a State Department of Transportation (DOT), an MPO, a non-MPO Regional Planning Organization, or a municipal agency. These are distinguished below as either State or regional (includes municipal). Agency goal areas are also included and, as shown in the table, most transportation planning products address multiple goals. The fourth column lists specific projects that planning agencies address. These projects are generally incorporated into some of the comprehensive products listed, such as the Long-Range Plan or Congestion Management Plan, while others may be “one-off” studies. The fifth column lists the agency tools and processes that are used to conduct business and develop their products. Connected and automated vehicle technologies will have impacts on the full range of activities identified below, and these will serve as the building blocks for the case studies developed and evaluated in Task 4 of the project.

**Table 1. Typology structure for transportation planning products.**

<b>Typical Transportation Planning Products</b>	<b>State or Regional Scope</b>	<b>Primary Agency Goal Areas in Product</b>	<b>Project Types</b>	<b>Common Agency Tools and Processes</b>
Long-Range Visioning	State, Regional	Mobility, Safety, Economic Development, Environment	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Statewide Long-Range Transportation Plan	State	Mobility, Safety, Economic Development, Environment Preservation	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Regional Long-Range Transportation Plan	Regional	Mobility, Safety, Economic Development, Environment, Preservation	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Transportation Improvement Program	State, Regional	Mobility, Safety, Economic Development, Environment	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.

**Table 1. Typology structure for transportation planning products (continuation).**

<b>Typical Transportation Planning Products</b>	<b>State or Regional Scope</b>	<b>Primary Agency Goal Areas in Product</b>	<b>Project Types</b>	<b>Common Agency Tools and Processes</b>
Short-Range Transportation Plan	State, Regional	Mobility, Safety, Economic Development, Environment, Preservation	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Congestion Management Plan	Regional	Mobility	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Asset Management Plan	State, Regional	Mobility, Safety, Preservation	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
ITS and Operations Plan	State, Regional	Mobility, Safety, Environment	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
ITS Architecture	State, Regional	Mobility, Safety	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Strategic Highway Safety Plan	State	Safety	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Highway Safety Improvement Program	State	Safety	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
State Implementation Plan	State	Environment	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Transit Development Plan	Regional	Mobility, Environment, Economic Development	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Transportation Demand Management Plan	Regional	Mobility, Safety, Environment, Economic Development	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.

**Table 1. Typology structure for transportation planning products (continuation).**

Typical Transportation Planning Products	State or Regional Scope	Primary Agency Goal Areas in Product	Project Types	Common Agency Tools and Processes
Nonmotorized (bicycle and pedestrian) Plan			Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Corridor Studies (Modal or Multimodal)	State, Regional	Mobility, Safety, Economic Development, Environment	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Public Involvement Plan	Regional	Mobility, Safety, Economic Development, Environment	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Freight Plans	State, Regional	Mobility, Safety, Economic Development, Environment, Preservation	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Financing Plans	State, Regional	Mobility, Economic Development, Preservation	Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.
Unified Planning Work Program			Refer to a complete list of common project types following this table.	Refer to a complete list of common agency tools and processes following this table.

Source: Cambridge Systematics, Inc.

**Project Types** (Items identified are common project types but are not directly related or aligned with all planning products.)

- New roadway corridor
- Roadway capacity expansion
- Corridor upgrade
- Corridor operational improvements
- New interchange(s)
- Major operational changes (high-occupancy vehicle (HOV), managed lane, etc.)
- New transit lines
- Transit line extension

- Transit capacity expansion
- Ride share services
- Spot physical improvements (capacity and/or safety)
- Intelligent Transportation Systems (ITS) deployments
- Signal timing
- Bicycle and pedestrian improvements
- Freight rail improvements
- Truck facilities
- Border crossing facilities and improvements

**Common Agency Tools and Processes** (Items identified are common agency tools and processes but are not directly related or aligned with all planning products).

- Public involvement program
- Customer surveys
- Historical data analysis
- Economic forecast
- Traffic and travel time data collection
- System condition data collection
- Travel demand forecast
- Micro- and meso-simulation
- Asset management analysis tools
- Investment tools
- Benefit-cost tools
- Data Security Plans
- Air quality modeling

## Impacts

The development of the C/AV impact typology also involved a literature review and stakeholder interviews to collect a range of information of perspectives. This work revealed that there are six primary categories for the impacts of C/AV on transportation planning:

- Strategy.
- Performance measurement and evaluation.
- Infrastructure investment.
- Planning products.
- Data collection, processing, and analysis.
- Education and training.

While impacts are listed in a single category below, it is important to note that there is significant overlap between categories and many of the impacts identified apply to multiple categories. Some of the key documents and projects that will help planners obtain an understanding of C/AV technology are summarized in text boxes throughout this section.

## Strategy

- With the mass production of C/AVs on the horizon, transportation agencies should understand how C/AVs affect strategy identification, investment priorities, monitoring, and reporting.
- The Federal Highway Administration (FHWA) Performance-Based Planning and Programming Guidebook provides instruction regarding developing goals and objectives, with an emphasis on outcomes. Transportation agencies should establish goals and objectives informed by careful thought regarding C/A vehicles.
- ITS strategic plans serve as roadmaps for implementing ITS projects system-wide over a period of time. An ITS strategic plan, developed by a State transportation agency or an MPO, should give consideration to CV infrastructure to address mobility needs.
- DOTs and other agencies recognize liability concerns in managing transportation operations; thus, they can use their expertise to help guide the process of officially determining who or what entity owns the data transmitted between vehicles by vehicle-to-vehicle (V2V) technologies. In the event of a crash, officially recognized practices make it easier to determine liability.
- Through its experience in connected vehicle (CV) deployment Michigan DOT has identified the following as important strategic factors for successful CV programs.
  - **Encourage regulation**—Only government has the ability and obligation to establish CV mandates and ensure infrastructure necessary to realize safety benefits.
  - **Form coalitions**—Public-private partnerships are instrumental to successful tests and deployment.
  - **Create industry competition**—Set standards, create infrastructure test deployments, then invite manufacturers to participate.
  - **Develop programmatic themes and bold goals**—Emphasize themes such as safety, and use bold goals to motivate achievements.
  - **Generate agency expertise**—Nurture CV/ITS skill development to create future opportunities and demonstrate ability to contribute to competitive bids for Federal projects.
  - **Standardize data architectures**—Implementing common CV technology standards is necessary to support interregional connectivity as well as decrease equipment costs (via increased production volumes).
  - Leadership by regional and State governments is crucial for CV success. Strong leadership must support sensible regulation to create catalysts for adopting and incentives for improving safety applications.
- Agencies must think about automated vehicles and their impact on operations. The concept of operations for a network of fully automated vehicles will be significantly different than that for routine operations, will likely be more complex, and will impact

- planning for all modes that use roads. DOTs should note that all rollouts of CV will be incremental due to resource scarcity at the State level. In particular, CV/ITS projects require significant operations and maintenance expenditures.
- Agencies must work with the private sector. Private sector entities play a role in the technology arena and can share information about emerging technologies and support development of mutually beneficial standards.
  - Emergency response applications can serve as effective early deployments of C/AV technology. They can also provide some of the infrastructure that will later help to support applications that can be used by a broader audience, such as traveler information data and signal timing and phasing information. In addition, working with first responders is a way to engage a wider audience beyond transportation agencies and build public support for broader deployments.
  - Agencies with limited resources can focus on smaller demonstrations covering an intersection or limited corridor to demonstrate CV concepts. These can then be expanded incrementally over time.

## Performance Measurement and Evaluation

- Deployment of C/AV technology, particularly near-term vehicle to infrastructure (V2I) deployments, must be justified based on benefits and costs. The impacts of these deployments must be evaluated so that data generated from them can be used to measure the performance of other improvements and the overall system itself.
- DOTs must develop a clear business case for external audiences regarding the costs and benefits of ITS and CV projects. The audience should include politicians, local agencies, agency board members, and the general public.
- Measures are important to implementing a performance-based planning process. Guidance in the Performance-Based Planning and Programming Guidebook can be used to help determine what performance measures matter most in a C/A vehicles environment.
- C/AV data could be used in monitoring and reporting to assist implementation and evaluation of planning strategies. Transportation staff must consider the feasibility and practicality of collecting, storing, and analyzing C/AV data.
- Operations data are often used to identify and investigate congested locations. Collected C/AV operational data can be used as part of a Congestion Management Process, as well as in mapping congestion bottlenecks and in needs identification.
- The U.S. DOT's Real-Time Data Capture and Management Program is potentially useful to planning agencies in the following respects:
  - This program generates important information and guidance for planning agencies on the data that might be made available and the applications for which they can be used.
  - Planning agencies should participate in or least monitor closely the progress of demonstration projects conducted under this program.
- C/AV technology will generate safety-related data that can be helpful in measuring potential impacts of the technology on crash rates and thus in planning future safety

improvements. As C/AV market penetration increases over time and the fleet mix evolves, safety policies and investments will change.

- In combination with V2V, V2I technologies offer additional safety features, such as providing drivers with additional warnings when traffic signals are about to change—warnings that could help reduce collisions at intersections. V2I technologies also offer potential mobility and environmental benefits: they can collect, analyze, and provide drivers with data about upcoming roadway and traffic conditions and suggest alternate routes when roadways are congested. V2I systems require significantly higher public investments, however. In the context of government resource scarcity, enabling V2V systems is gaining ground as a valued strategy for DOTs wishing to improve public health via road safety.

## Infrastructure Investment

- DOTs and other deploying agencies must phase in C/AV-related infrastructure and recognize that earlier phases can yield much public benefit without requiring a mature CV environment. Deployment of CV systems will create challenges for State DOTs in terms of delivering durable infrastructure that can allow the collection and processing of vast amounts of potential data.
- Some potential impacts on V2I deployment that planners need to be aware of are as follows:
  - **Backhaul communications**—Investment in the arterial network is critical for transmission of CV data (backhaul) to the traffic operations centers. This must be phased in before CV deployment.
  - **Advanced Signal Controllers**—All controllers require replacement. When they are upgraded, new models should include Internet protocol (IP)-ready ports and National Transportation Communications for Intelligent Transportation System Protocol (NTCIP) compliance for a full scale CV deployment while achieving integration into the Advanced Traffic Management System (ATMS).
  - **Conduit Installation**—Conduit must be considered an essential component of any arterial roadway upgrade.
  - **Data Management Planning**—Detailed technical requirements and a concept of data management operations must be developed that are harmonized with (or within) a statewide data warehouse strategic plan.
- Traditional roadway technologies presume maintenance and a gentle slope for lifetime utility. In the beginning CV infrastructure may increase the level of uncertainty over the cost of constructing and maintaining roadways. It is important that DOTs track operations and maintenance costs so that the life-cycle costs of future deployments can be projected with greater confidence.

## Planning Products

- The ITS strategic plan can often provide the mechanism for bringing stakeholders together to address transportation operations and management issues that may affect multiple agencies or organizations. The ITS strategic plan can then be used to initiate C/AV infrastructure deployments for a broad cross section of organizations.
- The planning community should participate in the development of the toolbox that will provide guidance on procuring connected vehicle ITS equipment, identify installation specifications, and summarize all the benefits of vehicle to infrastructure communication and safety applications. This will be important reference material for planners.
- There are many competing system needs, so CV/ITS deployments must be harmonized with State Transportation Improvement Program (STIP) and long-range transportation plans.
- Agencies must identify constraints to technology in the planning process so steps can be taken to proactively mitigate them.
- Specific planning products that are likely to be affected by an automated vehicle focused infrastructure project such as this include the following:
  - **Long-range transportation plans**—Agencies must identify how and where corridors are planned for specific upgrades to accommodate automated vehicles.
  - **Corridor plans**—The plans for specific corridors must reflect changes resulting from the deployment of automated vehicles and related technologies. Specifically, corridor plans should reflect the anticipated impact on capacity and congestion and the necessary infrastructure to support automated vehicles.
  - **ITS plans**—ITS Plans should reflect the technologies necessary to support automated vehicle technology and fully realize the benefits.
  - **Project Environmental Impact Assessments**—Agencies must capture the anticipated benefits of automated vehicle operation in terms of emissions reductions and fuel savings.

## Data Collection, Processing, and Analysis

- The U.S. DOT is working to provide a data environment in which real-time data are captured, managed, and disseminated to mobility applications (including those within vehicles). Fully connected vehicles can transmit data on latitude, longitude, time, speed, lateral acceleration, longitudinal acceleration, throttle position, brake status, steering angle, headlight status, wiper status, external temperature, turn signal status, vehicle length, vehicle width, vehicle mass, and bumper height. ITS infrastructure can send messages on cross street speeds, weather, e.g., fog, oncoming trains, available parking, and signal phasing and timing.
- Once CV-equipped vehicles start communicating with the system, new data will be generated that can be used for system analysis and operational planning— for example, calibrating microsimulation models. Ongoing analysis of capacity impacts will help to make larger investment decisions in the future.

- When DOTs are assembling data from multiple sources, collection practices and data security/privacy measures must be consistently implemented so that data are useful for achieving multiple agency goals.
- Interface requirements for gathering and inputting data into existing DOT systems should be developed and standardized in collaboration with companies and agencies that are likely data partners.
- CV and ITS deployments should be aligned with agency performance standards and holistic data requirements so that DOTs can leverage data sources across the organization.
- Meeting agency goals requires different types of data collection:
  - Safety applications such as intersection collision avoidance with very short latency needs require the application to run at the roadside.
  - Asset management applications where data about pavement conditions are aggregated over a period of months or even years can use data that are aggregated and analyzed on remote servers.
- Operational planning to utilize CV deployments to capture travel time and origin-destination (O/D) data must start early and include outreach to and awareness by major stakeholders.

## Education and Training

- The American Association of State Highway and Transportation Official (AASHTO) Footprint proposes infrastructure augmentation for all DOT public assets. Improvements of that scale and scope will require a greater number of, and more and differently trained, DOT analysts, planners, and engineers.
- The importance of communicating basic instructions to users of these new systems is especially high. Planners must be aware of the burden placed on the user to learn new systems and should by default strive to develop user interactions that are consistent and intuitive.
- CV applications will provide a significant amount of system performance data. These data are potentially helpful to planners in many areas (traffic data, counts, infrastructure condition, weather management, etc.). Processing such large volumes of data and making them useful requires highly skilled information technology (IT) professionals and data scientists who DOTs or other agencies simply do not have on staff at present. DOTs must coordinate with educational institutions to adapt curricula, develop new job classifications, create many new jobs, and improve the capacity of a large number of existing staff to begin to meet the requirements of successful CV application and infrastructure deployment. DOTs may choose to contract out much of the IT work associated with C/AV technology functions. DOTs will still have to plan for IT infrastructure and will need to be knowledgeable about it, but the day-to-day logistics may be handled, to various degrees, by IT contractors.
- Public acceptance drives V2V effectiveness and yields public safety benefits; therefore, far in advance of V2V deployment, DOTs may find it beneficial to partner

- with automobile manufacturers to develop an effective public outreach strategy to communicate potential safety benefits of V2V technologies.
- Planning for CV/ITS implementation requires a hybrid skillset that combines an understanding of transportation with skills in the areas of electronics, programming, and computer science, placing professionals with this skillset in high demand. State salaries and legacy job descriptions create challenges to attracting and keeping valuable staff on-board.
  - Agencies must monitor technology advancements. They may not be the lead testing agency, but they still need to learn from active research programs. Agencies also must implement change management to keep up with and adapt to new technologies.

## Equity and Legal Compliance

- Planners should expect that CV infrastructure will be incrementally (organically) brought online; therefore, the system's benefits will be unequally distributed among potential users. Ample research must be completed to justify and transparently document how pilot locations are prioritized. Care should be taken to ensure that CV infrastructure projects are compliant with Title VI of the Civil Rights Act.
- As the role of State DOTs will henceforth include planning for IT and IT systems customer service, it is especially important that CV projects be compliant with section 508 of the Rehabilitation Act as well as the Americans with Disabilities Act. This is an especially important issue because C/AV technology and infrastructure will offer significant mobility advantages to people with disabilities who are currently unable to drive.

This wide range of impacts leaves transportation agencies and planners with questions about how these impacts will shape the planning products discussed in the typology above—as well as the goals, projects, processes, methods, and tools associated with these products. For instance:

- Where is “tipping point” when investment decisions change?
- What are locations, costs, and impacts of incorporating CV infrastructure into projects? How does this change with project timeframe?
- What are impacts on agency tools and processes and when do they come into play?
- What changes will happen in stakeholder mix, public-private partnerships, and financing?

To close the loop, the following section documents the specific impacts of C/AV on individual planning products through a series of case studies.

# Case Studies

The case studies developed a number of illustrative scenarios of connected/automated vehicle (C/AV) impacts in transportation planning, based on real-world planning products and environments. The case studies highlight the various ways that C/AVs can be addressed in planning processes and products. From the larger list of transportation planning products discussed in the Impact Typology section, the project selected the 11 products listed below for case study analysis. These case studies represent the broad spectrum of planning products developed by States, metropolitan planning organizations (MPO), and local agencies and illustrate the variety of potential impacts that C/AV technologies are expected to have on the transportation planning process and related activities.

1. Transportation Improvement Program
2. Intelligent Transportation System (ITS) Architecture and Operations Plan
3. Bicycle and Pedestrian Planning
4. Long-Range Metropolitan Transportation Plan
5. Transportation Asset Management Plan
6. Strategic Highway Safety Plan
7. State Implementation Plan
8. Transit Development Plan
9. Public Involvement Plan
10. Freight Plan
11. Financial Plan

Each case study includes an overview of a specific transportation plan or program, explores potential impacts of C/AV in terms of the key components of the plan/planning process, and presents an example C/AV project that might be included within that product. In exploring the potential impacts of C/AV, the case studies discuss how C/AV can be incorporated into planning and programming functions in the short and medium to long term, the roles and responsibilities of stakeholders, and existing U.S. Department of Transportation (DOT) planning guidance and tools that can provide support. The case studies focus on only the most significant or unique impacts of C/AV on the given type of transportation plan; however, additional impacts and recommendations can be found in the associated report *Connected Vehicle Impacts on Transportation Planning, Technical Memorandum #5: Case Studies*.

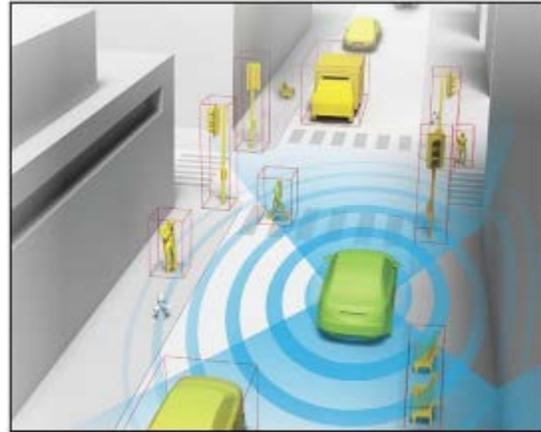
## 1. Transportation Improvement Program

Metropolitan planning organizations (MPO) develop Transportation Improvement Programs (TIP) to identify, evaluate, and provide funding information for all federally funded or regionally significant transportation projects that they plan to undertake over the next four years. TIPs focus on near-term goals, funding, and performance measurement—making them an important case study for the early incorporation of C/AV into transportation planning processes.

The case study discusses the impacts of C/AV on TIPs in terms of the four key elements of a TIP, listed below along with a short description. Recommendations for how MPOs can adapt each element of the TIP to embrace C/AV-related opportunities are presented along with the given impact.

**1. Project Selection Criteria:** Develop a set of evaluation metrics, such as “scoring techniques” or other quantitative approaches to rank projects:

- Project selection criteria in the TIP will need to be able to identify C/AV technologies that may help achieve the overarching goals/objectives of the transportation program.
  - Agencies should evaluate whether their project selection criteria can accommodate C/AV projects, and work to make changes in the criteria if needed.
  - Incorporating C/AV into selection criteria may be difficult in the beginning, but existing ITS project selection criteria and existing pilot deployments can be used as a starting point.
  - In general, lessons for C/AV in the TIP selection process can be gleaned from examining ITS projects in the agency’s TIP programming.



**Figure 2. Illustration. Communications between connected/automated vehicles and connected/automated vehicle-enabled infrastructure and pedestrians.**

(Source: Cambridge Systematics, Inc.)

**2. Project List:** Prioritize a list of projects and strategies to be programmed over the next four years:

- Early C/AV projects selected in the TIP project list are likely to be demonstration projects or projects that do not require a high level of market penetration.
  - Agencies should look for opportunities to incorporate such C/AV projects into capital projects or replacements for ITS investments.
  - Public involvement in selecting early C/AV projects should accommodate the general public’s likely limited awareness of C/AV with educational components.
  - As C/AV advances, C/AV applications identified in the long-range Metropolitan Transportation Plan should be re-evaluated for any short-term applications bundles ready to be programmed.

**3. Financial Plan:** Determine the funding sources and match to projects and strategies:

- The financial plan in the TIP should identify funding program eligibility for C/AV investments and include any early benefit/cost analysis of alternative C/AV investment options and strategies where possible.
- The impacts of C/AV on financial plans are further explored in the project’s Financial Plan Case Study.

**4. Monitoring and Evaluation:** Monitor funded projects and strategies and evaluate their effectiveness in supporting performance targets established in the long-range transportation plan:

- C/AV will provide opportunities to collect data and monitor system performance that may be more cost effective than existing methods.
- Agencies should be prepared to assess these data collection opportunities as well as track the system benefits and costs of any early C/AV deployments.
- Early on, published final reports on the impacts of C/AV-enabled data collection will lag behind deployment of the technology. Agencies should share information about their works in progress.

**Example C/AV Project in a TIP:** To illustrate the type of project found in a TIP that would benefit from the incorporation of C/AV considerations, the case study discusses recent advances in traffic signal preemption for oncoming emergency vehicles. The emergency vehicle preemption application (abbreviated as PREEMPT) employs connected vehicle and infrastructure technology to enable emergency vehicles to broadcast their location, route, and final destination to vehicles and infrastructure in their path and request traffic signal preemption for a safer, more efficient trip. The large-scale deployment of PREEMPT will require a long-term strategy for implementation over multiple TIP cycles. The case study, however, gives an indication of the range of the costs associated with initial TIP planning for PREEMPT applications by providing estimates of the capital costs of a pilot PREEMPT project (see table 2, note that annual operations and maintenance costs are not captured here).



**Figure 3. Illustration. Connected vehicle technology used to preempt traffic signals for emergency vehicles.**  
(Source: U.S. Department of Transportation.)

**Table 2. High-level cost estimate of the capital costs to deploy a pilot emergency vehicle preemption project using connected/automated vehicles technology.**

Item	Quantity	Per Unit Cost	Total Costs
Dedicated short-range communication roadside units	20 intersections	\$13,100 to \$21,200	\$262,000 to \$424,000
Signal controller upgrade	20 intersections	\$3,200	\$64,000
Backhaul communications	1 system (20 intersections)	\$30,000 to \$40,000	\$600,000 to \$800,000
Light vehicle on-board units	10 vehicles	\$4,700	\$47,000
Connected/Automated Vehicles Project Total	—	—	\$973,000 to \$1,335,000
Dedicated short-range communication roadside units	20 intersections	\$13,100 to \$21,200	\$262,000 to \$424,000

Source: Cambridge Systematics, Inc.

## 2. Intelligent Transportation Systems Architecture and Operations Plan

The United States Department of Transportation (U.S. DOT) requires that States and regions deploying ITS projects funded from the Highway Trust Fund develop a statewide/regional ITS architecture based on the National ITS Architecture. While this case study focuses on statewide ITS architectures, the discussion is also relevant to regional ITS architectures.

Generally speaking, C/AV are expected to impact statewide ITS architectures by: enhancing current ITS services in the short term and replacing ITS services/providing new services in the long term; strengthening the linkage between the operations and planning of ITS by involving a wider array of stakeholders in activities such as creating and sharing new data sources; and introducing new priorities in ITS operations and planning. For example, if the potential of C/AV to significantly reduce crashes is realized it would allow States to reallocate some resources currently dedicated to safety and incident management.

The case study discusses the impacts of C/AV on ITS architectures in terms of the six key elements of a statewide ITS architecture, listed below along with a short description. Recommendations for how States can adapt each element of the architecture to embrace these impacts and opportunities are presented along with the given impact. This document focuses on only the most significant or unique impacts of C/AV, and additional impacts and recommendations can be found in the associated report *Connected Vehicle Impacts on Transportation Planning, Technical Memorandum #5: Case Studies*.

**1. Scope and Stakeholders:** Based on the scope of the region, identify the relevant stakeholders, one or more champions, and the team involved in architecture development:

- State Departments of Transportation (DOT) will need to engage and educate an array of C/AV stakeholders:

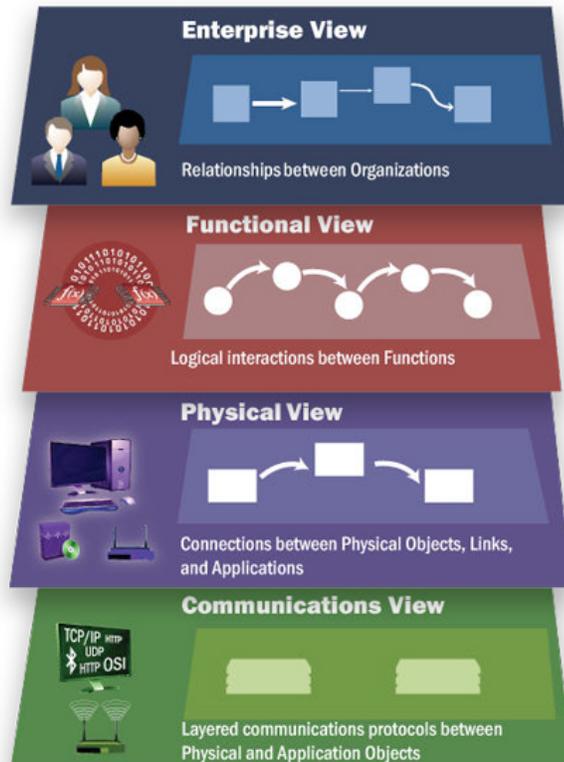
- Some potential C/AV stakeholders can be contacted through existing ITS working groups while others will require tailored outreach efforts.
- Traffic engineers, transit agencies, emergency response personnel, planners, and private companies providing C/AV services (Original Equipment Manufacturers (OEM) and telematics companies) are examples of important stakeholder groups.
- State DOTs should identify and/or train staff who are knowledgeable about C/AV and ITS architecture to spearhead this outreach effort.

**2. Data:** Inventory existing and planned ITS systems in the region, define the roles and responsibilities of each stakeholder, and identify the ITS services that should be provided in the region:

- C/AV technology and projects will need to be incorporated into the inventory, needs, and operational concept of State ITS systems.
  - State DOTs should document existing assets related to C/AV to create a baseline for measuring the impacts of C/AV deployment.
  - State DOTs should clearly define the functional requirements of C/AV and work to gain consensus on the services that these functional requirements provide.
  - Agencies should define/update roles and responsibilities for the deployment, operations, and maintenance of C/AV elements.

**3. Interfaces:** Define existing and planned interfaces between ITS systems including connections and information exchange. Interfaces include connections between different systems, between systems and equipment or between different pieces of equipment (for example, a connection between a regional freeway operations center and a local traffic signal management center):

- All new C/AV-related interfaces will need to be defined.
  - DOTs should define the means of information flow between C/AV elements and existing ITS elements, taking security requirements into consideration.
  - As a resource, the most recent National ITS Architecture 7.1 and the



**Figure 4. Diagram. The four views of the Connected Vehicle Reference Implementation Architecture—a Federal tool for developing connected/automated vehicle architectures that align with National Intelligent Transportation Systems Architecture standards.** (Source: U.S. Department of Transportation.)

associated Turbo Architecture tool connect services packages with C/AV applications defined in the Connected Vehicle Reference Implementation Architecture (CVRIA).

- In the short term, C/AV will likely enhance the functionality of current ITS services, in the medium to long term C/AV may replace some ITS elements and/or provide new services, such as replacement of Dynamic Message Signs with tailored in-vehicle displays.
- A transition plan may be useful in describing how existing interfaces will be updated as C/AV technology is integrated.

**4. Agreements and Standards:** Define additional products to guide implementation of projects that will flow from the regional ITS architecture, including a sequence of projects, a list of requisite agency agreements, and a list of standards:

- As C/AV projects are planned, information exchange agreements and standards between stakeholders will need to be established.
- Since many C/AV projects will likely be implemented through public-private partnerships, DOTs will need to incorporate data-ownership and right-of-way provisions into such agreements.
- Agencies should identify common standards for C/AV projects to provide interregional connectivity and a consistent user experience for the traveling public.

**5. Regional Architecture Use:** Utilize the architecture in transportation planning and project implementation to identify opportunities for making ITS investments in a more cost effective fashion:

- This element of statewide ITS architectures can provide content for how C/AV projects fit within and benefit the greater ITS system.
  - State DOTs should take advantage of this opportunity to help integrate and implement C/AV projects.
- The process of integrating C/AV elements into the statewide ITS Architecture can enhance the linkage between operations and planning through involvement of a wider array of stakeholders.
- In the long term, C/AV technology may significantly reduce crash rates and change operations planning priorities, with fewer resources allocated to incident management, operations and maintenance (O&M) strategies. ITS/operations plans should be updated accordingly.

**6. Regional Architecture Maintenance:** A maintenance plan guides controlled updates to the regional ITS architecture baseline so that it continues to accurately reflect the region's existing ITS capabilities and future plans:

- State DOTs should identify the entity that can lead the maintenance effort related to C/AV, and develop a maintenance plan.
- Given C/AV's evolving nature, frequent updates to the C/AV-related ITS architecture and maintenance plan will be needed.

**Example C/AV Project in Statewide**

**ITS Architectures:** To illustrate the type of C/AV technologies and systems that States may incorporate into ITS architectures, the case study discusses the benefits and costs of “virtual” C/AV-enabled dynamic message signs (DMS). In this application, connected/automated vehicles equipped with dedicated short-range communications (DSRC) technology could receive and display messages from nearby C/AV-enabled roadside units (RSU), rather than only receive information from traditional DMSs as they pass (see figure 5). Messages could be made audible so that drivers can keep their eyes on the road, or even translated into another language.



**Figure 5. Photo. A traditional dynamic message sign.**  
(Source: [U.S. Department of Transportation.](#))

A Mid-Atlantic Universities Transportation Center (MAUTC) benefit-cost study found that virtual DMS systems provide a more cost effective and flexible solution since the technology can be utilized for other in-vehicle messages such as work zone and queue warnings. In the short term, however, 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 will be difficult to motivate voluntary investment solely for benefit of more effective information dissemination. 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. Over the medium to long term, DSRC technology is anticipated to become standard and will not require additional investment from the traveling public.

Table 3 lists and compares the capital costs of a traditional and a virtual C/AV-enabled DMS system. The total average cost of the traditional DMS system is \$560,000 and total high-end cost of the C/AV-enabled DMS system is \$122,000. 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, a DSRC RSU can be installed along the road since messages are received inside the vehicle.

**Table 3. High-level cost comparison of the capital costs associated with traditional dynamic message sign systems versus virtual dynamic message sign systems that can communicate with connected/automated vehicles.**

Traditional Dynamic Message Sign Item	Traditional Dynamic Message Sign Total Average Cost	Virtual Connected/ Automated Vehicles enabled Dynamic Message Sign Item	Virtual Connected/ Automated Vehicles enabled Dynamic Message Sign Total Maximum Cost
Dynamic Message Sign (2)	\$217,000	Roadside Unit (2)	\$42,000
Support Structures (2)	\$231,400	–	–
Communications and Power (0.5 mile)	\$67,500	Backhaul Communications (2)	\$80,000
Controller and Other	\$43,800	–	–
Total	\$559,700	Total	\$122,400

Source: Cambridge Systematics, Inc.

### 3. Bicycle and Pedestrian Planning

Federal legislation requires metropolitan planning organizations (MPO) to include bicycle and pedestrian elements in the Metropolitan Transportation Plan (MTP) and Transportation Improvement Plan (TIP), such as: policy statements and goals related to bicycle and pedestrian transport; bicycle/pedestrian projects and programs; and financial resources. The focus of this case study is on MPOs, but the discussion applies to State bicycle and pedestrian planning as well.

Generally speaking, C/AV are expected to impact bicycle and pedestrian planning by enabling greater visibility of bicyclists and pedestrians to the motor vehicles and the entire traffic system. C/AV technology also will provide the opportunity to collect new data on bicycle/pedestrian infrastructure condition, travel patterns and performance measures.

The case study discusses the impacts of C/AV in terms of the five key elements of bicycle and pedestrian planning efforts listed below along with a short description. Recommendations for how MPOs can adapt each element to embrace these opportunities are presented along with the given impact. This document focuses on only the most significant or unique impacts of C/AV, and additional impacts and recommendations can be found in the associated report *Connected Vehicle Impacts on Transportation Planning, Technical Memorandum #5: Case Studies*.

**1. Vision, Goals, and Performance Measures:** Develop high-level vision statements, measurable goals, and performance measures:

- C/AV can make bicyclists and pedestrians more visible to traffic systems, potentially improving both safety and mobility.

- MPOs should ensure that visions, goals, and performance measures reflect these improvements.
- MPOs could promote the benefits of C/AV to bicyclists and pedestrians to encourage participation, for example providing them with information on smartphone or navigation system applications that can make them more visible to motorists.

**2. Current Conditions and Needs:** Collect baseline information such as current level of use, injuries and fatalities, and infrastructure conditions. Use the developed performance measures to assess needs and identify gaps:

- C/AV will introduce cost effective data sources and collection methods.
  - In the medium to long term, MPOs can use C/AV to supplement or replace existing sources and methods for collecting bicycle and pedestrian data.
- C/AV probe applications are one innovative way to collect bicycle infrastructure condition and performance data.
- Agencies should identify existing infrastructure that should be upgraded/integrated in order to support C/AV bicycle and pedestrian applications.
  - For example, signal controllers may need to be modified/upgraded to communicate with dedicated short-range communications (DSRC) roadside units (RSU).

**3. Strategies to Meet Vision and Goals:**

Identify strategies to meet the stated goals and determined needs. These can include policies, educational efforts, or infrastructure improvements:

- As there will likely be limited C/AV pilot deployments focused on bicycles and pedestrians in the near term, MPOs could work to develop small-scale pilots to generate interest in and safely test C/AV applications.
- In the medium to long term, C/AV may reduce the required width of vehicle travel lanes, as well as some parking requirements.
  - This could free up space for MPOs to plan more bicycle and pedestrian infrastructure on existing roads.
- C/AV technology can improve bicyclist/pedestrian safety by warning vehicles of their presence, and improve the mobility of disabled and/or elder pedestrians by extending walk indications.



**Figure 6. Photo. Pedestrians waiting at a signalized crosswalk.**  
(Source: iStockphoto.)

**4. Inclusion in the MTP and TIP:** Incorporate the identified strategies into the MTP and TIP, following the timeframe and update cycle:

- To help include bicycle and pedestrian elements in MTPs and TIPs, as well as accessibility transition plans, MPOs could collaborate with local transit agencies and other State/regional agencies to integrate bicycle and pedestrian elements into transit- and motor vehicle-focused C/AV investments.

**5. Evaluation of Progress:** Monitor progress toward identified vision and goals and update strategies accordingly:

- Bicycle and pedestrian-related C/AV projects will need to be evaluated as part of the performance-based planning feedback process.
  - MPOs should document the impacts, costs, and benefits of these projects.
  - Smartphone applications provide an opportunity to collect this information, although privacy concerns would need to be addressed.

**Example C/AV Project in Bicycle and Pedestrian Planning:**

To illustrate the type of C/AV technologies and projects that MPOs may incorporate into bicycle and pedestrian planning, the case study discusses the benefits and costs of the mobile pedestrian signal system application known as PED-SIG. PED-SIG allows pedestrian users, such as senior citizens and the disabled, to broadcast their location and extend walk time through the use of smartphones enabled with dedicated short-range communication (DSRC)

technology. The application can provide visual and haptic feedback to help visually impaired users. PED-SIG could also apply to bicyclists. The use case for bicyclists is at actuated intersections where bicycle detection and travel time is not sufficient. Further, the application could collect data and inform authorities of traffic signals that should be adjusted to better accommodate bicyclists.



**Figure 7. Photo. The Pedestrian Signal System application offers safety benefits to many types of pedestrians, for example pedestrians who use wheelchairs.**

(Source: iStockphoto.)

Table 4 presents a high-level estimate of capital costs to deploy C/AV infrastructure, equipment, and the PED-SIG application for a pilot PED-SIG project. DSRC RSUs will be installed at each of 10 intersections and pedestrians/bicyclists will be equipped with DSRC-enable smartphones. Each intersection will require a signal controller and backhaul upgrade. While there are separate applications with various mobility and safety features, development of a comprehensive application will require additional software costs. The total budget of this project ranges from \$772,000 to \$958,000. (There are other costs not captured here, such as annual operations and maintenance costs and public outreach costs.) Nonetheless, the benefits of incorporating a C/AV project such as

PED-SIG into bicycle and pedestrian planning efforts are that it would provide an effective solution to addressing the needs of vulnerable users that could be implemented in the short term.

**Table 4. High-level cost estimate of capital costs to deploy connected/automated vehicles infrastructure, equipment, and the Pedestrian Signal System application.**

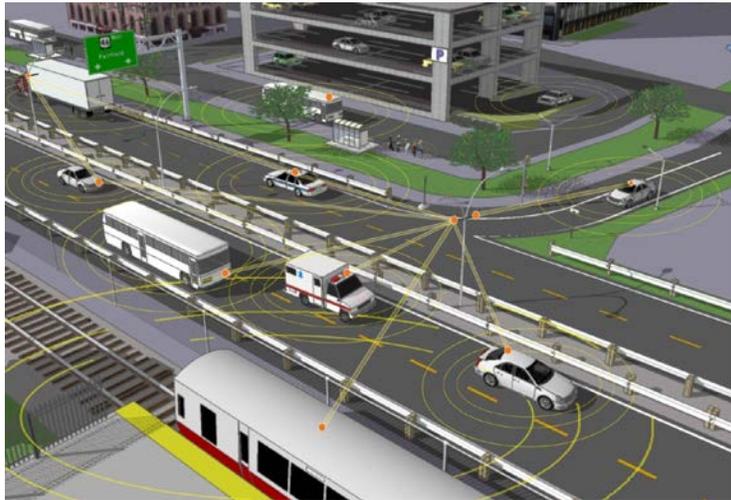
Item	Quantity	Per Unit Cost	Total Costs
Dedicated short-range communications roadside unit	10 intersections	\$13,100 to \$21,200	\$131,000 to \$212,000
Signal controller upgrade	10 intersections	\$3,200	\$32,000
Backhaul communications	1 system (10 intersections)	\$30,000 to \$40,000	\$300,000 to \$400,000
Mobile application development	1 application	\$300,000	\$300,000
Mobile smartphone upgrade	30 units	\$300	\$9,000
Connected/Automated vehicles Project Total			\$772,000 to \$958,000

Source: Cambridge Systematics, Inc.

## 4. Long-Range Metropolitan Transportation Plan

MTPs guide decisionmaking around regional transportation investments by setting goals, evaluating alternative strategies to meet these goals, and measuring progress. MTPs must cover all modes of surface transportation over a 20+ year horizon. Since C/AV technologies have the potential to revolutionize transportation over the next 20 years, it is imperative to start thinking about how C/AV can be incorporated into the goals and strategies of MTPs now.

The case study discusses the impacts of C/AV on MTPs in terms of the seven key elements of an MTP, listed below along with a short description. Recommendations for how MPOs can adapt each element of the MTP to embrace these C/AV-related opportunities are presented along with the given impact. This document focuses only on the most significant or unique impacts of C/AV on MTPs, and additional impacts and recommendations can be found in the associated report *Connected Vehicle Impacts on Transportation Planning, Technical Memorandum #5: Case Studies*.



**Figure 8. Illustration. A range of connected/automated vehicle technologies.**

(Source: U.S. Department of Transportation.)

**1. Gather Information on the Baseline Transportation System:** Identify existing transportation assets, compile estimates on travel patterns and land use, and incorporate analysis of system revenue and cost:

- MTPs will need to identify existing infrastructure that needs to be upgraded/integrated to support C/AV.
  - MPOs have the opportunity to schedule C/AV upgrades during planned replacements and maintenance of existing infrastructure.
- Estimates of the regional C/AV market penetration will be needed to anticipate the extent of C/AV impacts on all modes and all projects in the MTP over the next 20 years.
  - MPOs should establish a regular process for reviewing C/AV technology and trends to help inform the MTP baseline analysis and to estimate regional C/AV market penetration.

**2. Establish Goals and Objectives:** Engage the public and stakeholders to establish goals and objectives:

- MTP goals and objectives related to issues such as sustainability, data security, and social equity may be impacted by C/AV (e.g., changes in travel behavior and data collection; access to new technology).
  - Scenario planning around C/AV can help MPOs understand the range of potential sustainability, equity, and security impacts.
  - MPOs should proactively factor in these issues while envisioning C/AV infrastructure and policies.
- The MTP should describe how C/AV can enhance the vision for transportation in the region—while being realistic about the short-term impacts and clearly explaining the nature, goals, benefits, and challenges of C/AV.

**3. Develop the Performance Measures and Targets:** Determine the performance measures (PM) and targets used to track progress toward objectives:

- C/AV is projected to reduce crash rates over time and, therefore, impact safety PMs and targets.
  - Performance target setting in MTPs should consider the short-/medium-/long-term potential of C/AV to lower crash rates.
- The types of PMs that MPOs are able to collect will likely expand with new data available from C/AV.
  - MTPs should track and be prepared to take advantage of opportunities to improve data collection and analysis using C/AV technology.

**4. Analyze Alternatives:** Identify system needs and analyze the alternatives that will move the system toward established targets:

- C/AV will likely present opportunities to collect and apply new sources of data in the alternatives analysis.
  - For example, travel times and pavement condition data can be collected by C/AV in the short term.
- C/AV will increase the level of uncertainty inherent in the alternatives analysis.
  - MTPs should include a range of scenarios and risk analyses related to different C/AV penetration rates in the alternatives analysis.
    - Attention should be paid to potential risks to vulnerable road users such as pedestrians and those not participating in the C/AV environment.
  - MTPs should also incorporate the potential socioeconomic impacts of C/AV into this analysis, including impacts on land use density and the location of economic activity.
  - Engineers, operations personnel, modelers, and others will need to work more closely together to define and understand alternatives.

**5. Develop a Financial Plan and Investment Priorities:** Assess funding sources, prioritize alternatives, and select the most cost effective solutions.

- Estimates for the costs and benefits of C/AV need to be considered in the financial plan, but there will significant limitations and uncertainty associated with early estimates.
  - MPOs must clearly communicate the C/AV cost estimation methodologies, and the inherent uncertainty, to decision makers and the public to maintain support for C/AV investments in the long term.
  - The Federal Highway Administration's CO-PILOT software is available for sketch planning level cost estimates.
  - The alternative of not investing in C/AV infrastructure and technology should be assessed as well (the "do-nothing" alternative).

**6. Perform Transportation Planning and Programming:** Assess funding sources, prioritize alternatives, and select the most cost effective solutions.

- Programming of C/AV investments should consider replacement cycles for existing ITS investments, as well as whether C/AV can replace current ITS investments.
- In the narrative discussion that translates the plan to the program, agencies could identify short-term C/AV applications bundles that are ready to be programmed, along with applications that will be assessed in the future.

**7. Implement and Monitor:** Implement the transportation plan and monitor the performance measures.

- C/AV is expected to evolve quickly, as are the impacts of C/AV on the current programs, planned capital investments, and performance measures in MTPs.

- Potential C/AV impacts on all of the above elements—especially on major planned capital investments—should be reevaluated regularly in light of C/AV advancements and market penetration.

**Example C/AV Project in an MTP:** To illustrate the type of C/AV strategies that MPOs may analyze in MTPs, the case study discusses a C/AV strategy—comprised of four C/AV applications—that an MPO in a major urban area identified to help reach its own regional transportation goals. These four C/AV applications are:

- Pedestrian/Bicyclist in Signalized Crosswalk for Transit Vehicles (PSCWT).
- Probe-Based Pavement Maintenance (PBPM).
- Emergency Vehicle Preemption (EVP).
- Eco-Arrival and Departure at Signalized Intersections (EADSI).

In this case, the C/AV strategy is a medium- to long-term strategy, evolving a small-scale pilot to a large deployment over time. Table 5 demonstrates how these C/AV strategies are able to help the MPOs meet its goals by lining up the recommended C/AV solutions with the specific MPO goals, as well as with the traditional non-C/AV solution. This provides an example of how an MPO might incorporate and analyze C/AV solutions along with more traditional solutions in an MTP.

**Table 5. Metropolitan Planning Organization goals with the associated desired performance, tradition solution, and potential connected/automated vehicle solution.**

Goal Areas	Desired Performance	Traditional Solution	Potential Connected/Automated Vehicle Solution
<b>Safety:</b> Reduce vehicle injuries and fatalities	Mitigate crashes on left turns between vehicles and pedestrians/bicyclists	Install protected left-turn signals	Pedestrian/Bicyclist in Signalized Crosswalk for Transit Vehicles
<b>Agency Data:</b> Maintain pavement data	Capture real-time pavement condition so repairs can be expedited where necessary	Manual field survey of pavement	Probe-Based Pavement Maintenance
<b>Mobility:</b> Improve emergency vehicle response time	Allow system to dynamically respond to emergency vehicle needs	Emergency vehicle signal priority	Dedicated short-range communications-based Emergency Vehicle Signal Priority
<b>Environmental:</b> Reduce emission	Promote greener driving behavior via controlled speed through signalized intersections	N/A	Eco-Arrival and Departure at Signalized Intersections

Source: Cambridge Systematics, Inc.

Finally, table 6 provides a high-level estimate of the capital costs associated with deploying this four-pronged C/AV strategy, broken down into deployment elements, quantity, per unit cost, and total cost (note that annual operations and maintenance costs are not captured here.). Once applications are developed they can be used by multiple agencies, reducing the unit cost.

**Table 6. High-level cost estimate of the capital costs to deploy the four-pronged connected/automated vehicle strategy.**

Item	Quantity	Per Unit Cost	Total Costs
Dedicated short-range communication roadside units	100 intersections	\$13,100 to \$21,200	\$131,000 to \$2,120,000
Signal controller upgrade	100 intersections	\$3,200	\$320,000
Backhaul communications	100 intersections	\$30,000 to \$40,000	\$3,000,000 to \$4,000,000
Emergency Light vehicle on-board units	200 vehicles	\$4,700	\$940,000
Mobile device upgrade to enable Dedicated short-range communications	100 pedestrians and bicyclists	\$300	\$30,000
Probe-Based Pavement Maintenance mobile application development	1 application	\$200,000	\$200,000
Connected/Automated Vehicles Project Total	–	–	\$4,620,000 to \$7,610,000

Source: Cambridge Systematics, Inc.

## 5. Transportation Asset Management Plan

Transportation Asset Management Plans (TAMP) inventory transportation system assets, conditions, and strategies to maintain/improve assets and system performance. Each State Department of Transportation (DOT) is required to develop a TAMP for the National Highway System (NHS), as a result this case study focuses on State TAMPs. Generally speaking, C/AV technology will impact TAMPs by enabling the collection of real-time information on traffic and infrastructure condition. This will allow States to better understand their assets, prioritize investments, and select cost effective repair and maintenance techniques.

The case study discusses the impacts of C/AV in terms of the six key elements of a TAMP listed below, along with a short description. Recommendations for how States can adapt each element to embrace C/AV-related opportunities are presented along with the given impact. This document focuses on only the most significant or unique impacts of C/AV, and additional impacts and recommendations can be found in the associated report *Connected Vehicle Impacts on Transportation Planning, Technical Memorandum #5: Case Studies*.

**1. Asset Inventory and Condition:** Summarize the inventory of pavement and bridge assets on the NHS in the State and their condition; assess historic condition information, current and future traffic volumes, and new assets being built as part of capital expansion programs:

- In the short term, C/AV applications will likely reside in State DOT or other public sector agency vehicles, and can be used to supplement existing data collection methods.

- For example, pavement data is now largely collected by specially outfitted vehicles. C/AV vehicles and smartphones will be able to provide more cost effective alternative data collection methods.
- In the medium to long term, C/AV market penetration will increase and crowdsourced data can potential replace existing data collection methods.
- To support CV and eventually AV applications on infrastructure systems. Traditionally ITS systems such as communication systems, field controllers, and networks shall be added to the asset inventory and conditions.
  - Make, model, connectivity, owner, and maintenance status of field systems shall be inventoried.
  - Version, attributes setting, and support status of software on field systems shall be inventoried.
  - Communication network, network protocol, communication equipment, network topology, ownership, and maintenance status shall be inventories.

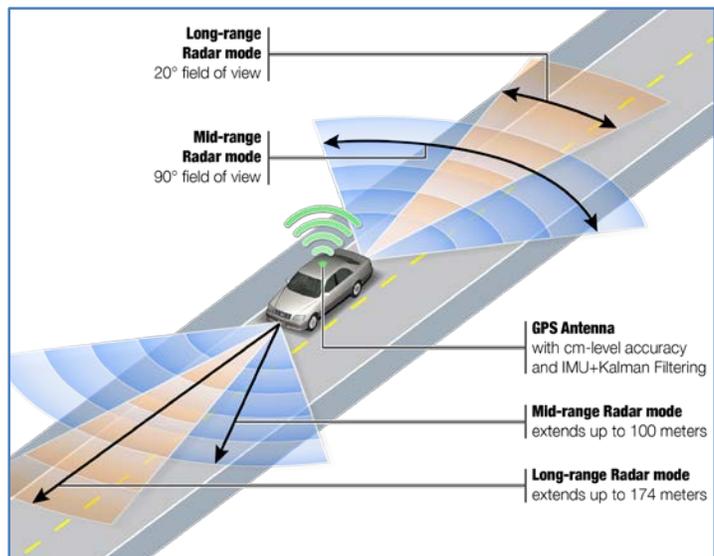
**2. Objectives and Measures:** Define objectives of the asset management program, levels of service and measures, and short-term and medium- to long-term condition targets:

- In order for the traveling public to participate in the C/AV environment (e.g., provide condition data), agencies should clearly explain the technology, its benefits, and address any concerns such data privacy and security.
- Real-time information collected by C/AV will provide States the opportunity to identify poor performing assets sooner and take proactive actions.
  - However, State DOTs will have to manage public expectations for short-term repair, and balance resources against longer-term needs.

**3. Performance Gap Assessment:**

Define objectives of the asset management program, levels of service and measures, and short-term and medium- to long-term condition targets:

- Continuous C/AV data will allow performance gap assessments to be performed more frequently, enabling dynamic adjustment for changing traffic patterns.
- Forecasting assumptions and models will need to be updated accordingly, and new tools will be needed to process large amounts of new C/AV data.



**Figure 9. Illustration. Connected/automated vehicle technologies used to obtain information on the surrounding environment.**

(Source: Cambridge Systematics, Inc.)

- During the transition period from manual data collection to probe data collection, agencies should be aware of gaps that may occur between the two datasets.
  - It is likely that some funding will be needed to continue manual methods for some time, in order to create a baseline.

**4. Alternative Investment Plans:** Use life-cycle cost and risk assessment analysis to develop alternative investment plans; define both programmatic and system risks:

- Asset management probe data will be collected from in-vehicle devices provided by automobile manufacturers, suppliers, or aftermarket companies.
  - In terms of asset management, agencies will be concerned primarily with the roadside equipment collecting the data, and back office processing and data management services.
- New tools and personnel will be needed to process and analyze large amounts of C/AV data (if third parties perform this work, planning agencies will need to be able to assess the reliability/quality of the information).
- Agencies should identify risks associated with various technological investments related to asset management data collection and analysis.
  - Rapid changes will require agencies to keep up with technological developments and share experience through peer exchanges.
  - Life cycle analysis for equipment should include consideration of difference in benefit/cost from technology changes and obsolescence in hardware, software/firmware, or virtual/cloud services.

**5. Financial Plan:** Identify funding sources and forecast funding levels over the short and medium to long term; analyze implications of various funding levels in terms of asset valuation and financial sustainability:

- C/AV considerations for the financial plan element of the TAMP are included in the Financial Plan case study for this project. See the separate Financial Plan case study memo for further information.

**6. Investment Strategy:** Compare investment plans and develop a fiscally constrained investment strategy:

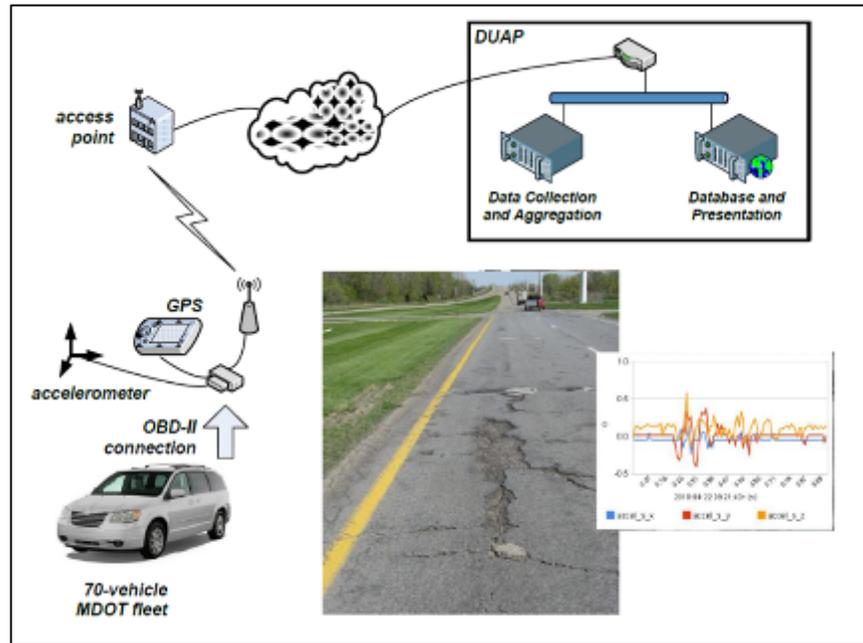
- State-specific prototype installations are recommended for assessing the opportunities and challenges of C/AV adoption in the investment strategy.
  - An example prototype is a comparison of the data accuracy between manual and C/AV probe-based collection methods.

**Example C/AV****Project in the TAMP:**

To illustrate the type of C/AV technologies and projects that States may incorporate into the TAMP, the case study discusses the benefits and costs of Probe-Based Pavement Maintenance (PBPM). Most agencies collect pavement maintenance data through both visual surveys and driving vehicles with surface profile measurement equipment. This time-consuming and expensive process is usually done once

every few years. As part of the U.S. DOT Connected Vehicle Research Program, Michigan DOT's (MDOT) Data Use Analysis and Processing (DUAP) project evaluated the uses and benefits of applying C/AV technology to collect PBPM data instead. With PBPM, a driver's smartphone application would track vertical displacement, assess if it was a pothole, and send location and pothole size through the cellular network to a back office. PBPM would be a more cost effective and efficient method. However, for this sort of crowdsourced data to ultimately replace current methods, there would need to be a critical mass of users and adequate system coverage.

Table 7 presents a high-level cost estimate to deploy and pilot C/AV infrastructure, equipment, and PBPM application. Since this is a cellular-based application, there is no DSRC infrastructure. Aftermarket OBUs would be installed into agency-owned vehicles. The total cost of the project is \$123,000. (There are other costs not captured here, such as acquiring resources to store and analyze the data.) After analyzing the benefits and costs, MDOT concluded that C/AV technology has significant potential to enhance pavement data collection and that PBPM could be programmed into TAMPs in the next three to five years.



**Figure 10. Diagram. Michigan Department of Transportation Data Use Analysis and Processing project test and results of deploying a Probe-Based Pavement Maintenance application.**

(Source: Michigan Department of Transportation.)

**Table 7. High-level cost estimate of capital costs to deploy connected/automated vehicles infrastructure, equipment, and the probe-based pavement maintenance application.**

Item	Quantity	Per Unit Cost	Total Costs
Smartphone	30 users	\$500	\$15,000
Cellular data plan (\$50/month)	3 years	\$600	\$1,800
Probe-Based Pavement Maintenance mobile application development	1 application	\$100,000	\$100,000
Probe-Based Pavement Maintenance mobile application support	30 users	\$200	\$600
Connected/Automated Vehicles Project Total			\$122,800

Source: Cambridge Systematics, Inc.

## 6. Strategic Highway Safety Plan

As part of the Federal Highway Safety Improvement Program (HSIP), State Departments of Transportation (DOT) are required to develop, implement, evaluate, and update a Strategic Highway Safety Plan (SHSP). An SHSP identifies the State's greatest safety needs, and guides investment decisions regarding strategies with the greatest potential to save lives and prevent injuries. In general, C/AV will impact SHSPs by introducing new cost effective data that can supplement the crash, traffic, and vehicle data used in the SHSP. Certain types of crashes are also likely to be reduced over time as C/AV market penetration increases. In the long term, C/AV may improve safety to the point of allowing reductions in some safety investments included in SHSPs.

The case study discusses the impacts of C/AV in terms of the six key elements of a SHSP listed below along with a short description. Recommendations for how States can adapt each element to embrace these impacts and opportunities are presented. This document focuses on only the most significant or unique impacts of C/AV, and additional impacts and recommendations can be found in the associated report *Connected Vehicle Impacts on Transportation Planning, Technical Memorandum #5: Case Studies*.

**1. Leadership and Vision:** Identify personnel to lead the development effort and relevant stakeholders to involve in the process of developing a vision of the SHSP. Establish an organizational structure and collaboration framework:

- Personnel knowledgeable about on C/AV safety applications will be needed to steer C/AV aspects of the SHSP and to engage stakeholders.
- DOTs, along with partner agencies such as law enforcement, should identify and/or train such personnel.

- These personnel should provide the public and other stakeholders with a clear presentation of the nature, benefits, challenges, and objectives of C/AV in order to gain their support.
- C/AV safety applications may necessitate the involvement of new stakeholders in the SHSP, such as private C/AV equipment providers.
- Existing and new stakeholders should discuss the potential of C/AV investments to achieve the vision of the SHSP, as well as the long-term impacts of C/AV on the nature of the vision itself.

**2. Data Collection and Analysis:** Analyze available data to identify critical highway safety issues and safety improvement opportunities. Identify mechanisms and improvement strategies for data sharing, accuracy verification, and analysis methods:

- C/AV can collect new data that was previously unavailable, expensive, or difficult to collect.
  - For example, near-crashes can be reported, which DOTs can use to proactively identify hazardous locations.
  - In the short term, baseline information will likely continue to be collected by traditional methods; over the medium to long term, C/AV technology can supplement and replace existing sources and methods.
- DOTs should track pilots and tests to help identify possible C/AV safety investments.
- Agencies should consider potential needs created by C/AV investments, particularly any resources needed to store/analyze increased volumes of C/AV data.

**3. Emphasis Areas:** Develop emphasis areas based on data analysis and input from stakeholders representing the 4 Es of safety (engineering, education, enforcement, and emergency medical services). For each emphasis area, establish goals and measurable objectives along with performance measures:

- Emergency response applications may be an effective early deployment of safety-related C/AV technology.
  - State DOTs should collaborate with first responders on such applications, which would also help engage a wider audience and build support for broader projects.
- C/AV may significantly reduce crashes, and thus reduce the State resources needed for safety investments in the long term.
  - State DOTs should consider how this will impact/shift SHSP emphasis areas in the long term.

**4. Strategies and Countermeasures:** Develop strategies to achieve goals and countermeasures to support and implement strategies, while incorporating funding considerations. Evaluate and select preferred strategies and countermeasures:

- As C/AV matures and market penetration increases, safety warnings will be increasingly sent directly to vehicles and integrated with automated functions.
- State DOTs should account for this long-term shift in their strategies and countermeasures, while being careful to also plan for vehicles without C/AV technology.
- Agencies should actively educate stakeholders and the public to ensure that “safety complacency” does not occur, as C/AV systems will not be foolproof.
- Agencies should foster realistic expectations for short-term impacts of C/AV applications, as initial applications will be modest in terms of scope, geography, and capabilities.



**Figure 11. Photo. A crash between two nonconnected/automated vehicles on a roadway.**  
(Source: iStockphoto.)

**5. Action Plans:** Identify specific action steps for each countermeasure, assign responsibility to stakeholder(s), and document time lines:

- Action Plans will need to identify the skills required to implement safety-related C/AV strategies, from planning to design to deployment.
  - State DOTs that partner with private providers may need to acquire expertise in areas such as communications, security, and data management.
- Leadership should recognize that flexibility is needed in development of C/AV action plans since both the technology and estimates of market penetration levels will change.

**6. Implement and Evaluate:** Document implementation approach and evaluation methods. Evaluate the extent to which the SHSP is achieving its goals and objectives. Improve existing programs and develop new programs:

- Safety-related C/AV pilots tailored to State needs are a recommended method for assessing the challenges and opportunities of C/AV adoption, as well as an agency’s internal capacity.
  - State DOTs should plan and budget for such technical development activities; partnerships with universities may be a particularly effective resource.
- To motivate future C/AV-related safety investments, it will be critical to evaluate how effectively C/AV investments support safety targets, both directly (installing infrastructure) and indirectly (collecting data).

**Example C/AV Project in the SHSP:**

To illustrate the type of C/AV technologies and projects that States may incorporate into the SHSP, the case study discusses the benefits and costs of applying C/AV technology to enhance Curve Speed Warning (CSW) systems with the objective of providing more effective warnings. Current curve speed warning (CSW) systems use dynamic message signs (DMS) and radar to display warnings to drivers when their travel speeds exceed safety thresholds. C/AV technology could potentially integrate data from the infrastructure (e.g., slippery road surface condition) and nearby vehicles to deliver more accurate and robust warnings to drivers through in-vehicle displays. 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 vehicle sensor, digital map, and Global Positioning System (GPS) information and provide appropriate warnings when speeds were too high.



**Figure 12. Photo. Vehicles driving along a curvy road.**  
(Source: iStockphoto.)

Table 8 presents a high-level cost estimate of the capital costs to deploy C/AV infrastructure, equipment, and C/AV CSW. Dedicated short-range communication (DSRC) road-side units (RSU) will be installed along 10 curves with high crash rates and aftermarket on-board units (OBU) will be installed in 30 agency vehicles. The total cost of the project is from \$731,000 to \$912,000. (There are other costs not captured here, such as annual operations and maintenance costs.)

**Table 8. High-level cost estimate of the capital costs to deploy connected/automated vehicle infrastructure, equipment, and connected/automated vehicle-enhanced curve speed warning application.**

Item	Quantity	Per Unit Cost	Total Costs
Dedicated short-range communications roadside units	10 curves	\$13,100 to \$21,200	\$131,000 to \$212,000
Backhaul communications	1 system (10 curves)	\$30,000 to \$40,000	\$300,000 to \$400,000
Light vehicle aftermarket on-board unit	30 vehicles	\$10,000	\$300,000
Connected/Automated Vehicles Project Total			\$731,000 to \$912,000

Source: Cambridge Systematics, Inc.

## 7. State Implementation Plan

The Clean Air Act requires each State to develop a State Implementation Plan (SIP), a general plan for attaining and maintaining the National Ambient Air Quality Standards (NAAQS). An SIP demonstrates that States have the basic air quality management program components in place to meet the NAAQS. In general, C/AV will impact SIPs by increasing the efficiency of the transportation system—potentially making each trip more environmentally friendly by reducing the congestion/delay-related emissions. This could be offset in part by providing additional travel opportunities to those who cannot currently drive a vehicle. As C/AV technology develops, mobile emissions monitoring data may become available for use in the SIP and planning for NAAQS compliance.

The case study discusses the impacts of C/AV in terms of the three key elements of a SIP listed below, along with a short description. Recommendations for how States can adapt each element to embrace these impacts and opportunities are presented along with the given impact. This document focuses on only the most significant or unique impacts of C/AV, and additional impacts and recommendations can be found in the associated report *Connected Vehicle Impacts on Transportation Planning, Technical Memorandum #5: Case Studies*.

**1. Enforceable Emissions Limitations:** Identify provisions (emissions limits and other control measures) that limit pollutant emissions relevant to the subject NAAQS:

- C/AV, and the real-time information it will provide, will enable users to utilize the transportation system in a more environmentally efficient way.
  - For example, in the long term States may be able to optimize large portions of the transportation system by using real-time data from vehicles to implement dynamic signal timing among other strategies.

**2. Ambient Monitoring Program:** Establish and describe the system and methods to monitor data on ambient air quality:

- Mobile emissions data will become more available as C/AV technology is developed.
  - States should track the impact of C/AV on air quality by establishing method to collect and analyze data.
  - States should begin considering the policies and data infrastructure needed to capture and store the increased volume of data.

**3. Personnel, Resources, and Legal Authority:** Identify the organizations that will carry out the provisions to implement the NAAQS, along with the personnel and funding sources:

- States should identify the private and public organizations that can pilot C/AV deployment for the purposes of reducing emissions.
- States should emphasize coordinating C/AV investments with local investment projects, as C/AV will be more effective if networked and coordinated with other applications.
  - Furthermore, State and local agencies should pool and share resources, such as personnel and funds, when considering C/AV investments.

**Example C/AV**

**Project in the SIP:** To illustrate the type of C/AV technologies and projects that States may incorporate into the SIP, the case study discusses the benefits and costs of the Eco-Arrival and Departure at Signalized Intersections (EADSI) application, which is an application under the U.S. DOT’s Application for the Environment: Real-Time Information Synthesis (AERIS)



**Figure 13. Illustration. The Eco-arrival and departure at signalized intersections application.**

(Source: U.S. Department of Transportation.)

program. EADSI uses vehicle-to-infrastructure (V2I) communications, signal phase and timing (SPaT) information, and geographic information to determine the most efficient and eco-friendly speed at which a vehicle can either pass through the next signal on green or decelerate to a stop.

Table 9 presents a high-level estimate of the capital costs to deploy C/AV infrastructure, equipment, and EADSI applications. Dedicated short-range communications (DSRC) roadside units (RSU) will be installed at each of the 10 intersections and aftermarket on-board units (OBU) will be installed on each of the 20 agency vehicles. Each intersection will require a signal controller and backhaul upgrade. The total budget of this project from \$663,000 to \$844,000. (There are other costs not captured here, such as annual operations and maintenance costs.)

**Table 9. High-level cost estimate of the capital costs to deploy connected/automated vehicle infrastructure, equipment, and the Eco-arrival and departure at signalized intersections application.**

Item	Quantity	Per Unit Cost	Total Costs
Dedicated short-range communications roadside units	10 intersections	\$13,100 to \$21,200	\$131,000 to \$212,000
Signal controller upgrade	10 intersections	\$3,200	\$32,000
Backhaul communications	1 system (10 intersections)	\$30,000 to \$40,000	\$300,000 to \$400,000
Light vehicle aftermarket on-board unit with graphic interface	20 vehicles	\$10,000	\$200,000
Connected/Automated Vehicles Project Total			\$663,000 to \$844,000

Source: Cambridge Systematics, Inc.

## 8. Transit Development Plan

Transit Development Plans (TDP) analyze the existing transit system and the investments needed to meet future needs. There are no Federal requirements for TDPs, but some states require TDPs and many local/regional transit agencies develop TDPs for their own needs. In general, C/AV will impact TDPs by enhancing transit data and other relevant transportation system data. Transit agencies will have the opportunity to apply this data to support service reliability and safety goals.

The case study discusses the impacts of C/AV in terms of **the eight key elements of a TDP** listed below along with a short description. The eight key elements are based on the Virginia Department of Rail and Public Transportation's (DRPT) requirements for TDPs developed by all transit agencies in Virginia. Recommendations for how States can adapt each element to embrace these impacts and opportunities are presented along with the given impact. This document focuses on only the most significant or unique impacts of C/AV, and additional impacts and recommendations can be found in the associated report *Connected Vehicle Impacts on Transportation Planning, Technical Memorandum #5: Case Studies*.

**1. Overview of Transit System:** Provide a brief overview of the transit system, ITS program, and public outreach:

- Transit agencies will need to evaluate how C/AV will impact their system, ITS program, and outreach program.
  - Agencies should assess which corridors are suitable for C/AV and which vehicles and facilities would need to be upgraded.
- Agencies should identify and/or train staff who are knowledgeable about C/AV technology/ongoing research initiatives and understand the challenges of C/AV so that they can respond to any concerns that the public and internal stakeholders may have.

**2. Goals, Objectives, and Standards:** Establish and describe goals, objectives, and performance standards:

- Agencies will need to identify how C/AV can support objectives, goals, and performance measures.
  - In the short term, C/AV applications can support service reliability and safety goals.
  - In the medium to long term, C/AV applications can help achieve more ambitious goals and objectives.
- Potential C/AV applications for transit include transit signal priority (TSP) and alerts to bus drivers of pedestrians in signalized crosswalks (PSCWT).
- C/AV will expand data availability for transit agencies, for example C/AV-enabled transit vehicles could be used as probes that permit an expanded set of performance measures and improve tracking of set targets.

**3. Service and System Evaluation:** Evaluate route-level and systemwide performance against current performance standards for each mode and/or type of service:

- C/AV will introduce new cost effective data sources and collection methods, supplementing and replacing current practices in the long term.
  - Bus speeds and travel times are two sets of data that agencies could collect using C/AV technology in the short term.

#### 4. Service Expansion Project

**Descriptions:** Summarize each proposed service expansion project, including estimates of ridership, cost, and funding:

- Agencies should evaluate the potential impact of C/AV on ridership forecasts.
  - **Short term:** C/AV can improve operations and ridership by improving reliability and traveler information.
  - **Medium to long term:** Ridership could either decline or increase depending on the interaction with C/AV technology in motor vehicles (including Transportation Network Companies (TNC)).
- Region-specific prototype installations are recommended for assessing the opportunities and challenges of C/AV adoption, as well for helping agencies cultivate their internal professional capacity for providing C/AV-enhanced services.



**Figure 14. Photo. A Chicago Transit Authority bus.**  
(Source: Cambridge Systematics, Inc.)

**5. Operations Plan:** Describe the fixed route and demand response services the operator intends to provide over the plan period:

- Some C/AV applications will provide audible alerts to operators, such as notifying operators of potential collisions or pedestrians in crosswalks.
  - Regulatory requirements should be reviewed to address concerns about driver distraction.
- Many agencies have a limited number of spare buses that can be utilized for C/AV testing and revenue service vehicles may be utilized instead.
  - This will need careful planning so existing operations are not disrupted.
- As C/AV develops, the public will become increasingly connected to the transit system through smart phones and ITS.
  - This will provide agencies the opportunity to implement C/AV applications such as intermittent bus lanes.

**6. Capital Improvement Program:** Describe the capital programs required to carry out the operations and services set out in the operating plan:

- Agencies should track C/AV advances and market penetration rates in order to account for C/AV advances in scheduled upgrades/replacements of existing infrastructure.
  - For example, traffic signals upgrades/replacements should ensure that they can interface with C/AV enabled roadside-units.
- Agencies should identify existing infrastructure and vehicles that require upgrading/integration to support C/AV applications.
  - For example, vehicles may need aftermarket units to communicate with dedicated short-range communications (DSRC) roadside units (RSU).

**7. Financial Plan:** Develop a financial plan consisting of the capital and operating budget forecast; Federal, State, and local revenue projects; fare policies; and other financial information:

- C/AV considerations for the financial plan element of the TAMP are included in the Financial Plan case study for this project. See the separate Financial Plan case study memo for further information.

**8. Monitoring and Evaluation:** Describe the process to monitor and evaluate progress towards implementation of plan:

- The effectiveness of C/AV deployments in improving transit service, along with costs and best practices, should be documented and continually assessed.
- Experiences should be shared with State DOTs, MPOs, and other transit agencies.
- New sources of data from C/AV should improve the ability to track the performance of C/AV and other investments.
  - To fully realize these benefits, resources should be dedicated to storing and analyzing the data, especially in the early stages.

**Example C/AV Project in the TDP:** To illustrate the type of C/AV technologies and projects that transit agencies may incorporate into their TDP, the case study discusses the benefits and costs of C/AV-enhanced Transit Signal Priority (TSP) systems. Many transit agencies use transit signal priority (TSP) to improve the on-time performance and reliability of their services. C/AV technology can provide a more integrated means to request and grant TSP. The traffic signal system will have more accurate data and enhanced awareness of existing conditions (e.g., traffic volume on



**Figure 15. Photo. Transit signal.**

(Source: Raysonho @ Open Grid Scheduler/Grid Engine—Own work, [CC0](#).)

surrounding roadways), allowing TSP systems to minimize negative impacts on general traffic. Dedicated short-range communication (DSRC) technology will 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, DSRC technology will enable traffic operations personnel to better handle multiple TSP requests. To enhance safety, emergency vehicle preemption should be integrated on the same communication platform. In the short term, C/AV TSP will provide similar functionality to current TSP systems. Over the medium to long term, as market penetration of C/AV-enabled passenger vehicles increases and as emergency vehicles adopt C/AV technology, the benefits of a connected vehicle environment can be fully realized.

Table 10 presents a high-level cost estimate of the capital costs to deploy C/AV infrastructure, equipment, and the C/AV-enhanced TSP application. DSRC roadside units (RSU) will be installed at each of the 10 intersections, while aftermarket on-board units (OBU) will be installed on each of five transit vehicles. Each intersection will require a signal controller and backhaul upgrade. The total budget of this project ranges from \$513,000 to \$695,000. (There are other costs not captured here, such as annual operations and maintenance costs.)

**Table 10. High-level cost estimate of the capital costs to deploy connected/automated vehicle infrastructure, equipment, and the transit signal priority application.**

Item	Quantity	Per Unit Cost	Total Costs
Dedicated short-range communications roadside units	10 intersections	\$13,100 to \$21,200	\$131,000 to \$212,000
Signal controller upgrade	10 intersections	\$3,200	\$32,000
Backhaul communications	1 system (10 intersections)	\$30,000 to \$40,000	\$300,000 to \$400,000
Transit vehicle aftermarket on-board unit	5 vehicles	\$10,000	\$50,000
Connected/Automated Vehicles Project Total			\$513,000 to \$695,000

Source: Cambridge Systematics, Inc.

## 9. Public Involvement Plan

States and Metropolitan Planning Organizations (MPO) are required to develop a Public Involvement Plan (PIP). PIPs define outreach processes that assure full opportunity for public review and comment during the transportation planning process. There are Federal guidelines on developing a PIP, however agencies have significant flexibility to tailor their PIPs. It is likely that, in many cases, the implementation of PIPs will serve the important role of introducing C/AV technology to the general public. Through implementation of the PIP, agencies will have the opportunity to motivate public interest in and regional coordination on C/AV planning through presentations, discussion, and small-scale demonstrations of C/AV technology and applications.

The case study discusses the impacts of C/AV in terms of the five key elements of a PIP listed below along with a short description. Recommendations for how States can adapt each element to embrace C/AV-related opportunities are presented along with the given impact. This document focuses on only the most significant or unique impacts of C/AV. Additionally impacts and recommendations can be found in the associated report *Connected Vehicle Impacts on Transportation Planning, Technical Memorandum #5: Case Studies*.



**Figure 16. Photo. Participation at a public meeting.**  
(Source: iStockphoto.)

**1. Set Goals and Objectives:** Set goals and objectives derived from the specific circumstances of a given transportation plan, program, or project:

- C/AV deployment will likely have broader impacts on public participation than ITS.
- C/AV may change roadway layouts and operation and certainly presents the possibility of social, economic, and environmental impacts.
  - These factors will likely trigger more intensive public involvement.
- C/AV is already generating public questions and concerns related to data privacy, security, and the implications of a mixed fleet.
  - Agencies should consider how to reach different audiences and draft C/AV outreach material that gives a clear presentation of the technology.

**2. Identify the Public Audience:** Identify and analyze the individuals and groups who are directly and indirectly affected:

- C/AV pilots are not likely to have major public impacts, but can help form an interested community of “early adopters” to support expanding efforts.

- New audiences will likely include industries experiencing near-term economic impacts (e.g., large warehouse operators).
- Organized groups involved in transportation (construction, trucking, and modal advocacy groups) that may already participate in transportation planning could be leveraged to involve a wider audience.
- U.S. DOT places great importance on involving groups that traditionally experience barriers in participating (such as low-income groups, minority, persons with disabilities, and nonnative English speakers). Upcoming C/AV technology presents both opportunities (e.g., mobility for those who cannot drive) and challenges (e.g., inability to purchase C/AV technology) to these groups.
  - Agencies should be aware of these opportunities and challenges and proactively work to involve and plan for these groups.

**3. Develop General Strategies:** Develop strategies to meet established goals and objectives and to involve the targeted audience(s).

- Agencies will need to develop public involvement strategies related to C/AV, some suggestions include:
  - Pursuing C/AV pilots could provide an effective opportunity to educate the public on C/AV technology.
  - U.S. DOT Professional Capacity Building programs provide planners with information that can inform outreach strategies.

**4. Select Specific Techniques:** Based on past experience and existing manuals, analyze and select specific techniques to carry out develop strategies:

- Effective C/AV PIP techniques may include:
  - High-level presentations on C/AV for business or economic development groups may help generate interest, especially at meetings addressing capital projects.
  - Portable exhibits at unconventional sites (local fairs, markets, festivals, etc.).
  - Developing closer ties with educational institutions at all levels to educate the next generation and provides a way to reach parents as well.



**Figure 17. Photo. A demonstration of connected vehicle technology by DENSO at 2014 Intelligent Transportation Systems World Congress.**

(Source: Cambridge Systematics, Inc.)

**5. Monitor and Evaluate:** Assess the impact of the selected strategies and techniques on public involvement, and update as needed:

- It will be important to document the effectiveness of C/AV-related PIP strategies.
- Local experiences should be shared with other States and MPOs.

## 10. Freight Plan

The United States Department of Transportation (U.S. DOT) is required to establish a national freight plan and national freight performance measures (PMs). States are encouraged to develop statewide freight plans, and projects identified in these plans are eligible for specific new freight funding. States are also required to set performance targets in relation to the national freight PMs, which can be incorporated into the statewide freight plan and/or the State long-range transportation plan (LRTP). C/AV offers significant potential benefits to the freight industry, including increased efficiency, reduced emissions, improved safety, and economic benefits. Given this, the freight industry is expected to be an early adopter of C/AV, making it particularly important to begin incorporating C/AV into freight plans.

The case study discusses the impacts of C/AV on in terms of the six key elements of a freight plan, listed below along with a short description. Recommendations for how States can adapt each element of the freight plan to embrace these impacts and opportunities are presented along with the given impact. This document focuses only on the most significant or unique impacts of C/AV on freight plans, and additional impacts and recommendations can be found in the associated report *Connected Vehicle Impacts on Transportation Planning, Technical Memorandum #5: Case Studies*.

**1. Baseline Freight System:** Create an inventory of freight transportation assets. Identify significant freight system trends, needs, and issues:

- The C/AV technologies currently being implemented will need to be cataloged.
  - States should collaborate with private freight companies to collect this information.
  - Ensuring the confidentiality of this information will be key to making such collaboration work.
- Existing infrastructure needing to be upgraded/integrated to support C/AV will need to be identified:
  - States have the opportunity to strategically plan for these upgrades in connection with capital improvement and maintenance projects.
- Estimates of the regional C/AV market penetration in the overall fleet over the will be useful to the freight planning process.

**2. Policies, Strategies, and Institutions:** Discuss freight-related funding programs, regional planning activities, and infrastructure owners that will guide the freight improvement strategy:

- Vehicle-related C/AV deployments will be primarily funded by the private sector.
  - Public investments should leverage these private investments to the extent possible.

- Secure V2V and V2I interfaces will be critical to getting private freight companies to accept and cooperate with public sector policies and strategies.
- Freight plans should take note of lessons learned in C/AV test beds and pilots. As likely early adopters of C/AV, freight-oriented businesses should be included as important stakeholders in the design and development of test beds (e.g., the U.S. DOT Connected Vehicle pilot in Wyoming).

**3. Goals and Performance Measures:** Develop strategic goals and measures of condition and performance. Assess the condition and performance of the freight transportation system:

- As fleets deploy C/AV technology, they will track changes in performance.
- Private companies will want to protect this information for competitive reasons, but may be willing to provide aggregate or “scrubbed” data to help agencies identify future investments that help the industry.
- Partnerships with the freight industry will be key to obtaining the information agencies need to set realistic freight planning objectives and performance measures.
- C/AV technology in the long run may enable agencies to adopt more ambitious objectives and performance measure targets.
  - For example, NHTSA estimates that V2I and V2V systems can potentially address up to 79 percent of heavy vehicle crashes.
- Table 11 below shows goals of the Vermont State Freight Plan. Potential C/AV impacts on freight goals and performance measures have been added.

**Table 11. Proposed Vermont Freight Plan Performance Measures that will potentially be impacted by connected/automated vehicles and the goals associated with each performance measure (prepared for the Vermont Agency of Transportation by Cambridge Systematics, Inc.).**

Level	Goal	Highway Freight Measures Potentially Impacted by C/AV
Economy	Support the movement of goods into, out of, and within Vermont	Truck tons, ton-miles, value: Statewide; Major truck-intensive economic sectors
Economy	Ensure the effective and efficient delivery of projects, maintenance, incident management, and snow removal	Stakeholder outreach and communications
Logistics/Operations	Promote efficient operation of the transportation system	Travel time and reliability; Major market lanes; Border crossing delays
Logistics/Operations	Maximize safety on the transportation system	Fatalities and crashes; Statewide system

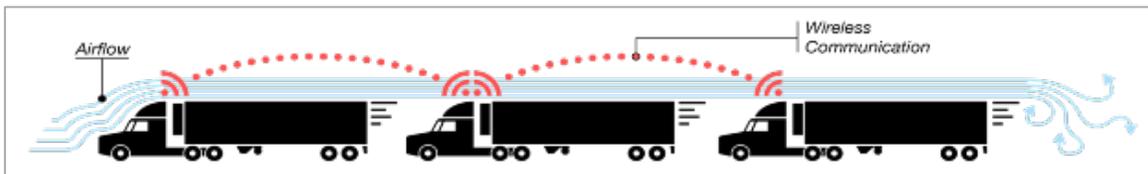
**Table 11. Proposed Vermont Freight Plan Performance Measures that will potentially be impacted by connected/automated vehicles and the goals associated with each performance measure (prepared for the Vermont Agency of Transportation by Cambridge Systematics, Inc.) (continuation).**

Level	Goal	Highway Freight Measures Potentially Impacted by C/AV
Logistics/Operations	Promote environmental stewardship	Greenhouse gas emissions; Hazmat spills
Infrastructure	Maintain existing infrastructure, preserve pavements and structures	Pavement condition: Pavement composite condition measure; Structural cracking index; Percent miles rated International Roughness Index “Good” Bridge condition; Number rated structural deficient Emergency Vehicle Signal Priority

Source: Cambridge Systematics, Inc.

**4. Alternative Improvements:** Develop alternative improvements such as investments and policies. Consider innovative technologies and operational strategies to improve mobility and maintain roads at risk of deterioration:

- C/AV (especially truck platooning enabled by C/AV) has the potential to increase the efficiency and safety of truck travel; this is already an emerging technology.
- Planners should track C/AV research so agencies can quickly address issues such as: will platoons need to be limited to inside lanes to allow other vehicles to safely exit?
- States should reevaluate investments in future port- and terminal-related infrastructure; increased truck throughput may reduce the needed amount of lane miles.



**Figure 18. Diagram. Freight truck platooning enhanced by connected vehicle technology.**  
(Source: Cambridge Systematics, Inc.)

**5. Improvements Strategy:** Analyze and prioritize improvements, including analysis of how each improvement will advance the strategic goals:

- Private companies will likely have data that can inform C/AV-related improvements strategies, but may be reluctant to share due to competition concerns.

- States should work with the private sector to address these concerns in order to access as much information as possible.
- C/AV is an emerging technology and it may be difficult to rank C/AV projects using traditional metrics such as benefit-cost ratio, which are still stabilizing and depend on factors such as market penetration, industry competition, and regional coordination.
- Impacts of C/AV technology on major medium- to long-term investments will increase as market penetration of C/AV technology and users matures.

**6. Implementation Plan:** Develop short-term and medium- to long-term strategies and a timeline for proposed freight improvements, taking into account funding considerations:

- C/AV implementation will consist of field infrastructure and freight truck on-board units (OBU).
- States should coordinate with freight companies to schedule infrastructure deployment with freight truck upgrades/purchases, ensure compatibility of devices, and put data collection/sharing agreements in place.
- Ongoing monitoring of deployments is important to provide thorough documentation of the effectiveness of C/AV in meeting freight objectives, along with costs and deployment best practices.



**Figure 19. Photo. Freight terminal.**  
(Source: Cambridge Systematics, Inc.)

**Example C/AV Project in the Freight Plan:**

To illustrate the type of C/AV strategies that States may incorporate into the freight plan, the case study discusses the U.S. DOT's Freight Advanced Traveler Information System (FRATIS) project, which is part of the Connected Vehicle program, under the category of Dynamic Mobility Applications (DMA). The goal of FRATIS is to improve freight transportation system efficiency through improved data sharing between freight supply chain partners and through improving the quality and dissemination of freight-oriented traveler information. There are two specific FRATIS DMA applications under one bundle that help illustrate C/AV applications in freight planning. The first part, Freight Specific Dynamic Travel Planning and Performance, consists of a series of applications that integrate freight traveler information, dynamic route guidance, and public sector performance monitoring through ITS systems, purchased travel time data or other technologies. The second part, Drayage Optimization, involves integrated load matching and freight information exchange including appointment scheduling and equipment availability at intermodal terminals. Additionally, in FRATIS Phase II deployment, select corridors in Los Angeles will become equipped with dedicated short-range communications (DSRC) roadside units (an example of vehicle-to-infrastructure (V2I) communication). These devices will provide faster, more targeted traveler information to truckers to route them more efficiently (reducing congestion) and will provide better planning information to terminal and warehouse operators

Table 12 presents a high-level preliminary estimate of costs to deploy and pilot C/AV infrastructure, equipment, and the FRATIS Phase II applications in this Los Angeles project. DSRC roadside units will be installed at each of the 20 intersections and freight vehicles will be equipped with on-board units and navigation devices. Each intersection will require a signal controller and backhaul upgrade. There will also be Wi-Fi/Bluetooth readers at port terminals for queue detection, service fees and agreements, and annual operations and maintenance costs. The total budget for this project ranges from \$1.6 million to \$2.0 million. (There are other costs not captured here, such as software development costs.)

**Table 12. High-level cost estimate of costs to deploy and pilot connected/automated vehicle infrastructure, equipment, and the Freight Advanced Traveler Information System Phase II applications in the Los Angeles project.**

Item	Quantity	Per Unit Cost	Total Costs
Dedicated short-range communication roadside units	20 intersections	\$13,100 to \$21,200	\$262,000 to \$424,000
Signal controller upgrade	20 intersections	\$3,200	\$64,000
Backhaul communications	1 system (20 intersections)	\$30,000 to \$40,000	\$600,000 to \$800,000
Freight vehicle on-board units	50 freight vehicles	\$10,000	\$500,000
Navigation device	50	\$400	\$20,000
Hardware for queue detection	8	\$16,000	\$128,000
Service fee and agreements	1	\$7,000	\$7,000
Annual Operations and Maintenance	1 year	\$30,000	\$30,000
Connected/Automated Vehicles Project Total	–	–	\$1,611,000 to \$2,011,000

Source: Cambridge Systematics, Inc.

## 11. Financial Plan

Financial plans provide information and investment analyses to guide project selection. Generally, agencies develop financial plans as part of other planning documents, rather than as a separate document. For example, financial plans are required to be included in Metropolitan Planning Organizations' (MPO) long-range Metropolitan Transportation Plans (MTP) and Transportation Improvement Programs (TIP). Financial plans are not required but may be incorporated into some statewide long-range plans and other planning documents. Separate financial plans are sometimes developed for specific purposes such as tolling proposals or public-private partnership projects. The case study focuses on financial plans as they relate to the MTPs of MPOs, however the discussion is also relevant to other planning products that include a financial plan. Generally speaking, C/AV will impact financial plans by introducing a new set of C/AV-related infrastructure funding requirements,

along with new opportunities to leverage various sources of funding. Agencies will need to track cost estimates for C/AV deployment and will likely need to develop new criteria and tools for assessing C/AV costs and benefits.

The case study discusses the impacts of C/AV in terms of the three key elements of a financial plan listed below, along with a short description. Recommendations for how MPOs can adapt each element to embrace C/AV-related opportunities are presented along with the given impact. This document focuses on only the most significant or unique impacts of C/AV, and additional impacts and recommendations can be found in the associated report *Connected Vehicle Impacts on Transportation Planning, Technical Memorandum #5: Case Studies*.

**1. Funding Streams:** Indicate and describe funding streams from public and private sources at the Federal, State, and local levels:

- MPOs may be able to access new or additional sources of funding for C/AV deployment. Some potential funding sources and C/AV uses include:
  - Vehicle-to-infrastructure (V2I) communication technology and operations and maintenance (O&M) costs may be eligible for various Federal-aid funding programs, much like Intelligent Transportation Systems (ITS) field infrastructure.
  - Specific V2I safety applications may be eligible for Highway Safety Improvement Program (HSIP) resources.
  - V2I mobility applications may be eligible for National Highway Performance Program and Surface Transportation Program funds.
  - V2I environmental applications may be eligible for Congestion Mitigation and Air Quality funds.

**2. Funding Projections:** Estimate project funding to be available from each funding stream over the life of the transportation plan:

- In the long term, widespread adoption of C/AV could reduce the need for some current investments such as capital expansion, safety, and ITS.
  - This may create an opportunity for MPOs to shift some funds to C/AV-related deployments.
- C/AV, combined with the sharing economy, may reduce revenues from funding mechanisms such as vehicle registration fees, sales tax, traffic violations and towing fees.
  - This will add to a larger trend of decreased revenue from traditional transportation funding sources, such as the gas tax. New and innovative sources of revenue will be needed and any funding opportunities resulting from C/AV technology should be identified.

**3. Financing Strategies:** If needed, include additional financing strategies such as pricing mechanisms (specific taxes or pricing strategies) to finance specific projects or to incentivize certain behaviors:

- The private sector will likely provide the in-vehicle components of C/AV, however, public regulation of the devices is likely (NHTSA announced its intention to require DSRC devices in new light vehicles in ~2019-2020) and is currently developing a regulatory framework for automation.

- It is not known how much inspection of these vehicles will be required, but additional funding mechanisms, such as user fees may be needed to support inspections and security.
  - Cost-sharing opportunities with the private sector could help fund needed public C/AV investments, for example, vehicle owners (fleets or individuals) may pay fees for security.
- Financing plans should be reviewed at more frequent intervals as C/AV market penetration trends become clearer and new financial strategies emerge (C/AV costs are expected to come down and stabilize).

# Analytical Tools and Techniques

The project's research on analytical tools and techniques identified enhancements to existing transportation planning tools that will be needed in order to adapt those tools to the future impacts of connected/automated vehicles (C/AV). This research also considered the need to develop entirely new tools and datasets when existing ones could not feasibly be enhanced to enable C/AV analyses. The full results of this analysis are detailed in the project's associated report: *Technical Memorandum #3: Analysis of the Need for New and Enhanced Analysis Tools, Techniques, and Data*. The project's work in this area followed a logical progression through four major elements:

- 1. Summary of existing tools, data, and products.** This element identified and summarized the tools, data, and products currently used in transportation planning processes in a variety of contexts—including statewide and regional short- and long-range transportation plans in large/small States and urban areas.
- 2. Evaluation and comparison of existing tools.** This element included evaluation and comparison of existing transportation analysis tools with respect to their input/output interfaces, usability, modeling features, and calibration requirements. It also began to explore how these tools might be used to analyze connected vehicle strategies.
- 3. Gap analysis for existing tools and data.** This element considered the current limitations of existing tools and data regarding the representation and analysis of connected vehicle technologies and applications. Data and analysis tools used in traditional long-term transportation planning could potentially be modified or overhauled to accommodate analyses of connected vehicle applications and technology.
- 4. Roadmap for addressing the gaps.** This element defined 19 research topics that target the needs revealed by the gap analysis, identified which agency would be best suited for addressing these needs, established priority levels for each research topic, and discussed the expected availability of potential data sources to inform the research topics.

## Summary of Existing Tools, Data, and Products

This section provides an overview of existing analytical tools, techniques, and products used in transportation planning processes. These tools cover a variety of contexts—including statewide and regional short- and long-range transportation plans in large/small States and urban areas. This section also summarizes existing research related to connected vehicle field tests, pilots, case studies, and other analyses in order to illustrate the expected impacts of connected vehicles relevant to analytical tools. The tools reviewed in this section include the following four categories of tools:

## Sketch Planning Tools

These are used to evaluate common transportation improvement projects without necessitating a detailed analysis, making them useful for preliminary budgets and proposals. They rely on aggregated data and outcomes from past projects to produce estimates based on essential input variables:

- **Precision:** Order of magnitude.
- **Advantages:** Are simple to perform and require relatively low investment of money, time, and resources. More approachable than other tools in terms of cost, level of effort, and ease of use.
- **Limitations:** Results are imprecise approximations and lack analytical robustness.

## Travel Demand Models

By projecting future travel demands based on current conditions, demographic forecasts, and employment trends, these models can be used to predict benefits and impacts of major transportation improvement projects:

- **Precision:** High for capital improvement projects, but limited for Transportation Systems Management and Operations (TSM&O) (transportation system management and operations strategies, such as intelligent transportation systems).
- **Advantages:** Have the capacity to consider various modes, routes, destinations, and departure times.
- **Limitations:** As travel demand models do not consider vehicle dynamics, they are poorly suited for evaluating the impacts of operational strategies and cannot readily provide detailed operational outputs (e.g., detailed speed or delay data). They do not explicitly consider queue spillback effects, traffic weaving impacts, or other effects that require modeling of individual vehicles.

## Highway Capacity Manual Methods

The methods in the Highway Capacity Manual (HCM) are widely accepted and understood and are based on analytical deterministic models using operational and performance data for existing facilities. Procedures for analyzing different facility types are available, though unlisted facility types cannot be analyzed. Outputs are deterministic, aggregated, and generally focus on performance measures, such as level of service:

- **Precision:** Outputs are generally provided for facilities (not vehicles), in 15-minute or 1-hour time increments. Performance metrics such as expected delays or volume-to-capacity ratio are typical outputs.
- **Advantages:** Requires relatively few inputs and little initial configuration effort. More approachable than other tools in terms of cost, level of effort, and ease of use.
- **Limitations:** HCM methods generally require stationary traffic conditions and are best suited for isolated facility analyses rather than system wide analysis. They are poorly suited for analyzing queue spillback effects.

Tools and procedures in the Highway Capacity Manual can be classified as either performance assessment/evaluation tools (analytical and deterministic tools) or performance optimization tools (traffic signal optimization tools).

### ***Highway Capacity Manual Methods—Analytical/Deterministic Tools***

These are typically used to estimate performance of a single location or facility, over a set of predefined analysis periods. Analytical, closed-form, deterministic procedures are used to estimate various performance outcomes based on input facility and operational characteristics. These procedures are informed by empirical data, test bed research, and small-scale field experiments. Outputs may include predictions of capacity, density, speed, delay, and queues:

- **Precision:** Macroscopic averages of expected facility performance across a 15-minute or 1-hour analysis interval.
- **Advantages:** Available procedures enable analysis of a variety of facility types and characteristics. Results may be obtained relatively quickly with few inputs.
- **Limitations:** Poorly suited for assessing network effects or system-wide performance.

### ***Highway Capacity Manual Methods—Traffic Signal Optimization Tools***

As the name implies, this class of tools is generally used to develop optimized signal timing plans for intersections and corridors. This is done using deterministic numeric methods and procedures taken from the Highway Capacity Manual:

- **Precision:** Results can be applied directly in the field.
- **Advantages:** Simpler and faster than simulation. Provides optimized cycle lengths, splits, and offsets for coordination.
- **Limitations:** Can only be used to optimize simpler signalization situations. Better suited for smaller networks due to the use of manual procedures.

## **Traffic Simulation Methods**

These can be used to evaluate a wide range of operational strategies or roadway modifications across an entire network. Outputs are based on stochastic behaviors of drivers in the simulation and can be aggregated or disaggregated by link, driver, node, etc. The network is first constructed within the simulation environment, including facility and infrastructure configuration parameters such as node properties, link properties, and signal timing plans. It is loaded with appropriate levels of traffic and often calibrated to replicate real-world conditions as closely as possible within the needs and constraints of the analysis. Once prepared, the simulation model can be reconfigured or otherwise modified to gauge the operational and performance impacts of various strategies, adjustments, or improvements:

- **Precision:** Fine time-step resolution, with the possibility for simulation of individual vehicles and driver behaviors.
- **Advantages:** Can capture nonstationary traffic States including congestion growth or dissipation. Individual vehicles can be simulated with different driver parameters,

commonly drawn from a specified statistical distribution. Impacts of queue spillback can be modeled.

- **Limitations:** Cannot be used to model many realistic driver behaviors or situations, such as inattention or collisions. Requires a significant level of input data. Preparation of the model, including calibration, can be time consuming. Simulations can be computationally expensive to execute.

Traffic simulation models fall into three subcategories—microscopic, mesoscopic, and macroscopic simulation models. Generally, microscopic simulation models are better-suited for detailed analyses in which individual vehicle interactions are significant, while macroscopic simulation is more appropriate for larger networks that would be too time-consuming to simulate with the fine precision of a microscopic analysis. Mesoscopic models combine many of the characteristics of both microscopic and macroscopic models in order to achieve a balance between feasible network scale and degree of realism/precision in the simulation. Microscopic and mesoscopic simulation models are the most relevant to the discussion of analytical tools for incorporating C/AV into transportation planning.

### ***Microscopic Simulation Models***

Using car-following and lane-changing models to simulate driver behaviors and vehicle trajectories in time steps measured on the order of one second, these high-resolution simulations provide operational insight and detailed performance measures for a variety of strategies that affect demand, capacity, or facility operations:

- **Precision:** Provides detailed outputs at the segment, vehicle, intersection, or aggregate level. Can be configured to simulate traffic several times to capture certain stochastic effects.
- **Advantages:** Enables the analysis of a wide range of transportation improvement projects and operational strategies. Allows input parameters to be specified on a fine scale; for example, individual links can be assigned their own lane widths, grade, visibility distance, or other attributes.
- **Limitations:** Larger networks can become very computationally demanding. Model setup and calibration can be time-consuming as well.

### ***Mesoscopic Simulation Models***

As a balance between microscopic and macroscopic simulation models, these enable the simulation of large networks while maintaining a higher degree of realism than is available in macroscopic models. With mesoscopic models, individual vehicles are simulated on the network, which can have detailed parameters defined for individual elements (though to a lesser extent than is possible with microscopic models). Movements and behaviors are governed by macroscopic relationships rather than lane-changing and car-following models:

- **Precision:** Models individual vehicles, but in a less-precise manner than microscopic models.
- **Advantages:** Can simulate larger networks while being less computationally demanding than microscopic models yet still providing vehicle-level precision.

- **Limitations:** Not well equipped to handle the simulation of intersection operations, weaving zones, operational strategies, and facilities that require a high level of vehicle-to-vehicle interaction.

## Expected Impacts of Connected Vehicles

Several studies have been performed to date on the realized or potential impacts of connected vehicles across several benefit categories. This section summarizes the project's literature review of such studies (more information is included in *Technical Memo #3*). The discussion is organized by benefit category, rather than by study or project, including capacity impacts; emissions and fuel consumption benefits; and crash reduction potential.

### Potential Capacity Impacts of Connected Vehicles

Research generally estimates that connected vehicles could at least double capacity on freeways. In an article published by *American Scientist*, Steven Shladover of the University of California, Berkeley, points out that computer-controlled vehicles could double or triple the maximum allowable traffic density on freeways at their peak performance. Similarly, in a joint investigation of Cooperative Adaptive Cruise Control (CACC) by Nissan Motor Co. and the California Partners for Advanced Transportation Technology (PATH) at U.C. Berkeley, simulation models and field testing indicated that CACC could increase lane capacities to 3970 vehicles per hour (vph), nearly double the capacity achieved using only adaptive cruise control alone. (S. Shladover, C. Nowakowski, H. Kawazoe, and H. Tsuda. Cooperative Adaptive Cruise Control to Stabilize Car Following (Second Generation). Presentation by California PATH Program, University of California, Berkeley.)

Connected vehicle (CV)-enabled vehicle platooning has also been linked to potential capacity gains. A 1997 study on I-15 in San Diego found that vehicle platooning using vehicle to vehicle (V2V) technology could increase lane carrying capacity from 2000 vph to 4300 vph when the maneuvering of entering and exiting vehicle were taken into account—and up to 5700 vph under more ideal scenarios. Likewise, the CHAUFFEUR automation system in Europe, designed to provide electronic platooning of heavy freight vehicles, has been estimated to yield a potential capacity increase of 8 percent.

### ***Potential Emissions and Fuel Consumption Benefits of Connected Vehicles***

Several studies have tested the ability of C/AV-enabled vehicle platoons to reduce fuel consumption, including studies by the SARTRE Project (Safe Road Trains for the Environment), the Japan Automobile Research Institute (JARI), and California PATH. Generally, these studies have found higher fuel savings in platoons with tighter vehicle spacing (fuel savings ranging from 8 to 16 percent for vehicle spacing between 4.7 and 10 meters) and for vehicles towards the back of the platoon (fuel savings ranging from 4.5 to 18.4 percent). Still, looser vehicle spacing (15 to 25 meters) and vehicles leading the platoon showed fuel savings ranging from 1.5 to 8 percent.

Other studies have estimated even higher potential fuel savings. Testing in a wind tunnel facility at the University of Southern California found that C/AV-enabled reductions in vehicle spacing—and, therefore, reductions in drag force—could result in savings of 20 percent to 25 percent in fuel economy and vehicle emissions. (Intellimotion.) The CHAUFFEUR program in Europe has estimated that C/AV could increase vehicle fuel economy by as much as 20 percent.

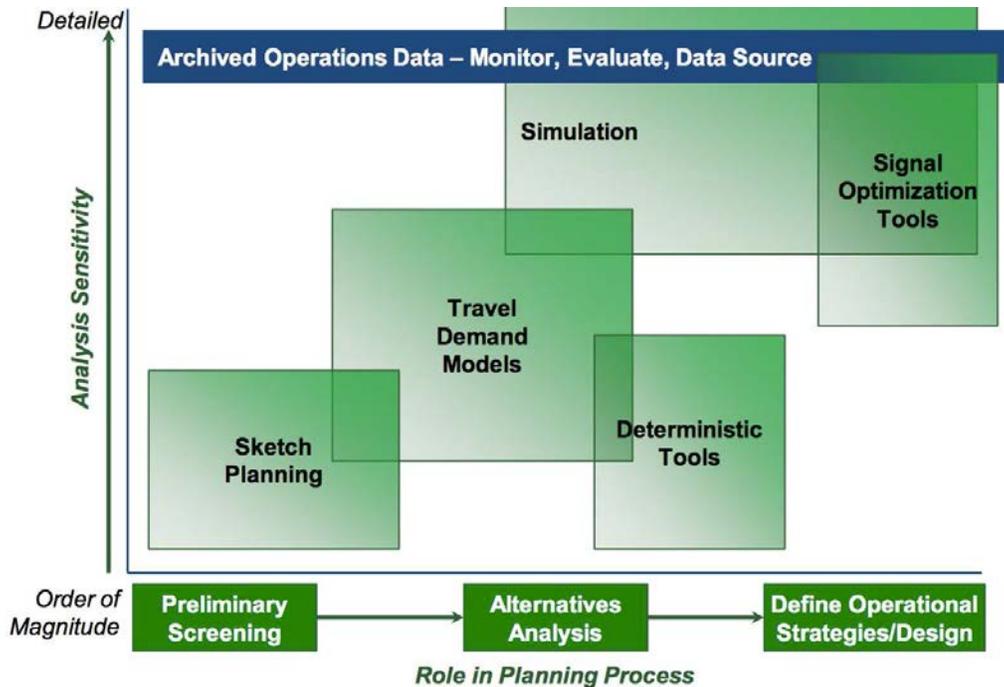
**Incident and Crash Reduction Potential**

A crash analysis sponsored by the Crash Avoidance Metrics Partnership (CAMP) and headed by Cambridge Systematics, Inc. and Jim Misener looked at California collision data for 2013 and found that roughly 78 percent of all crashes could be avoided by the use of V2V technologies based on the underlining determinant of crashes. This was based on a sample of 175,709 crash records from California Highway Patrol (CHP) data. (Cambridge Systematics and Jim Misener. Interoperability Issues of Vehicle-to-Vehicle Based Safety Systems Project Extension (V2V-I Phase 2): V2V Vehicle Density Analysis. December 10, 2014.) Additionally, U.S. Department of Transportation (DOT) has asserted that connected vehicle technologies can “reduce, mitigate, or prevent 81 percent of light-vehicle crashes by unimpaired drivers” (Motor Authority.)

**Evaluation and Comparison of Existing Tools**

This section summarizes the project’s evaluation and comparison of existing transportation analysis tools in terms of their general inputs, outputs, usability, and modeling features/capabilities. The project also specifically evaluated the tools’ ability to model connected vehicle applications and strategies.

Figure 20 provides a summary assessment of existing transportation analysis tools in terms of their roles in the planning process (ranging from preliminary screening to alternatives analysis to operational design), cross-referenced against the tools’ analytical sensitivity and/or resolution. Every tool type represents a tradeoff between geographic scope and level of sensitivity/resolution (scale versus complexity). Less detailed tool types are tractable for large networks, while more detailed tool types are restricted to smaller networks.



**Figure 20. Chart. Roles of existing transportation analysis tools in the planning process.**  
(Source: Cambridge Systematics, Inc.)

It can be argued that the analysis of the impact of connected vehicle strategies will require more detailed, higher-resolution data and tools. This hypothesis is supported by a review of the state of advanced transportation analysis practice in the last two decades, which reveals that simulation models have been increasingly used for the analysis of Intelligent Transportation Systems (ITS), Integrated Corridor Management (ICM), and Active Transportation and Demand Management (ATDM) strategies. The following paragraphs provide a summary evaluation and comparison the three current classes of simulation tools most frequently used by planners, as well as new emerging connected vehicle simulation models:

- **Travel Demand Models.** These have only limited capabilities to accurately estimate changes in operational characteristics (such as speed, delay, and queuing) resulting from implementation of operational strategies; they were not designed to evaluate travel management strategies such as CV, ITS, and other operational strategies. Because of these inadequacies, they are generally not suited for use for CV analysis, but they can potentially be used in conjunction with other tools and methods to support CV analysis.
- **Microscopic Simulation Models.** Because of the detailed representation of the traffic and road networks found in these models and because of their ability to model individual vehicles and traffic control strategies (such as ramp metering or traffic signal preemption), these tools show substantial promise for modeling CV applications and strategies.
- **Mesoscopic Simulation Models.** These combine properties of both microscopic and macroscopic simulation models, and although they can capture the effects of queue lengths and the temporal distribution of congestion, they do not consider dynamic speed/volume relationships and therefore provide less fidelity than microsimulation tools. They are, however, superior to travel demand models in that they can evaluate dynamic traveler diversions on large-scale networks. Thus, these tools are useful in the modeling of regional CV applications and strategies.
- **CV-Specific Simulation Models.** This emerging class of tools can simulate all types of sensors, vehicle, V2V, and vehicle-to-infrastructure (V2I) technologies at a microscopic level. A challenge will be to develop versions of these engineering tools that are approachable for practitioners, responsive to their needs, and accommodating of the desired level of precision for planners. In addition, developers and planning agencies will both want to integrate the capabilities of these models into their existing miso- and meso-based simulation tools, corridor planning workflows, and infrastructure assessments.

All of the above existing and emerging tools show promise regarding the analysis of various CV strategies; however, such analyses will require a number of tool enhancements, including modifications to the car-following and lane-changing logic and algorithms embedded in existing analysis tools. In some cases, it is furthermore possible that major restructuring of current analysis frameworks will be necessary to fully provide the following information:

1. The systemwide impacts of CV strategies.
2. The travelers' behavioral responses to imperfect, latent, and multiresolution real-time traveler information.
3. Improved transit, freight, parking, and pedestrian analysis capabilities.

4. Enhanced land use planning capabilities.
5. Risk analysis capabilities to address ranges of potential impacts.

Overall, these enhanced or new analysis frameworks must be capable of evaluating the cost effectiveness of CV strategies individually, in combination with each other, and in combination with other ITS strategies in the near term, midterm, and long term. In pursuit of this overall objective, additional requirements for these frameworks include the following capabilities:

1. Modeling both the transportation and communications impacts of CV strategies.
2. Identifying the operational conditions under which CV strategies will be most beneficial.
3. Distinguishing between different communications technologies and resolutions.
4. Testing different market penetrations for CV strategies.
5. Evaluating the impacts of communications errors, loss, or latency.

The project also compared the capabilities of the different categories of analysis tools across the following dimensions:

- Geographic scale of analysis.
- Usability and technical considerations.
- Facility types available for analysis.
- Travel modes available for analysis.
- Traveler response types available for analysis.
- Performance measure outputs available.

*Technical Memorandum #3* contains the comparison tables for all tools across all of the above dimensions. For illustration purposes, the comparison tables for the geographic scale dimension and the performance measure outputs dimension are provided below.

Geographic scale is generally a constraint that must be satisfied by any tool under consideration for a particular analysis, making this one of the initial factors to be considered when selecting an appropriate tool for a specific need. Isolated locations, typically single junctions, are the smallest in scale. Segment-sized analyses also include small grid networks, while a corridor-sized model typically includes both a primary roadway and neighboring parallel routes as well. Regional models are the largest, generally having a coverage area of 200 square miles or more.

**Table 13. Geographic scale of analysis capabilities by tool category.**

<b>Geographic Scope</b>	<b>Sketch Planning</b>	<b>Travel Demand Models</b>	<b>Highway Capacity Manual</b>	<b>Simulation Models</b>
Isolated location	Poorly suited	Poorly suited	Highly relevant	Highly relevant
Segment	Limited applicability	Poorly suited	Highly relevant	Highly relevant
Corridor or small network	Limited applicability	Limited applicability	Limited applicability	Highly relevant
Regional	Limited applicability	Highly relevant	Poorly suited	Limited applicability

Source: Cambridge Systematics, Inc.

Available performance measure outputs vary depending on the type of analysis tool used, as shown in table 14. This reflects the native capabilities of each tool category, without consideration of additional outputs obtained through post processing. Accuracy of the outputs is dependent on several factors, including reliability and resolution of the input data, assumptions inherent in the particular tool being used, and quality of the model calibration (if applicable). Although table 14 indicates which performance metrics are generally currently available from each type of analysis tool, future research may make additional outputs available for the combinations in the table that currently have a “poor” rating. Consequently, this table should not be interpreted as a representation of what each analysis tool type is inherently suitable or unsuitable for, but rather as a summary of what outputs are currently typically offered.

**Table 14. Performance measures available for output.**

<b>Performance Measure</b>	<b>Sketch Planning</b>	<b>Travel Demand Models</b>	<b>Highway Capacity Manual</b>	<b>Traffic Simulation Models</b>
Level of Service	Poorly suited	Limited applicability	Highly relevant	Limited applicability
Speed	Highly relevant	Highly relevant	Highly relevant	Highly relevant
Travel time (including control delay)	Limited applicability	Limited applicability	Highly relevant	Highly relevant
Volume (expressed as a flow)	Highly relevant	Highly relevant	Highly relevant	Highly relevant
Travel distance (from origin to destination)	Poorly suited	Highly relevant	Poorly suited	Highly relevant
Ridership	Poorly suited	Limited applicability	Poorly suited	Limited applicability
Average vehicle occupancy (includes transit)	Poorly suited	Limited applicability	Poorly suited	Limited applicability

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Intelligent Transportation System Joint Program Office

**Table 14. Performance measures available for output (continuation).**

<b>Performance Measure</b>	<b>Sketch Planning</b>	<b>Travel Demand Models</b>	<b>Highway Capacity Manual</b>	<b>Traffic Simulation Models</b>
Volume to Capacity Ratio	Poorly suited	Highly relevant	Highly relevant	Highly relevant
Density	Poorly suited	Poorly suited	Highly relevant	Highly relevant
Vehicle-miles traveled or person-miles traveled	Limited applicability	Highly relevant	Limited applicability	Highly relevant
Vehicle-hours traveled or person-hours traveled	Limited applicability	Highly relevant	Limited applicability	Highly relevant
Delay (additional travel time beyond free flow travel time)	Limited applicability	Limited applicability	Limited applicability	Highly relevant
Queue lengths	Poorly suited	Poorly suited	Limited applicability	Highly relevant
Number of stops (based on a threshold speed)	Limited applicability	Poorly suited	Poorly suited	Highly relevant
Incidents	Limited applicability	Limited applicability	Poorly suited	Highly relevant
Incident duration	Poorly suited	Limited applicability	Poorly suited	Highly relevant
Travel time reliability (quantification of the uncertainty regarding travel times, e.g., as an extra time buffer that travelers must build into their schedules).	Limited applicability	Limited applicability	Poorly suited	Highly relevant
Emissions	Limited applicability	Limited applicability	Poorly suited	Highly relevant
Volume to Capacity Ratio	Poorly suited	Highly relevant	Highly relevant	Highly relevant
Noise	Limited applicability	Poorly suited	Poorly suited	Poorly suited
Mode split	Poorly suited	Highly relevant	Poorly suited	Limited applicability
Benefit/Cost Ratio (comparison of annualized, monetized benefits and costs).	Limited applicability	Limited applicability	Poorly suited	Limited applicability

Source: Cambridge Systematics, Inc.

## Gap Analysis for Existing Tools and Data

This section anticipates how analytical tools and data used in traditional long-term transportation planning would be modified or overhauled for use in near-term prediction for active management of the transportation system's performance. Below is a summary of general gaps in available analytical tools and data. *Technical Memorandum #3* additionally contains detailed lists of capability and data gaps specific to each tool type. These lists further connect each identified gap to the research topic(s) in the project's proposed Roadmap for Addressing Gaps that are designed to overcome the gap.

### General Gaps in Analytical Tools and Data

The following is a list of general gaps that were found to be common to a broad range of analytical tools, rather than being specific to only a particular tool category:

- Changes to infrastructure that will become possible (or even necessitated) by the advancement and spread of CV technologies are currently unaccounted for in analysis tools. These include the potential for narrower design tolerances (e.g., narrower lanes) or a reduced need for traveler information systems (e.g., guidance signage, traffic alerts via changeable message signs) as these become integrated directly into the vehicle.
- Optimization tools, such as those for signal timing with transit vehicle considerations, must be revisited and revised to account for the changes in driver behaviors that CV technology will produce, such as faster reaction times to phase changes, reduced need for clearance intervals, and reduced need for dedicated protected left turn phases due to changes in gap acceptance patterns.
- Decision support tools for operational decisions (e.g., incident management), maintenance activities, and freight management need to be updated to reflect the new capabilities afforded by CV technologies.
- Actual gains (in capacity, emissions, delays, etc.) achieved for various penetration rates of CV technology have not yet been thoroughly measured, investigated, or even estimated for C/AV strategies, including platooning, merge assistance, weaving assistance, or intersection movement assistance. These benefits must also be considered in the context of roadway types/environments (e.g., freeway, urban arterial) and traffic conditions (e.g., oversaturated). These analyses are a prerequisite to proper incorporation of these CV strategies into all classes of analysis tools.
- Guidance is needed regarding the suitability of various traffic analysis tools for analyzing each CV strategy in various contexts (e.g., platooning on freeways, intersection movement assistance on signalized arterials). It is anticipated that some classes of tools will be better suited for evaluating certain C/AV strategies than others (e.g., sketch-planning tools for safety impacts, or traffic microsimulation models for weaving section capacity improvements).
- The upcoming field tests of CV systems represent a good opportunity to explore the potential outcomes associated with CV technology. To ensure the utility of these deployments is maximized, an analysis and data collection methodology is needed to ensure the proper data are collected in each case, including sufficient data for model calibration and validation against real-world CV data.

## Roadmap for Addressing Gaps

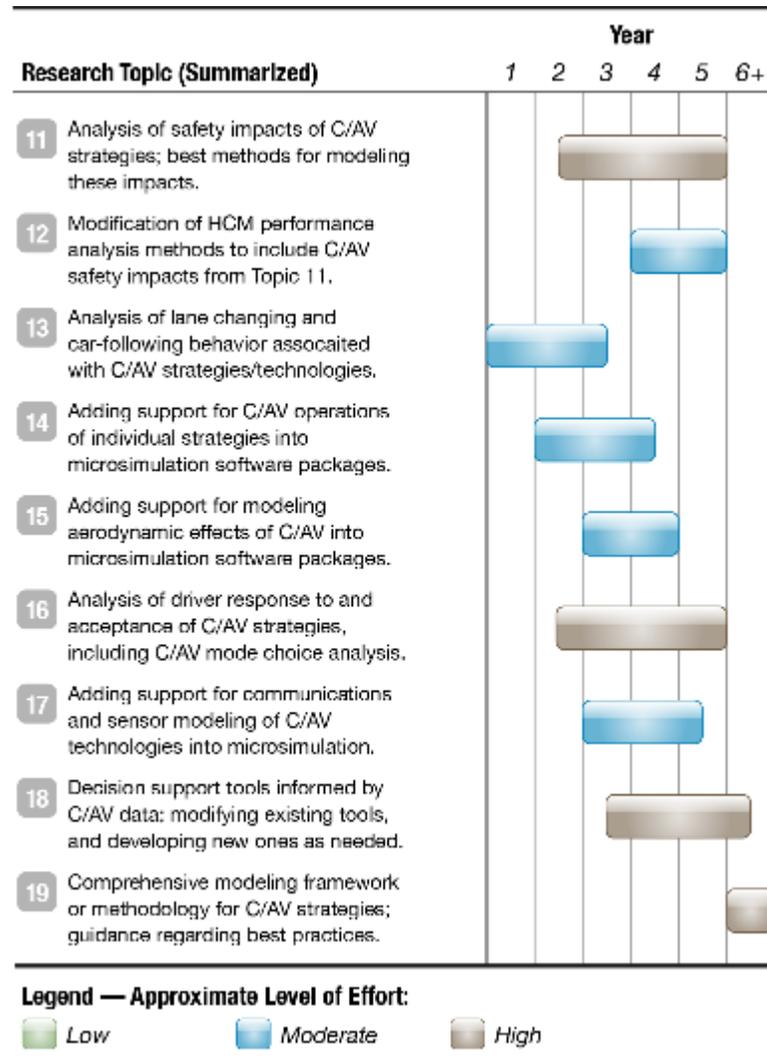
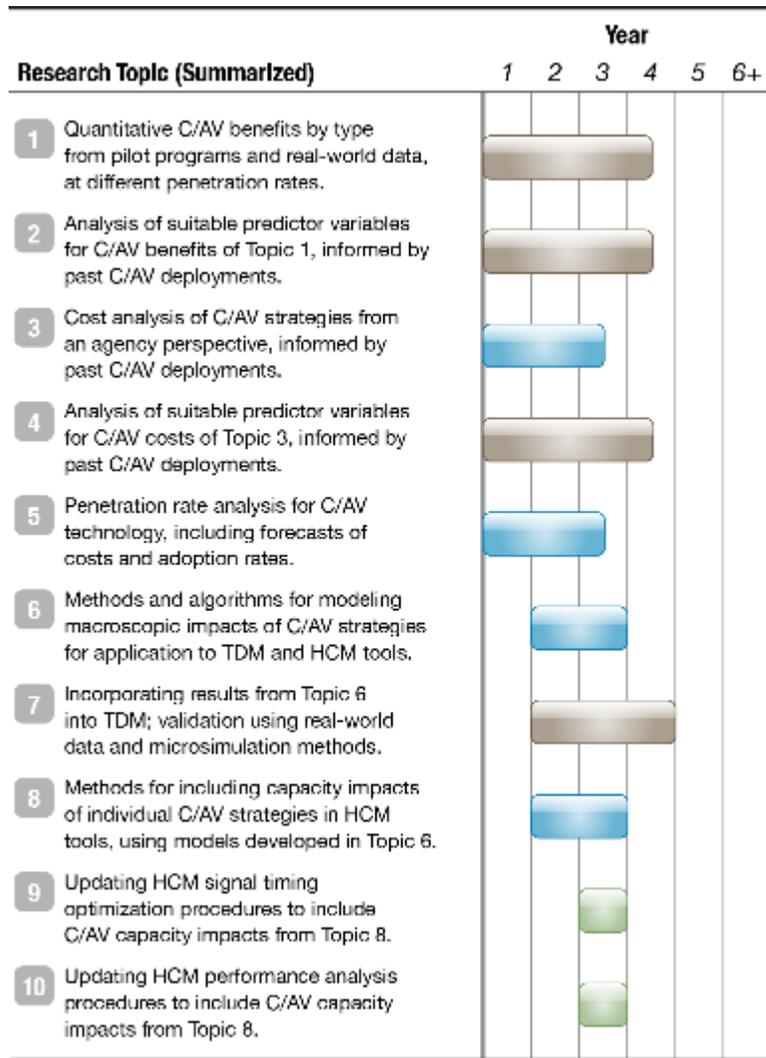
This section presents the project's proposed research roadmap for addressing the identified gaps in existing analytical tools and data. The research roadmap is comprised of 19 research topics that are designed to provide researchers and practitioners with the transportation planning tools they need to conduct C/AV analyses as the associated technologies mature and are deployed. The roadmap is designed to be a rational, tractable, and structured approach for addressing all identified gaps and needs, and to provide analysts and practitioners with the tools and resources they need to capture the impacts and outcomes associated with CV and AV applications as they are deployed. The roadmap has not yet been formally adopted or funded, and as such, its contents (including scope and timing) are tentative and subject to change.

Figure 21 gives an overview of the expected timing for each of the research topics in the proposed roadmap. However, *Technical Memorandum #3* provides detailed information on the following aspects of the research topics in the roadmap:

- **Description of the proposed research roadmap.** Description of the 19 research topics that comprise the proposed research roadmap; including resource needs and availability, potential lead organizations, and relevance to planning for C/AV technology.
- **Research topic prioritization.** Categorical prioritization for the 19 research topics (two levels of prioritization), including information on other research topics that are dependent on advances in the topic at hand and on which existing transportation tools are impacted by the topic.
- **Benefit types captured by each research topic.** Discussion of the specific C/AV benefits captured by each research topic; benefits include mobility, reliability, capacity, emissions, fuel usage, safety, costs, and traveler behavior.
- **Factors affecting the proposed research topics.** Discussion of the significance of empirical data and C/AV technology penetration rates in the context of the roadmap.

Within the schedule of expected timing for research topics in the roadmap (figure 21), the start time for a given topic is based on the expected availability of data required to support the topic, and on the timing of other prerequisite research topics on which the given topic depends. The duration for a given research topic is based on the resources required to complete the topic, and on the expected level of effort required to obtain the necessary supporting data. The “approximate level of effort” color labels in the figure facilitate rapid identification of the research tasks that have the shortest (green) and longest (red) durations, and are consequently expected to require relatively less or more resources to complete. All topics are also generally expected to require an additional six to twelve months for project development, including preparation of a request for proposal, collection of proposals, evaluation of received materials, negotiation with most promising candidates, and notification of awards. The end dates for each research topic in figure 21 are defined by their estimated start dates and durations, and are intended to suggest when initial results might be expected from those topics. Given the ongoing nature of these research topics, they should not be interpreted as the final dates that any work would be performed on the topic. It is expected that there will be ongoing work for all of these research topics even after their objectives have been initially accomplished, as the topic outcomes will continue to benefit from an infusion of new datasets as they become available over time.

All of the research topics described in the roadmap are concerned with CV technologies and applications; however, most are also expected to include AV considerations as well. *Technical Memo #3* provides information about the particular levels of automation that are expected to apply.



**Figure 21. Chart. Schedule for the proposed research roadmap.**  
 (Source: Cambridge Systematics)

# Workforce Skills and Training

Professional development and training are essential to the incorporation of connected/automated vehicles (C/AV) into the transportation planning process. In order to guarantee successful deployment, transportation planning agencies and their stakeholders must understand these technologies well enough to support both planning and operations functions. The objective of the workforce skills and training analysis was to assess and describe how professional development and training programs should be designed to impart the required knowledge and skills. More information on the workforce skills and training analysis can be found in the project's associated report, *Technical Memorandum #6: Skills and Expertise Required to Incorporate Connected Vehicles into Transportation Planning*. In general, the analysis revolved around the following four activities:

- **Benchmark existing training programs.** Research, define, and characterize existing C/AV training programs offered by the public sector, the private sector, and academic/nongovernmental organizations (NGO).
- **Conduct interviews.** Enhance findings by conducting interviews with relevant organizations in the public, private, and academic/NGO sectors.
- **Synthesize interview findings.** Synthesize the information obtained from the interviews around four main discussion topics.
- **Provide recommendations.** Based on the research and interview findings, provide recommendations and a strategy for developing C/AV training programs for the planning community.

## Benchmark Existing Connected/Automated Vehicle Training Programs

As a first step towards assessing the role of institutional training and professional development, research was conducted online to determine the current status of C/AV training programs in the public, private, and academic/NGO sectors. The online research identified 28 training programs—9 provided by public agencies, 10 provided by private agencies, and 9 provided by academic institutions or NGOs. The different training programs can be generally characterized as follows, based on the type of sponsor organization:

- In general, public agencies' training programs are provided online, with the U.S. Department of Transportation's (DOT) connected vehicle (CV) 101 and 102 online programs providing a CV overview suited to a relatively wide audience. Furthermore, a following course, CV 201, is currently being developed. This instructor-led course will build off of the CV101 and 102 online courses and is expected to roll-out in 2016.
- The private institutions' training programs were generally in the form of daylong seminars and focused more on operations- and technology-specific topics. In

contrast to other programs, privately sponsored programs seem to target populations with greater knowledge of C/AV technology.

- Other programs include workshops that offer courses at conferences and seminars. The programs sponsored by academic and NGOs were either in-person programs—involving primarily academic institutions, like the Washtenaw Community College or Michigan Tech Transportation Institute—or short webinars and presentations, seeking to provide a general overview of CV technology.

An important conclusion to be drawn from this benchmarking effort is that there is not one training program designed specifically for planners. Although the great majority of the programs found are open to the general public and could be of interest to planners, most of these program are either technology- or operations-centric or both. Clearly there remains a need for C/AV-oriented training programs that focus on planning activities. This underscores the need to build off the more technically oriented training courses for Intelligent Transportation Systems (ITS) and CV operations—translating content relevant to the stakeholders (transportation planners). Due to the nature of the program, C/AV is necessarily telecommunication connectivity heavy and driven by standards and operations parameters and data. Translating these into transportation-planner recognized terms will be critical to success.

## Conduct Interviews

In order to better understand training programs and their relevance for different transportation stakeholders, the team designed an interview process intended to obtain firsthand information from different stakeholders and experts in the field. In total, 30 different organizations were approached, including 17 planning organizations, 6 academic institutions, and 7 industry-related organizations. Of these, 18 organizations agreed to participate in interviews. Table 15 show a list of all participating organizations. In some cases more than one representative of an organization was interviewed, so that a total of 27 individuals participated in the process—20 of these interviewees are with transportation planning entities, and seven are more involved in transportation operations, but have an understanding of transportation planning needs.

**Table 15. Organizations interviewed.**

Organization Type	Organization
Academic	Georgia Tech
Academic	University of Arizona
Private	Leidos
Private	Transportation Research Board—Traffic Signal Committee
Public	Association of Metropolitan Planning Organizations
Public	Atlanta Regional Commission
Public	Baltimore Metropolitan Council
Public	Caltrans

**Table 15. Organizations interviewed (continuation).**

Organization Type	Organization
Public	Capital District Transportation Committee
Public	Corvallis Area Metropolitan Planning Organizations
Public	Genesee Transportation Council
Public	LA Metro
Public	MetroPlan Orlando
Public	New York Metropolitan Transportation Council
Public	Michigan Department of Transportation
Public	North Jersey Transportation Planning Authority
Public	Puget Sound Regional Council
Public	Virginia Department of Transportation

Source: Cambridge Systematics, Inc.

In addition, input was obtained from members of the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Planning (SCOP) and the Transportation Research Board (TRB) Statewide Multimodal Planning Committee at a Peer Exchange held on July 7, 2015 in Salt Lake City. Skills and training were among the topics discussed at this meeting and the inputs are reflected in this report. Of particular concern to AASHTO and TRB Committee members was the need for a better understanding of long-range planning scenarios related to C/AV.

## Interview Questions

The interviews were designed to be open-ended discussions in order to obtain as many insights from each respondent as possible. To help guide the discussion, however, the project developed a series of interview questions that were organized around the four objectives/discussion topics listed below. The full set of guiding questions is provided in *Technical Memo #6*:

- 1. The C/AV field and current training programs available.** The interviewee's experience with and understanding of training programs.
- 2. Current gaps and needs of C/AV training programs.** The gaps and most significant needs with regard to C/AV training programs for planners.
- 3. Defining the technical focus and content of C/AV training programs.** Specific topics that should be covered by C/AV training programs for planners.
- 4. Defining C/AV training options.** Developing recommendations for future training programs including length, format, and potential providers.

## Synthesis of Interview Findings

The following section provides a synthesis of the interview findings, organized to correspond with the four discussion topics.

### The Connected/Automated Vehicle Field and Current Training Programs Available

The first section was focused on understanding the respondents' awareness of training programs that are currently available, particularly as they relate to planning needs. The majority of the respondents were not aware of any C/AV training programs available for planners; however, most of them were aware of general informational sessions available online. Most respondents were aware of the U.S. DOT CV 101 and 102 programs. An interesting finding from this activity was that several of the public agencies have taken steps to become more involved in this topic: some State and municipal planning agencies are reaching out to other stakeholders and organizing events to keep themselves updated. The vast majority of the respondents indicated that there is a need to increase training among planners in this area.

Opinions regarding who should lead training efforts on C/AV topics for planners were divided. The majority of the respondents agreed that any stakeholder group (public, private, or academic) would be fit to provide training on this topic, as long as the instructors are knowledgeable about the technology and the course is relevant to planning. Furthermore, the pervasive sentiment was that a combination of these stakeholders would be desirable. The stakeholder most mentioned to lead these efforts was the U.S. DOT, but others were noted, including organizations such as the American Association of State Highway and Transportation Officials (AASHTO) and the National Highway Institute (NHI). Respondents agreed that different stakeholders could provide greater insights, depending on the specific topic. In general, respondents agreed that the private sector would be better suited to delivering training programs with a technical focus, while public-sector stakeholders would be a better fit for training sessions focused on policies and regulations. Respondents generally stated that the role of academic institutions should be to validate such programs but not lead these efforts. Respondents considered C/AV training programs to be more valuable if they keep a practical focus, instead of a theoretical one.

Finally, respondents were asked about the value of obtaining a certification from these training programs. Although some mentioned that it would help incentivize management support for training, the majority of the respondents agreed that they do not see value in certification at this stage of C/AV technology development. In general, respondents indicated that certification would be more useful once the nature of the preferred technology is more settled and skills validated, giving course certificates a greater value for professional purposes.

### Identifying Current Needs of C/AV Training Programs

The second general topic addressed the respondents' insights on important training needs for C/AV in planning. The insights obtained can be categorized by three needs:

- **Understanding Upcoming Changes.** The most discussed need was to understand the effect of C/AV deployment on current planning products. Respondents mentioned that there is a need to tailor training programs so that planners understand what

changes can be expected in regards to infrastructure, traffic signals, road side equipment, and capacity, among other topics. Respondents mentioned that there should be guidelines that show how these changes will be reflected in plans and regulations, like ITS Architecture, ITS/Operations implementation plans, and both short- and long-range planning documents.

- **Technical Changes.** A second common topic identified was the need for changes in planning analysis and evaluation tools. Respondents mentioned that there is a need to understand changes in modeling processes, performance measures, data management, and scenario planning to accommodate this technology in planning endeavors.
- **Integration.** Finally, an important training need discussed was the need to integrate planning activities with other tasks that are related to C/AV technologies. Planners should have a general understanding of C/AV engineering and technical concepts, enabling communication between stakeholders. This will promote a discussion of common planning challenges to be addressed, such as environmental impacts and transit and equity issues, during various steps of technology development.

To address these needs, respondents mentioned that planners must learn new skills or polish existing skills. The skill most mentioned was the ability to develop scenario analysis, considering shorter time horizons and incorporating different risks associated with the volatile way in which this technology is being developed. According to the majority of respondents, scenario analysis will be a useful tool to evaluate the incorporation of this technology in future plans. Respondents also highlighted the importance of considering technology market penetration rates and incorporating risk assessment in their evaluations. Another skill mentioned frequently was the ability to manage new data and abstract useful information that describes transportation system performance at shorter time horizons.

Finally, regarding the focus of training on planning, respondents generally agreed that all types of planners, from entry-level to top managers, require training in this field. Within this broad audience, respondents would like training programs to be tailored to specific subsets of the planning audience.

## Defining the Technical Focus and Content of C/AV Training Programs

In order to obtain more detailed information on desired training programs, respondents were asked to comment on specific technical objectives and goals for these training programs. When asked about what objectives training programs should have for planners, respondents answered according to their background and experience. The majority of operations-oriented planners stated that the chief aim should be to educate them about C/AV technologies, rather than technical specifications. They further indicated the program should focus on impacts of the technologies across different planning activities. On the other hand, more policy-oriented planners stated that these programs should have the objective of educating them about full range of impacts and possible future scenarios.

## Defining Connected/Automated Vehicle Training Options

The last section of the interviews focused on the respondents' views on training program formats. The objective of this section was to understand what types of content would better fit a desirable C/AV training program. The vast majority of the respondents agreed that webinars are a useful format for reaching a wide range of audiences and should provide general overviews of the training topic. On the

other hand, seminars were considered good for building curiosity, keeping up to date about technology development, and sharing experiences. For more indepth training, workshops and in-person sessions were considered the most effective methods.

The final topic asked respondents to describe their ideal C/AV training program for planners. Responses varied, but in general respondents described programs that were tailored to the audience (both area of expertise and level of management), applied a combination of strategies depending on the audience, and were organized to provide planners with progressively more detailed information on C/AV technology.

## Recommendations and Potential Strategy

After further distilling the interview comments, themes emerged that speak to future training activities. These themes inform the trends, gaps, and needs—in the form of recommendations—for C/AV training programs for the planning community. These recommendations are grouped by future training content, audience, and delivery approach. Building on these recommendations, this section also offers a potential strategy for a proposed training program.

### Future Training Content

**Increase Awareness of Existing C/AV Programs for Planners.** When viewed by background (planner, operations, other), planning staff are less likely to be aware of or to have taken existing training programs regarding C/AV. Additional information may be provided specifically to the planning profession about the availability of current C/AV awareness programs such as the CV 101 and 102 training.

**High-Level Training for Leaders.** Early training development should target agency leaders and senior planners. High-level training should examine broad impacts and policy ramifications. This training would discuss the technology in general terms with particular focus on timing of C/AV impacts. Information on the potential timing of C/AV deployment and the impacts of that deployment is essential.

**Scenario Planning.** Given the level of uncertainty in timing and fleet penetration rates, training through scenario planning is highly beneficial, and is recommended as an early training effort. An example of a scenario would be a Year 2025 scenario, with assumed marketing penetration of 15 percent of the vehicles on the road being equipped with Dedicated Short-Range Communications (DSRC), and would also outline deployments of CV infrastructure that the relevant planning agency was responsible for maintaining. Federal Highway Administration (FHWA) developed a Scenario Planning Handbook that focuses on socioeconomic and land use scenarios; the general approach used in this handbook could potentially be used to develop guidance to develop scenarios that address the impacts of C/AV technology. Moreover, the ITS-Joint Program Office (JPO) Professional Capacity Building program has developed two formal case studies for training—for Adaptive Signal Control and for the ITS National Architecture—that provide instructors ITS Case Studies that provide for scenario-based learning tool that exposes students to real-world decisions that come with planning, deploying, and operating ITS technologies. These two case studies, and future case studies developed under this program, can also support the development of the C/AV scenarios. Finally, it's important to realize that a lot of unknowns exist in how to develop C/AV scenario planning. In moving forward, it will be incumbent on the ITS-JPO to develop scenario planning tools and guidance which planners can use to develop scenarios that meet regional/local needs. Here,

the role of the ITS-JPO can be to set the standards by which such scenario development should occur, thus ensuring the C/AV developments occur across the Nation based on well-understood and consistent scenario development.

### **Technical Training for Planning Staff**

- **General Planning Implications**—Training should include modeling, capacity impacts, infrastructure investment, design, and land use. This training effort should have a technical and practical focus and be specifically designed to address the needs of planning staff.
- **Data Implications**—Encompasses disaggregating, understanding and using “big data” in the planning activities. This training area will comprehensively assess new and emerging data sources, public and private data sharing, and use of data and data outputs to improve planning.

## **Target Audience**

**Audience-Specific Training.** Training is needed at all levels of the planning profession. The planning community is not homogeneous; consequently, training must take into account the differing roles and responsibilities of planning professionals and the need to engage across disciplines. For example, managers and senior leaders may need early training because internal policies and processes are driven from the top. More technical training is needed for modelers and those engaged with the details of plan development and analysis.

**Multiagency and Multidiscipline.** C/AV technology impacts cross transportation disciplines and geographic boundaries. Training activities therefore should encourage participation across organizational lines in order to foster communication and understanding.

## **Delivery**

**Range of Delivery Types.** Due to travel restrictions and funding limitations, it is important to provide a range of delivery options matched to the content and audience. Options include webinars, in-person workshops (one to two days), in-person workshops at conferences (one-half to one full day), conference sessions, articles in journals, and Web portals.

**Sources of Training.** The transportation planning community in general is familiar with the organizations that traditionally provide transportation training such as U.S. DOT, NHI, and AASHTO, and they should continue to do so, as agencies will look there first. Larger agencies, however, may benefit from having their own training programs. In that case, materials developed for U.S. DOT, NHI, or AASHTO may be shared so that these agencies have consistent information delivered to them in a timely way. The developers of training can come from a range of providers as long as the training is practical and not theoretical. Use of the “train the trainers” technique is assumed for all training approaches.

**Frequency.** Due to the fast-moving nature of developments in C/AV technology, planning professionals may be provided with frequent updates. Delivery options include webinar updates, articles, and information on Web portals.

## Proposed Strategy

Building upon these recommendations, the proposed training program consists of five steps, focusing on different aspects of C/AV topics in planning and oriented towards specific audiences. Table 16 describes the proposed training programs considered. Following table 16, a brief description of each training program is presented. In this table, “costs” represent the cost for development and delivery of the training; for the ranges of costs, “low” represents 20 hours or less of labor, “medium” represents 20 to 80 hours of labor, and “high” represents greater than 80 hours of labor.

**Table 16. Summary of recommendations for connected/automated vehicle training programs.**

Target Audience	Content	Resulting Skills/Focus	Delivery	Frequency	Cost	Priority
All planning staff	Introduction to technology—applications and possible impacts	Focus on existing Connected/Automated Vehicle training, general awareness of Connected/Automated Vehicle technology and applications, awareness of potential impacts	Webinars, articles, conference sessions, Web portals	Scheduled periodically for live or on-demand (recorded) presentation, articles and conferences as available	Medium	High
Leadership, politicians, appointees	Overview of technology and impacts on planning	General awareness of magnitude and timing of Connected/Automated Vehicle impacts	Conference sessions, articles	Opportunistic	Low	High
Planning leaders	Overview of policy benefits and impacts—timing, financial implications	Awareness of magnitude and timing of Connected/Automated Vehicle impacts, ability to assess impacts on policy, land use, and major investments	Webinars, conference sessions	Scheduled periodically for live or on-demand (recorded) presentation	Medium	High
Planning managers	Planning for Operations and Scenario planning—how to incorporate scenarios in planning evaluation tools	Development of viable scenarios, conduct scenario analyses considering impact over time, assess Connected/Automated Vehicle impacts on land use, transit, and transportation investments, incorporate Connected Vehicle infrastructure in short-term plans	In-person programs	Conference workshop opportunities, scheduled sessions one to two per year	High	Medium
Planning technical staff	General planning implications—modeling, technology, capacity, infrastructure, data	Model Connected/Automated Vehicle impact, estimate capacity impact, incorporate infrastructure needs into short-term plans, incorporate Connected Vehicle in Intelligent Transportation Systems Architecture	In-person workshops	Yearly workshop, for a one-half to two-day program	High	Low
Planning technical staff	Data Implications	Encompasses disaggregating, understanding and using “big data” in the planning activities	In-person workshops	Yearly workshop, for a one-half to two-day program	High	High

Source: Cambridge Systematics, Inc.

The following expands on the recommended training programs defined in the “Content” columns of table 16:

- **Introduction to Technology.** This program can adapt the current CV 101 and 102 programs to explain the basic concepts that all planners must understand to work with C/AV technology issues. The U.S. DOT should encourage planning agencies, working from the State to local levels, to take CV 101 and 102 online.
- **Overview of Technology and Impacts.** This program would focus on describing general impacts related to city planning and transportation. The main objective of this program should be to inform participants about what to expect once C/AV technology is deployed at different penetration rates and with varying efficacy rate and timeframes for implementation. This program can take place in conference sessions, where planning managers and decisionmakers can understand in some depth the general impacts of these technologies. It is recommended that U.S. DOT lead this effort by organizing an initial set of seminars, preferably taking advantage of an already organized seminar or conference such as the Transportation Research Board Annual Meeting, Association of Metropolitan Training Organizations, or the AASHTO Planning Subcommittee.
- **Overview of Benefits of Integrating CV in Short- and Long-Range Transportation Planning Processes.** This training would be aimed at local leadership, politicians, and rather than being technical in nature, it would instead provide a general understanding of the benefits of incorporating CV into Transportation Planning (long and short range).
- **Overview of Policy Impacts.** This program can be designed as an additional webinar offered by U.S. DOT but exclusively targeting planning audiences. This program should focus on identifying the impact this technology would have on current policies and addressing how planners should incorporate this effect in planning efforts. U.S. DOT should lead this program, by designing the webinar content and making it accessible to the general planning community.
- **Planning for Operations.** Planners should be aware of the operational impacts their policies and decisions have. In order to facilitate communication and understanding between planners and operations-oriented personnel, FHWA has established a program called “Planning for Operations.” This program centralizes a number of resources for planners to have at their fingertips as they identify investments that will improve existing and future system operation.
- **Scenario Planning.** This program should show participants how to implement scenario planning techniques that incorporate the effects of C/AV technology on transportation systems and socioeconomic and land use forecasts. Topics covered should include guidelines to define feasible and realistic horizons, as well as methods to embellish current risk analysis. U.S. DOT could participate in this effort by providing in-person workshops, preferably through established popular conferences and seminars.
- **Technical Implications.** This program should cover more technical issues of interest to planners. The content should address how to incorporate C/AV technologies into current ITS Architectures, transportation models, and data analysis, among other technical platforms. Given the nature of this program, it is proposed as a one-half to

two-day in-person workshop, where modelers and analyst can gather and obtain the necessary information to update their skills. U.S. DOT could organize and host these events yearly, targeting exclusively technical staff.

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