Connected Vehicle Impacts on Transportation Planning

Outreach to Planning Community

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16. Abstract

This document presents outreach memos on 11 case studies analyzing the impacts of connected and automated vehicles (C/AV) on transportation planning products. These 11 case studies are documented indepth in the associated project document entitled *Connected Vehicle Impacts on Transportation Planning—Technical Memorandum #5: Case Studies* (December 2015). The outreach memos are designed to provide transportation planners with a quick and concise source of the information detailed in Technical Memorandum #5. Each of the 11 memos contains a summary of key messages for transportation planners and a high-level account of the most significant or unique (relative to other transportation planning products) impacts of C/AV on that particular transportation planning product. The principal objective of the case study research was 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. The outreach memos/case studies included are: 1) Transportation Improvement Program; 2) Statewide Intelligent Transportation Systems (ITS) Architecture; 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; and 11) Financial Plan.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
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")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
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
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* 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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Transportation Improvement Program

Summary: Impacts of Connected and Automated Vehicles on Transportation Improvement Programs

Metropolitan Planning Organizations (MPO) develop Transportation Improvement Programs (TIP) to identify transportation projects from their long-range Metropolitan Transportation Plan (MTP) that they plan to advance over the next four years. As the TIP focuses on near-term goals, funding, and performance measures, these plans will likely initially include small-scale connected and automated vehicle (C/AV) pilot projects, with large-scale investments over multiple TIPs becoming more common as the technology progresses.

Key Messages for Transportation Planners

- A key impacts of C/AV for planners and desionmakers will be the type and level of detailed data provided available. The data generated by C/AV technology is expected to enhance the ability of planners to quantitatively assess projects that have low capital costs but ongoing operation and maintenance (O&M) requirements, allowing for improved project selection criteria.
- Intelligent transportation systems (ITS) projects offer connected vehicle (CV) planners relevant lessons and project selection criteria for C/AV projects. Compared to traditional capital projects (roadway expansion, new transit service, etc.), ITS projects have relatively low capital costs but require ongoing O&M costs. C/AV investments and O&M costs are eligible for Federal-aid funds in the same manner that ITS investments are.
- In the short term, C/AV deployment will likely take the form of small-scale pilot projects that are assessed and adjusted with each TIP. In the medium to long term, C/AV deployments are likely to become a standard strategy, with large-scale investments over multiple TIPs. It is important to note that even when C/AV pilots are funded with special grants, ongoing maintenance and operations funding should be provided if the project is to continue after initial funds run out.

Case Study

This case study explores how connected and automated vehicles (C/AV) will likely impact transportation improvement programs (TIP), and provides guidance on how these plans can embrace the impacts and opportunities of C/AV. Metropolitan planning organizations (MPO) develop TIPs 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.

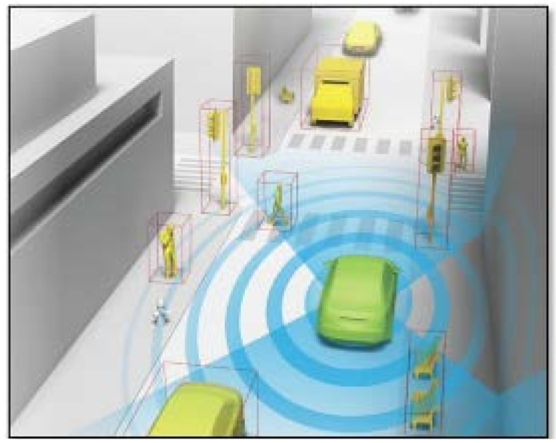

Figure 1. Illustration. Communications between connected/automated vehicles and connected/automated vehicle-enabled infrastructure and pedestrians.
(Source: Cambridge Systematics, Inc.)

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. This document focuses on only the most significant or unique impacts of C/AV on TIPs, and additional impacts and recommendations can be found in the associated report *Connected Vehicle Impacts on Transportation Planning, Technical Memorandum #5: Case Studies (FHWA-JPO-16-281)*.

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.

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 1, note that annual operations and maintenance costs are not captured here).

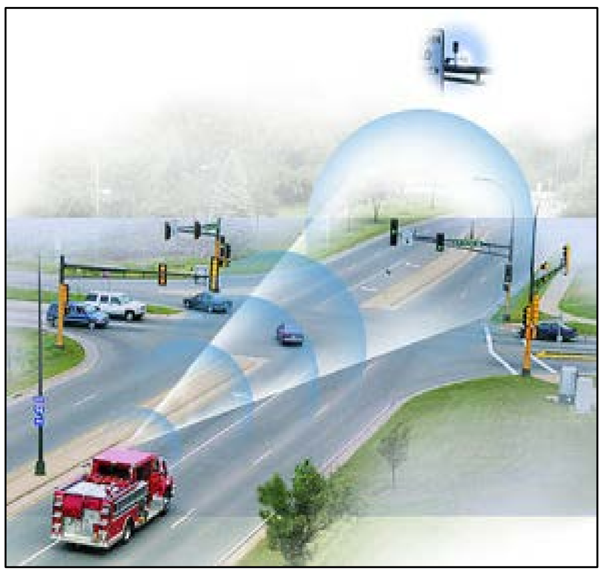

Figure 2. Illustration. Connected vehicle technology used to preempt traffic signals for emergency vehicles.
(Source: U.S. Department of Transportation.)

Table 1. 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[1]	20 intersections	$3,200	$64,000
Backhaul communications	1 system (20 intersections)	$30,000to $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.

Note: Costs developed from multiple sources, including U.S. Department of Transportation CO-PILOT and 2011 American Association of State Highway and Transportation Officials Connected Vehicle Deployment Analysis.

[1] Note here that upgrading the signal controller is not necessarily required in all instances depending on the existing signal controller system capabilities and also considering alternative cellular communications support of certain connected vehicle applications.

Statewide Intelligent Transportation Systems Architectures

Summary: Impacts of Connected and Automated Vehicles on Intelligent Transportation Systems Architectures

States and regions that deploy intelligent transportation systems (ITS) projects funded by the Highway Trust Fund are required to develop a statewide or regional ITS Architecture, using the National ITS Architecture as a guideline. Connected and automated (C/AV) technology is expected to enhance or replace existing ITS systems, resulting in a need to update existing interfaces and integrate new interfaces. Additionally, increased data sharing between planning and operations can help leverage the new data sources created by C/AV applications.

Key Messages for Transportation Planners

- In the short term, planners should recognize that connected vehicle (CV) elements will enhance the functionality of current ITS services. Over the medium to long term, CV elements may replace ITS elements (for instance, will we need dynamic message signs if vehicles and infrastructure are communicating with one another?) and/or provide new services. Planners may find it useful to work with operations and maintenance managers to develop a transition plan and identify how existing interfaces will be updated and new interfaces integrated.
- CV data will strengthen the linkage between operations and planning of ITS and other advanced technologies (consider the emerging integration with Smart Cities). The process of integrating CV elements into the statewide or regional ITS Architecture demonstrates where the data linkages exist and allow for more direct sharing between operations and planning; and further identifies the involvement and interests of a wider array of stakeholders. Also, planners will need to work with stakeholders to ensure that the creation of new data sources are integrated with existing and legacy systems.
- In the medium to long term of CV technology deployment, planners can expect to see a reduction in numbers of crashes and incidents. These changes are expected to impact operations planning priorities, with planners allocating fewer resources to incident management and more resources to system optimization. These changes will further impact operations and maintenance strategies and planners will find a need to update the State Long-Range Transportation Plans and ITS/operation plans.

Case Study

This case study explores how connected and automated vehicles (C/AV) will likely impact statewide intelligent transportation systems (ITS) architectures, and provides guidance on how these architectures can embrace the impacts and opportunities of C/AV. 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.

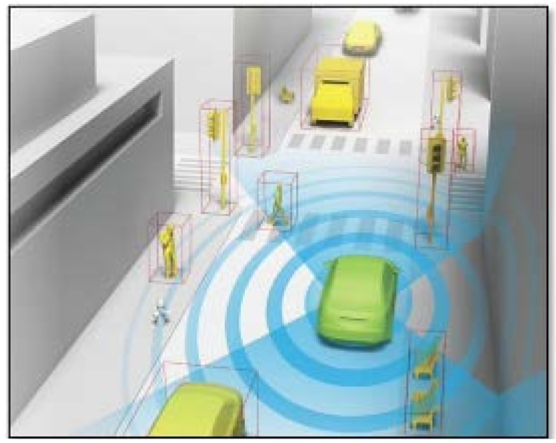

Figure 3. Illustration. Communications between connected/automated vehicles and connected/automated vehicle-enabled infrastructure and pedestrians.
(Source: Cambridge Systematics, Inc.)

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 (FHWA-JPO-16-281)***.**

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 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.

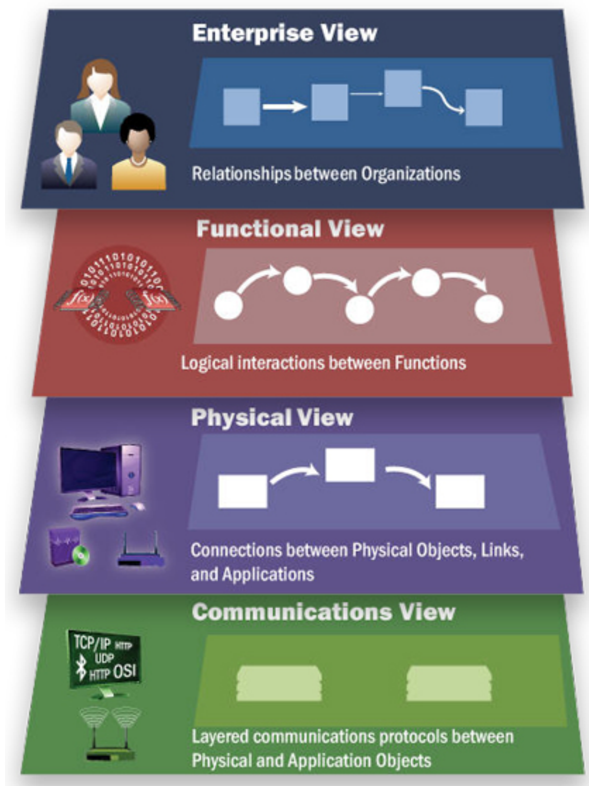

Figure 4. Diagram. The four views of the Connected Vehicle Reference Implementation Architecture—a Federal tool for developing connected/automated vehicle architectures that align with National Intelligent Transportation Systems Architecture standards.
(Source: U.S. Department of Transportation.)

- 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.

7. Regional Architecture System Security: In regards to the inclusion of C/AV applications, addressing system security will now be a critically important element in the development of a statewide ITS Architecture. This is an emergent architectural need and will require the developer to consider architecture data, interfaces, agreements, and standards. There are no specific details available at this point in time but developers should identify and monitor this emerging area as a near-term consideration.

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, http://www.ops.fhwa.dot.gov/Wz/its/index.htm.)

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 2 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 must 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 2. 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.

Note: Costs developed from multiple sources, including U.S. Department of Transportation CO-PILOT and 2011 American Association of State Highway and Transportation Officials Connected Vehicle Deployment Analysis.

Bicycle and Pedestrian Planning

Summary: Impacts of Connected and Automated Vehicles on Bicycle and Pedestrian Planning

Federal legislation requires metropolitan planning organizations (MPO) to include bicycle and pedestrian elements in the Metropolitan Transportation Plan and Transportation Improvement Plan. Connected and automated vehicle (C/AV) applications are expected to improve the safety and mobility of vulnerable road users by improving the ability of vehicles and infrastructure to detect and accommodate these users.

Key Messages for Transportation Planners

- Planners need to understand how C/AV data will change the nature of bicyclist and pedestrian experiences as they use transportation facilities. Some examples include:
  - C/AV technology can improve bike/pedestrian safety by warning vehicles of their presence and improve the mobility of disabled and/or elder pedestrians by extending walk indications.
  - The installation of C/AV technology on transit vehicles could broadcast to bicyclists/pedestrians when vehicles are approaching transit stops, thereby helping with modal changes.
  - Bike share stations can broadcast their location and availability to bicyclists—addressing the problem of arriving at a bike share station where either all bikes have been taken or all empty spots are full.
- Planners can expect that data broadcast from bicycles or pedestrian mobile devices will enrich data sets and provide greater detail about use and demand for nonmotorized travel options. Bicycle travel times, pavement condition, and routing data are expected to be available through connected vehicle technology broadcasts. This richer data set could aid in the identification of system gaps and/or deficiencies. Such data is also expected to impact the development of bicycle and pedestrian plans.
- MPOs could conduct pilots that equip transit buses or city vehicles with C/AV technology to explore how the technology improves drivers' ability to see and avoid bicyclists/pedestrians.

Case Study

This case study explores how connected and automated vehicles (C/AV) will likely impact bicycle and pedestrian planning and provides guidance on how these planning efforts can embrace the impacts and opportunities of C/AV. 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.

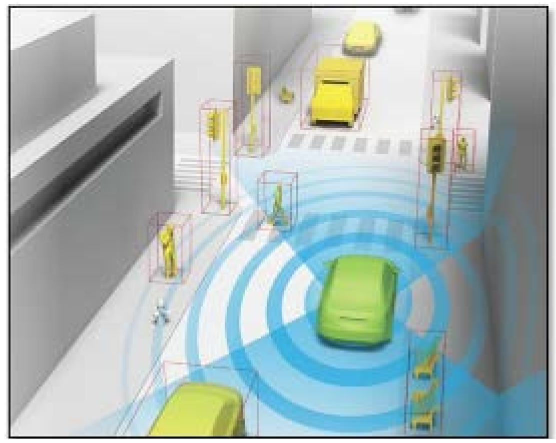

Figure 6. Illustration. Communications between connected/automated vehicles and connected/automated vehicle-enabled infrastructure and pedestrians.
(Source: Cambridge Systematics, Inc.)

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 (FHWA-JPO-16-281)*.

1. Vision, Goals, and Performance Measures: Develop high-level vision statements, measureable 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 meets 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.

Figure 7. Photo. Pedestrians waiting at a signalized crosswalk.
(Source: iStockphoto.)

- 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.

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.

Figure 8. Photo. The Pedestrian Signal System application offers safety benefits to many types of pedestrians, for example pedestrians who use wheelchairs.
(Source: iStockphoto.)

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.

Table 3 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 3. High-level cost estimate of capital costs to deploy connected/automated vehicles infrastructure, equipment, and the PED-SIG 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[2]	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.

Note: Costs developed from multiple sources, including U.S. Department of Transportation CO-PILOT and 2011 American Association of State Highway and Transportation Officials Connected Vehicle Deployment Analysis.

[2] Note here that upgrading the signal controller is not necessarily required in all instances depending on the existing signal controller system capabilities and also considering alternative cellular communications support of certain connected vehicle applications.

Long-Range Metropolitan Transportation Plan

Summary: Impacts of Connected and Automated Vehicles on Long-Range Metropolitan Transportation Plans

Metropolitan planning organizations (MPO) develop long-range Metropolitan Transportation Plans (MTP) covering all modes of surface transportation over a 20+ year time horizon. These plans guide decision-making around regional transportation investments by setting goals, evaluating alternative strategies to meet these goals, and measuring progress. Connected and automated vehicle (C/AV) technologies could significantly alter transportation systems in the long term, which creates a need for using new data sources to inform existing and planned performance measures. Agencies will need to establish mechanisms for partnering with private organizations to efficiently collect and analyze this new data. Additionally, MTPs will need to consider alternative land use and economic scenarios due to the expected but uncertain long-term socioeconomic impacts of C/AV technologies.

Key Messages for Transportation Planners

- C/AV technology will introduce cost effective data sources and collection methods. In the short term, baseline information will continue to be collected by traditional methods. Over the medium to long term, C/AV technology can supplement and replace existing sources and methods. For example, travel times and pavement conditions data can be generated collected by C/AV technology.
- A key benefit of new C/AV data sources and methods will be expanded types of data, such as vehicle probe datasets. This new data is expected to result in a greater ability to track performance and guide investment decisions to achieve performance targets. In addition, C/AV infrastructure can efficiently support multiple applications across multiple areas of performance measurement.
- New C/AV data will be available for use in MTP alternatives analyses and will help to better understand new land use, transportation facility use, and socioeconomic 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.

- Planners work with baseline information on the transportation system. As connected vehicle (CV) technologies emerge, planners are likely to have questions about how to estimate market penetration. Some of this information will be available in the National Highway Traffic Safety Administration (NHTSA) rulemaking (different national penetration models will be offered) that can be modified for use at the local level. The United States Department of Transportation (U.S. DOT) analysis from field tests suggest that a small level of penetration (approximately 10 percent) can result in benefits.
- Planners can expect C/AV infrastructure to initially be deployed in some isolation. The Vehicle-to-Infrastructure (V2I) Deployment Coalition is considering how to support local deployment of CV Roadside Units within the next three years. Planners may want to join and/or track the progress of this planning.
- MPOs are going to need to establish a regular process for review of relevant documents addressing C/AV technology and applications, including test bed program reports, deployment guidance, proof-of-concept reports, industry product information, and use-cases.

Case Study

This case study explores how connected and automated vehicles (C/AV) will likely impact long-range transportation plans (LRTP), and provides guidance on how these plans can embrace the impacts and opportunities of C/AV. Both States and metropolitan planning organizations (MPO) develop LRTPs, although the case study focuses specifically on the LRTPs developed by MPOs, known as **Metropolitan Transportation Plans (MTP)**. The analysis, however, is applicable to State LRTPs as well.

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.

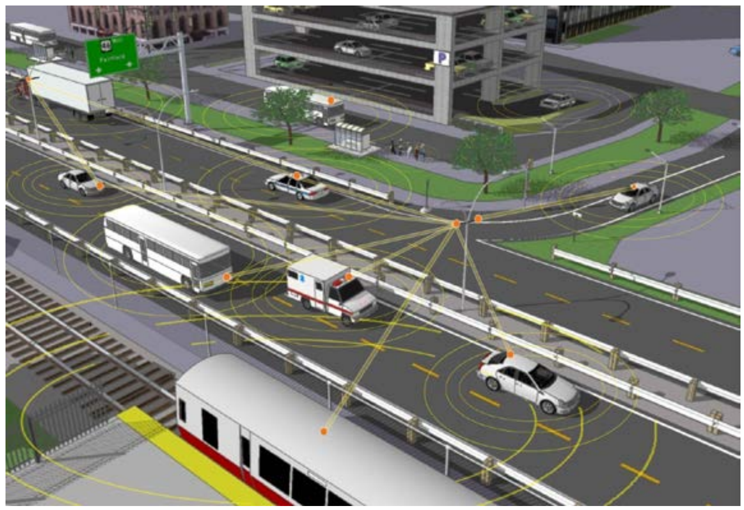

Figure 9. Illustration. A range of connected/automated vehicle technologies.
(Source: U.S. Department of Transportation.)

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 (FHWA-JPO-16-281)*.

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.

Figure 10. Illustration of an automated vehicle.
(Source: iStockphoto.)

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 decisionmakers and the public to maintain support for C/AV investments in the long term.
  - The Federal Highway Administration's CO-PILOT[3] 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.

[3] See: https://co-pilot.noblis.org/CVP_CET/.

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:

Figure 11. Illustration. The Eco-arrival and departure at signalized intersections application.
(Source: U.S. Department of Transportation.)

- 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 4 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 4. 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
Safety: 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
Agency Data: Maintain pavement data	Capture real-time pavement condition so repairs can be expedited where necessary	Manual field survey of pavement	Probe-Based Pavement Maintenance
Mobility: 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
Environmental: 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 5 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 5. 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[4]	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.

Note: Costs developed from multiple sources, including U.S. Department of Transportation CO-PILOT and 2011 American Association of State Highway and Transportation Officials Connected Vehicle Deployment Analysis.

4 Note here that upgrading the signal controller is not necessarily required in all instances depending on the existing signal controller system capabilities and also considering alternative cellular communications support of certain connected vehicle applications.

Transportation Asset Management Plan

Summary: Impacts of Connected and Automated Vehicles on Transportation Asset Management Plans

State Departments of Transportation (DOT) are required to develop a Transportation Asset Management Plan (TAMP) for the National Highway System. TAMPs inventory transportation system assets and conditions and outline strategies for maintaining or improving assets and system performance.

Key Messages for Transportation Planners

- Connected and automated vehicle (C/AV) technology is expected to reduce the cost of collecting asset management data and enable detailed data collection of transportation network and roadway segment conditions. Planners need to be aware that this data will provide the opportunity for agencies to identify poor performing assets earlier and take proactive actions. However, requests for quick repairs pose the risk of taking resources away from medium- to long-term rehabilitation needs (e.g., covering potholes as opposed to re-paving), potentially affecting both short-term and medium- to long-term condition targets.
- An additional potential concern is that the reporting of conditions at this level of detail and in near real time may heighten the traveling public's expectations regarding agency responsiveness. Planning agencies can expect to play a role in managing expectations and communicating to the public that faster identification of issues does not guarantee rapid response, which is still a function of available resources.
- The continuous data collection cycle potentially offered by C/AV technology allows performance gap assessment to be performed more frequently, or even on an ongoing basis, enabling dynamic adjustment for changing traffic patterns and other optimization techniques. Planners can expect that forecasting assumptions and models will need to be updated accordingly. New tools will be needed to process large amounts of data from individual vehicles, identify patterns, and create actionable information.

Case Study

This case study explores how connected and automated vehicles (C/AV) will likely impact Transportation Asset Management Plans (TAMP) and provides guidance on how these TAMPs can embrace opportunities provided by C/AV. TAMPs inventory transportation system assets, conditions, and strategies to maintain/improve assets and system performance. Each State Department of Transportation (DOT) is required to developed 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.

Figure 12. Illustration. Communications between connected and automated vehicle-enabled vehicles and infrastructure.
(Source: Cambridge Systematics, Inc.)

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 (FHWA-JPO-16-281)***.**

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 connected vehicle (CV) and eventually automated vehicle (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.
- 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.

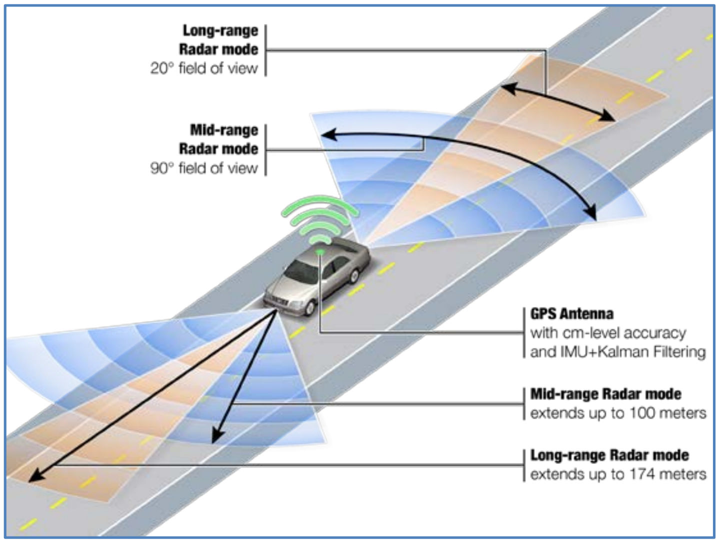

Figure 13. Illustration. Connected/automated vehicle technologies used to obtain information on the surrounding environment.
(Source: Cambridge Systematics, Inc.)

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.

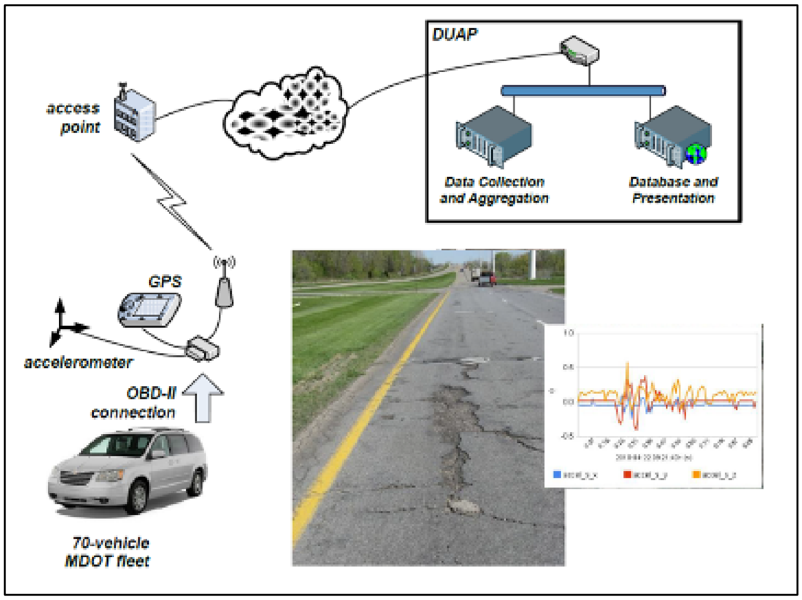

Figure 14. Diagram. Michigan Department of Transportation Data Use Analysis and Processing project test and results of deploying a Probe-Based Pavement Maintenance application.
(Source: Michigan Department of Transportation.)

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 6 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.

Table 6. 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.

Note: Costs developed from multiple sources, including U.S. Department of Transportation CO-PILOT and 2011 American Association of State Highway and Transportation Officials Connected Vehicle Deployment Analysis.

Strategic Highway Safety Plan

Summary: Impacts of Connected and Automated Vehicles on Strategic Highway Safety Plans

As part of the Federal Highway Safety Improvement Program, State Departments of Transportation (DOT) are required to develop, implement, evaluate, and update a Strategic Highway Safety Plan (SHSP). The SHSP identifies the State's greatest safety needs and guides investment decisions regarding strategies with the greatest potential to save lives and prevent injuries. Creating a safety data emphasis area can help agencies prepare to integrate connected and automated vehicle (C/AV) data with existing crash, traffic, and vehicle data. These combined data sources can then help planners select and prioritize additional emphasis areas.

Key Messages for Transportation Planners

- C/AV is expected to impact the selected emphasis areas. For example, if inclement weather affects the performance of automated vehicles, weather-related crashes may be selected as an emphasis area.
- C/AV will increase the need to select safety data as an emphasis area in the SHSP.
- The phased deployment of C/AV technology will shift priorities over time. Immediate priorities, such as developing mechanisms for collecting, sharing, and using safety data should be a primary emphasis.

Case Study

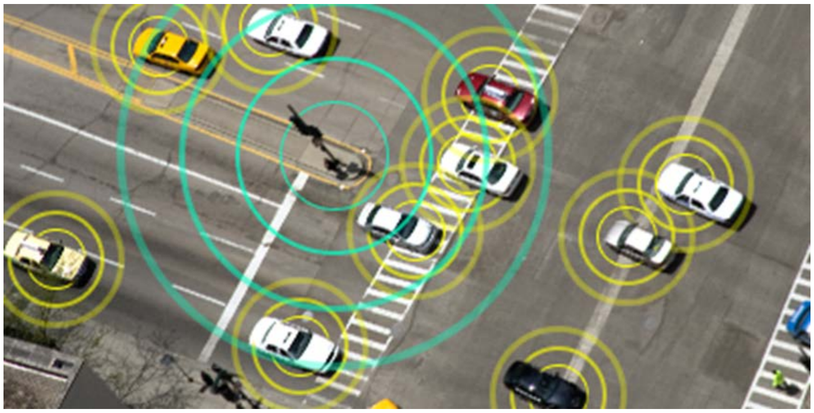

Figure 15. Illustration. Communications between connected and automated vehicle-enabled vehicles and infrastructure.
(Source: Cambridge Systematics, Inc.)

This case study explores how connected and automated vehicles (C/AV) will likely impact Strategic Highway Safety Plans (SHSP) and provides guidance on how these SHSPs can embrace C/AV-related opportunities. As part of the Federal Highway Safety Improvement Program (HSIP), State Departments of Transportation (DOT) are required to develop, implement, evaluate, and update an 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 (FHWA-JPO-16-281)*.

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 a 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.

Figure 16. Photo. A crash between two nonconnected/automated vehicles on a roadway. (Source: iStockphoto.)

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.

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).

Figure 17. Photo. Vehicles driving along a curvy road.
(Source: iStockphoto.)

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.

Table 7 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 7. 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.

Note: Costs developed from multiple sources, including U.S. Department of Transportation CO-PILOT and 2011 American Association of State Highway and Transportation Officials Connected Vehicle Deployment Analysis.

State Implementation Plan

Summary: Impacts of Connected and Automated Vehicles on State Implementation Plans

The Clean Air Act requires each State to develop a State Implementation Plan (SIP) for attaining and maintaining the National Ambient Air Quality Standards. New connected and automated vehicle (C/AV) applications for environmental performance and their associated data will provide additional detail to enhance air quality monitoring and provide users with decisionmaking support for utilizing the transportation system in a more environmentally efficient way.

Key Messages for Transportation Planners

- Mobile emissions monitoring data will become available as C/AV technology is deployed. Planners can expect that this means of data collection will likely supplement fixed-location monitoring devices to provide a more complete picture of air quality in a given area.
- Planners can benefit from the research performed by the United States Department of Transportation's (U.S. DOT) Application for the Environment: Real-Time Information Synthesis (AERIS) program on how to collect performance measure data on fuel use and emission reductions as a part of new connected vehicle (CV) data sets. Planning organizations and State/local Departments of Transportation (DOT) will be able to track and potentially visualize (in real time), the impact of transportation on air quality with new models and tools that analyze the data in real time.
- Planners will be able to find examples of how users will be able to utilize the transportation system in a more environmentally efficient way, including: the Eco-Arrival and Departure at Signalized Intersections (EADSI) application, dynamic eco-routing, and smart truck parking.

Case Study

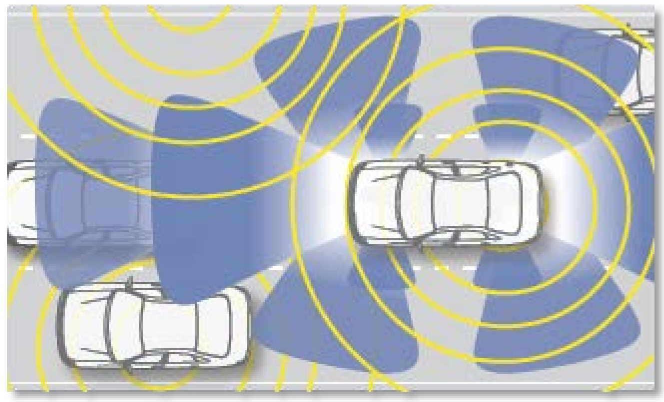

Figure 18. Illustration. Communications between connected vehicles.
(Source: Cambridge Systematics, Inc.)

This case study explores how connected and automated vehicles (C/AV) will likely impact State Implementation Plans (SIP) and provides guidance on how SIPs can embrace the impacts and opportunities of C/AV. 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[5]. 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 (FHWA-JPO-16-281)***.**

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.

[5] It is important to note here that the most critical element of a SIP is the emissions budget, attributed to the four areas in the budget, and strategies for undertaking programs and actions that lead to achieving or maintaining conformity with NAAQS. The four budget areas are: stationary source (factories, for example); area-wide (lawn mowers and aerosols, for example); mobile source—highway (vehicle base emissions); and mobile source—nonhighway (construction equipment, waterborne vessels, for example).

2. Ambient Monitoring Program:[6] 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) program. EADSI uses vehicle-to-infrastructure (V2I)

Figure 19. Illustration. The Eco-arrival and departure at signalized intersections application.
(Source: U.S. Department of Transportation.)

[6] Under the Ambient Monitoring Program, the inference is that MPO and DOT personnel should establish the system and methods to monitor the data on ambient air quality. Monitoring the air quality is performed by the State Air Agency as prescribed by U.S. Environmental Protection Agency (EPA). Designation of attainment and nonattainment is performed through operation of this monitoring. In place of monitoring the impact of C/AV on ambient air quality, the DOT and MPO should monitor the introduction of C/AV into the vehicle fleet and acquire knowledge on the emission benefits, if any, associated with these vehicles.

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 8 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 8. 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[7]	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.

Note: Costs developed from multiple sources, including U.S. Department of Transportation CO-PILOT and 2011 American Association of State Highway and Transportation Officials Connected Vehicle Deployment Analysis.

[7] Note here that upgrading the signal controller is not necessarily required in all instances depending on the existing signal controller system capabilities and also considering alternative cellular communications support of certain connected vehicle applications.

Transit Development Plan

Summary: Impacts of Connected and Automated Vehicles on Transit Development Plans

Many local and regional transit agencies develop Transit Development Plans (TDP), though there is no Federal requirement to do so, in order to analyze the existing transit system and the investments required to meet future needs.

Key Messages for Transportation Planners

- Transit planners can expect connected vehicle (CV) technologies to generate new data sources that can help enhance service reliability and traveler information as a benefit in the short term. In the longer term, the impact of connected and automated vehicles (C/AV) on the transit system as whole is uncertain (as detailed below). Transit planners can prepare for these potential long-term changes by developing mechanisms to use C/AV data for dynamic operations and optimization; and to develop innovative multimodal transportation options.
- In the short term, by improving service reliability and the quality and timeliness of traveler information, C/AV technology can improve transit operations and result in higher ridership. In the medium to long term, however, as C/AV technology extends to motor vehicles (including car sharing and ridesharing alternatives), ridership on traditional transit services could decline or could increase as C/AV technology provides improved feeder service and allows greater density of land use. Planners will need to incorporate these potential trends into their alternatives analyses, particularly when planning medium- to long-term major capital investments such as bus rapid transit or rail.
- In the medium to long term, as the traveling public is increasingly connected with the transit system through smart phones and intelligent transportation systems (ITS) technologies, C/AV applications can allow for dynamic operations and optimization through applications such as intermittent bus lanes, which allow transit vehicles to request priority bus lanes when needed. The surrounding traffic is notified with in-vehicle messages accordingly.

Case Study

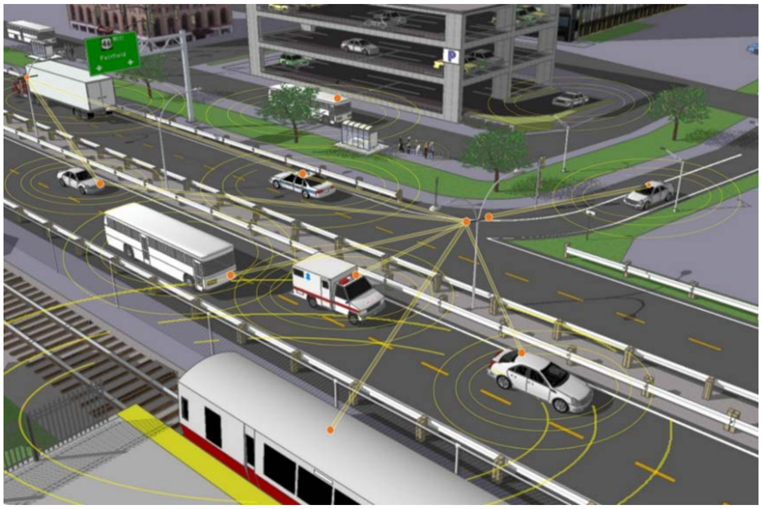

Figure 20. Illustration. Communications between connected/automated vehicle-enabled transit, emergency, and private vehicles, as well as infrastructure.
(Source: U.S Department of Transportation.)

This case study explores how connected and automated vehicles (C/AV) will likely impact Transit Development Plans (TDP) and provides guidance on how these TDPs can embrace the impacts and opportunities of C/AV. TDPs 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 (FHWA-JPO-16-281)*.

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:

Figure 21. Photo. A Chicago Transit Authority bus. (Source: Cambridge Systematics, Inc.)

- 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.

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.

Figure 22. Photo. Transit signal.
(Source: Raysonho @ Open Grid Scheduler/Grid Engine—Own work, CC0, https://commons.wikimedia.org.)

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 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 9 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 9. 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[8]	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.

Note: Costs developed from multiple sources, including U.S. Department of Transportation CO-PILOT and 2011 American Association of State Highway and Transportation Officials Connected Vehicle Deployment Analysis.

8 Note here that upgrading the signal controller is not necessarily required in all instances depending on the existing signal controller system capabilities and also considering alternative cellular communications support of certain connected vehicle applications.

Public Involvement Plan

Summary: Impacts of Connected and Automated Vehicles on Public Involvement Plans

States and metropolitan planning organizations (MPO) are required to develop Public Involvement Plans (PIP) to define outreach processes that ensure full opportunity for public review and comment during the transportation planning process.

Key Messages for Transportation Planners

- Planners can expect a need to be prepared to effectively communicate the implications of connected and automated vehicle (C/AV) technologies, including the challenges and opportunities associated with ensuring that they improve, rather than diminish, equity.
    - C/AV technologies will likely have wide-ranging impacts on both the transportation system and society as a whole—the influences of C/AV on the transportation system and society in general are likely to be much greater than those for ITS—resulting in a high level of public interest.
    - The United States Department of Transportation (U.S. DOT), along with other Federal agencies, has placed great importance on involving groups that have traditionally experienced barriers in participating in transportation public involvement activities. These include minority and low-income groups, persons with disabilities, and persons whose first language is not English. Individuals in these groups may be less likely to participate due to transportation limitations, second or third shift work hours, general lack of information, or a lack of notices in their native languages. C/AV technology presents both opportunities and challenges to these groups; many individuals who cannot currently drive may be able to benefit from automated vehicles, for example. Lower-income individuals, however, are likely to own older cars and thus may be the last to benefit from C/AV safety devices.

Case Study

Figure 23. Photo. Participation at a public meeting.
(Source: iStockphoto.)

This case study explores how connected and automated vehicles (C/AV) will likely impact Public Involvement Plans (PIP) and provides guidance on how these PIPs can embrace the impacts and opportunities of C/AV. States and Metropolitan Planning Organizations (MPO) are required to develop a 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 (FHWA-JPO-16-281)***.**

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.

Figure 24. Photo. A demonstration of connected vehicle technology by DENSO at 2014 Intelligent Transportation Systems World Congress.
(Source: Cambridge Systematics, Inc.)

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.

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.

Freight Plan

Summary: Impacts of Connected and Automated Vehicles on Freight Plans

The United States Department of Transportation (U.S. DOT) is required, and State Departments of Transportation (DOT) are encouraged, to develop a freight plan. The national Freight Plan establishes freight performance measures (PM), while the statewide plans identify projects that are eligible for specific new freight funding. States are also required to set performance targets based on the national PMs, which can be incorporated into the statewide freight plan and/or the State Long-Range Transportation Plan.

Key Messages for Transportation Planners

- Planners should be aware that the freight industry is anticipated to be an early adopter of connected and automated vehicle (C/AV) technology due to its potential efficiency, environmental, safety, and economic benefits. These early deployments will provide information on effective deployment methods and financing techniques.
- Planners' ability to compile estimates of the regional market penetration of C/AV technology in the overall fleet over the short term and the medium to long term will be useful to the freight planning process. Freight planners can expect that the safety, mobility, system optimization, and environmental benefits of C/AV technology and the impact on major medium- to long-term investments will increase as market penetration of C/AV technology and users matures.
- The U.S. DOT's Freight Advanced Traveler Information System (FRATIS) program is an important pilot program that offers State and local DOTs and trucking industry organizations new and innovative applications regarding travel planning and drayage optimization.
- For planners to achieve system-level benefits, there will be opportunities to leverage private investments of fleet operators. For instance, State/local agencies can participate in U.S. DOT efforts to develop C/AV standards for appropriate data sharing that benefit both public and private entities. Importantly, secure and safe interfaces for V2I (vehicle-to-infrastructure) and V2V (vehicle-to-vehicle) communications will be essential if these systems are to gain acceptance by private freight truck companies and drivers.

- For planners engaged in the establishment of commercial vehicle enforcement, C/AV will allow for more cost effective operations. For example, virtual enforcement technologies developed by the Smart Roadside Program can potentially reduce the need for future public investment in fixed truck inspection stations.
- Given the uncertainties in technology adoption and timing, planners should, as part of the alternatives analysis process, analyze different scenarios and conduct a more rigorous level of risk analysis than in the past—including consideration of alternative economic and land use assumptions. U.S. DOT will be developing and delivering tools and information for scenario planning in the 2017 to 2018 timeframe.

Case Study

This case study explores how connected and automated vehicles (C/AV) will likely impact freight plans, and provides guidance on how these plans can embrace the impacts and opportunities of C/AV. The United States Department of Transportation (U.S. DOT) is required to establish a national freight plan and national freight performance measures (PM). 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.

Figure 25. Photo. Freight trucks platooning as they travel along a highway.
(Source: iStockphoto.)

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 (FHWA-JPO-16-281)*.

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 needs 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 10 below shows goals of the Vermont State Freight Plan. Potential C/AV impacts on freight goals and performance measures have been added.

Table 10. 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., 2015).

Level	Goal	Highway Freight Measures Potentially Impacted by Connected/Automated Vehicles
Economy	Support the movement of goods into, out of, and within Vermont	Truck tons, ton-miles, value: Statewide; Major truck-intensive economic sectors
	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
	Maximize safety on the transportation system	Fatalities and crashes; Statewide
	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.

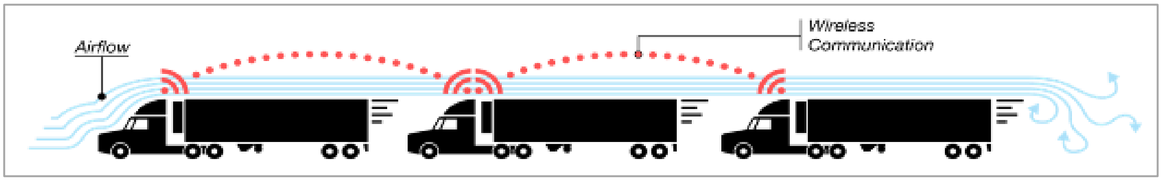

Figure 26. Diagram. Freight truck platooning enhanced by connected vehicle technology (aerodynamic benefits illustrated).
(Source: Cambridge Systematics, Inc.)

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 27. 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 11 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 11. 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[9]	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.

Note: Costs developed from multiple sources, including U.S. Department of Transportation CO-PILOT and 2011 American Association of State Highway and Transportation Officials Connected Vehicle Deployment Analysis.

9 Note here that upgrading the signal controller is not necessarily required in all instances depending on the existing signal controller system capabilities and also considering alternative cellular communications support of certain connected vehicle applications.

Financial Plan

Summary: Impacts of Connected and Automated Vehicles on Financial Plans

Agencies develop financial plans as part of planning documents, rather than as a separate product. For example, financial plans must be included in Metropolitan Transportation Plans and Transportation Improvement Programs. They may also be included in statewide long-range plans or other planning documents or they may be developed for specific purposes (e.g., tolling projects or public-private partnership projects).

Key Messages for Transportation Planners

- Connected and automated vehicle (C/AV) technologies will require funding for capital investments, as well as for ongoing operations and maintenance. These projects will be eligible for several existing funding programs and the development of new data sources will likely lead to opportunities to collaborate with private organizations.
- For planners working to achieve system-level benefits, there will be opportunities to leverage private investments. In looking at funding opportunities, it is important to remember that there are many complex issues regarding the security, privacy, and liability of C/AV technology that are not yet resolved.
- Metropolitan planning organizations (MPO) or States may need to have legislation/authorization to enter into public-private sector partnerships to accomplish certain C/AV goals and objectives. In particular, MPOs could consider ways to include private sector in-kind or cash contributions for projects and programs. The private sector could possibly provide capital funding because they will likely want to be able to utilize the data captured. This may require changes in legislation or policy to allow the private sector to coparticipate in projects and planners may need to revisit local laws on these types of partnerships.

Case Study

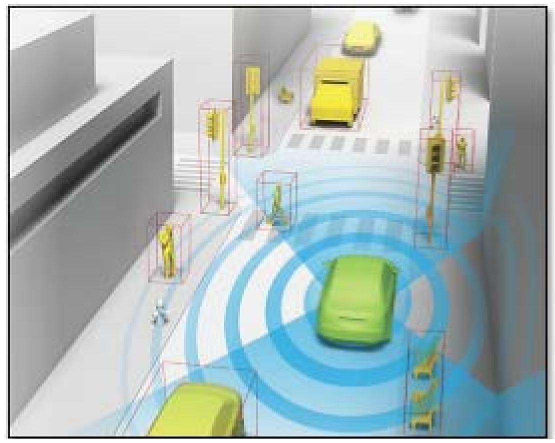

Figure 28. Illustration. Communications between connected/automated vehicles and connected/automated vehicle-enabled infrastructure and pedestrians.
(Source: Cambridge Systematics, Inc.)

This case study explores how connected and automated vehicles (C/AV) will likely impact financial plans and provides guidance on how these plans can embrace the impacts and opportunities of C/AV. 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 (FHWA-JPO-16-281)*.

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).

Figure 29. Illustration of an automated vehicle.
(Source: iStockphoto.)

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