Connected Vehicle Impacts on Transportation Planning

Desk Reference

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16. Abstract

The principal objective of this project, "Connected Vehicle Impacts on Transportation Planning," is to comprehensively assess how connected vehicles should be considered across the range of transportation planning processes and products developed by States, Metropolitan Planning Organizations (MPO), and local agencies throughout the country. This desk reference is designed to help transportation professionals quickly understand and begin planning for the wide variety of impacts that connected-automated vehicle (C/AV) technology is expected to have on transportation planning products and processes. It is a companion document to *Connected Vehicles in Transportation Planning: Final Report and Primer,* which provides a comprehensive summary of project impacts and case studies as well as project technical memoranda, which are described below. It summarizes and illustrates the connections between two key analyses conducted by the project: 1) a C/AV impact typology that identified how C/AV technology can be considered in transportation planning processes and products under a variety of circumstances; and 2) a series of case studies, including illustrative scenarios of C/AV in transportation planning, based on real-world planning products and environments. They highlight the various ways that C/AV can be addressed in planning processes and products. The reference is organized into three sections, summarized below. It is designed to be a flexible document, and it is not necessary to read the reference cover-to-cover or in order. Readers can simply turn their attention to whichever transportation planning product, planning step or process, C/AV impact, or C/AV application they need further information on. Sections include a brief summary of C/AV technology to provide readers with some background and context on the C/AV impacts cataloged in the desk reference. This is followed by a description of key elements which includes the transportation planning products impacted by C/AV, the transportation planning steps and processes *within* these planning products that are impacted by C/AV, the expected impacts of C/AV on planning products and planning steps, and the potential applications of C/AV technology relevant to transportation planning. The final section includes a series of tables which cross reference these key elements, allowing users to identify in which planning products and steps specific C/AV impacts are most likely to occur.

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Section 1.0—Introduction

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

This desk reference is designed to help transportation professionals quickly understand and begin planning for the wide variety of impacts that C/AV is expected to have on transportation planning products and processes. It is a companion document to *Connected Vehicles in Transportation Planning: Final Report and Primer,* which provides a comprehensive summary of project impacts and case studies as well as project technical memoranda, which are described below. It summarizes and illustrates the connections between two key analyses conducted by the project, described briefly below.

- **C/AV Impact Typology.** This analysis identified how C/AV technology can be considered in transportation planning processes and products under a variety of circumstances. From this, the project developed a typology of C/AV impacts on transportation planning as a framework for considering these impacts. The full results of this analysis are detailed in the project's associated reports: *Technical Memorandum #1: Framework for Connected Vehicle Planning Typology and Technical* and *Memorandum #2: Connected Vehicle Planning Processes and Products and Stakeholder Roles and Responsibilities.*[1]
- **Transportation Planning Case Studies.** The case studies developed a number of illustrative scenarios of C/AV in transportation planning, based on real-world planning products and environments. They highlight the various ways that C/AV can be addressed in planning processes and products. The full results of this analysis are detailed in the project's associated report: *Technical Memorandum #5: Case Studies*.[2]

The reference is organized into the following three sections, summarized below. It is designed to be a flexible document, and it is not necessary to read the reference cover-to-cover or in order. Readers

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1 Technical Memorandum #1 was an interim document that was incorporated into Technical Memorandum #2.

2 Technical Memorandum #4 was an interim document that was incorporated into Technical Memorandum #5.

can simply turn their attention to whichever transportation planning product, planning step or process, C/AV impact, or C/AV application they need further information on.

- **Section 2.0—Summary of Connected and Automated Vehicle Technology.** This section provides a brief summary of C/AV technology to provide readers with some background and context on the C/AV impacts cataloged in the desk reference. The summary covers three main topics: connected vehicle technology, automated vehicle technology, and the key potential benefits of C/AV technology.
- **Section 3.0—Description of Key Elements in the Desk Reference.** The reference tables provided later in the desk reference show connections between four categories of key elements that are essential to understanding the impacts of C/AV on transportation planning: 1) the transportation planning products impacted by C/AV (hereafter "planning products"); 2) the transportation planning steps and processes *within* these planning products that are impacted by C/AV (hereafter "planning steps"); 3) the expected impacts of C/AV on planning products and planning steps (hereafter "impacts"); and 4) the potential applications of C/AV technology relevant to transportation planning ("applications"). Section 3.0 lists and briefly describes the key elements under each of these four categories.
- **Section 4.0—Reference Tables**. This section provide the reference tables, illustrating the connections between the four categories of key elements essential to understanding the impacts of C/AV on transportation planning. Three reference tables have been designed to map out these connections:
    1. The **Planning Steps versus Planning Products** reference table provides the general transportation planning framework used in this desk reference to map out the impacts of C/AV on a broad range of transportation planning products and processes;
    2. The **Impacts versus Planning Steps versus Planning Products** reference table maps out the impacts of C/AV across a broad range of transportation planning products and processes by vertically listing the expected significant impacts of C/AV under the planning steps. The table then maps out horizontally the planning products that are expected to be influenced by the given impact.
    3. The **Planning Products versus Applications** reference table maps out which C/AV applications are likely to be relevant to various planning products and provide planners with examples of how C/AV can be incorporated into each type of planning product.

Section 2.0—Summary of Connected and Automated Vehicle Technology

This section provides a brief summary of connected-automated vehicle (C/AV) technology to provide readers with some background and context on the C/AV impacts cataloged in the desk reference. The summary covers three main topics: connected vehicle technology, automated vehicle technology, and the key potential benefits of C/AV technology.

Connected Vehicles

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

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

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

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

Automated Vehicles

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

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

A transportation system consisting primarily of highly automated vehicles may be decades away, but partially automated solutions assisted by V2V and V2I applications will be available sooner. For example, V2I systems can provide information on real-time traffic conditions, queue warnings, and Signal Phase and Timing (SPaT) to enable proactive responses by AVs. The National Highway Traffic Safety Administration (NHTSA) has defined five levels of vehicle automation, building off of current driver assistance technologies such as adaptive cruise control, lane departure warning, and left turn assist (figure 1).[3] Various combinations of levels 0, 1, and 2 are operating on the road today.

[3] The Society of Automotive Engineers (SAE) has defined a slightly different scale with 6 levels of automation http://www.sae.org/misc/pdfs/automated_driving.pdf.

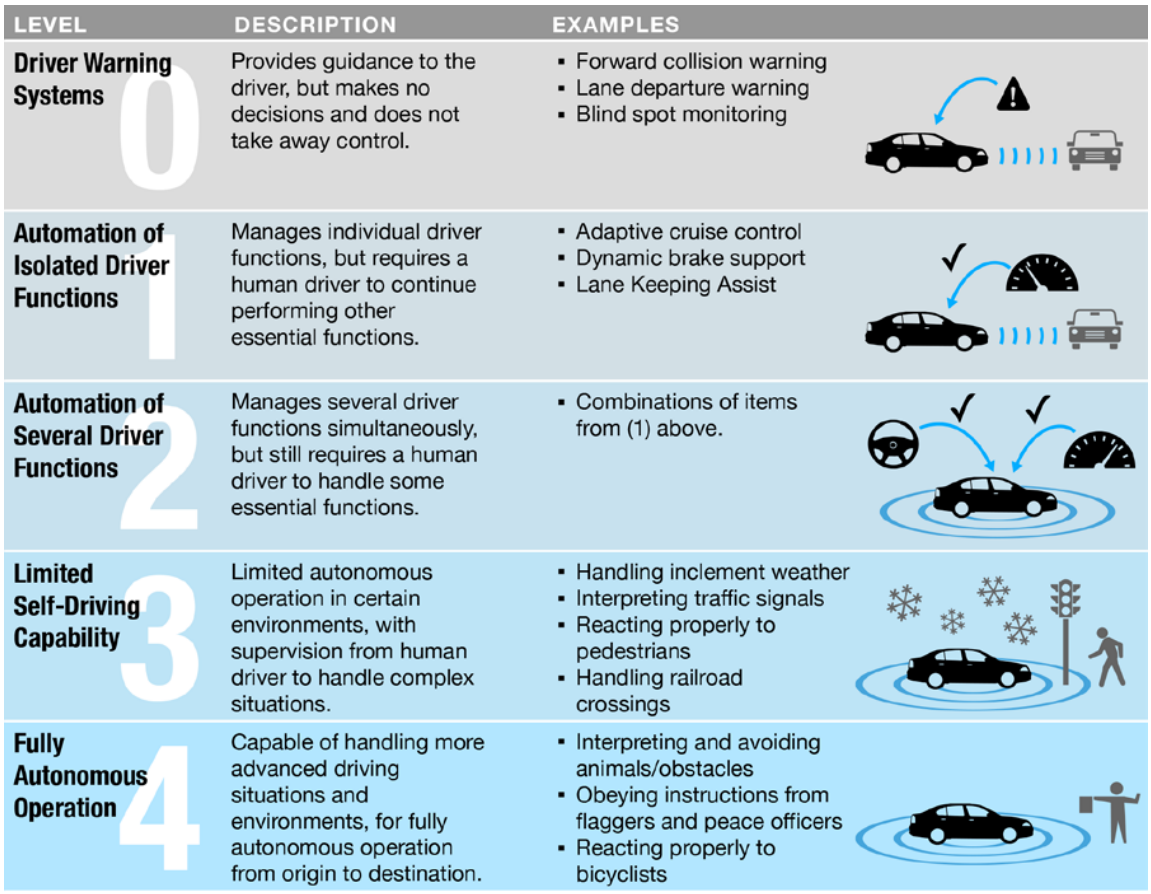

Figure 1: Diagram. The National Highway Traffic Safety Administration's five levels of vehicle automation.
(Source: National Highway Traffic Safety Administration.)

Benefits

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

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

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

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

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

Section 3.0—Description of Key Elements in the Desk Reference

The reference tables in section 4.0 show connections between four categories of key elements that are essential to understanding the impacts of connected-automated vehicles (C/AV) on transportation planning: 1) the transportation planning products impacted by C/AV (hereafter "planning products"); 2) the transportation planning steps and processes *within* these planning products that are impacted by C/AV (hereafter "planning steps"); 3) the expected impacts of C/AV on planning products and planning steps (hereafter "impacts"); and 4) the potential applications of connected and automated vehicle technology relevant to transportation planning ("applications"). This section lists and briefly describes the key elements under each of these four categories.

Transportation Planning Products

The project conducted indepth case studies on 11 transportation planning products, which are listed and briefly described below. For each planning product, the expected impacts of C/AV technology were outlined and discussed in terms of which processes/steps in the planning product would likely see the impacts become manifest. The complete case study analysis is documented in the project's report entitled *Technical Memorandum #5: Case Studies*. As noted below, the case study analysis for some planning products also applies to other related planning products. For example, the analysis of Long-Range Metropolitan Transportation Plans also is relevant to State Long-Range Transportation Plans. In such cases, information on these planning products in any of the reference tables in section 4.0 also is applicable to the related planning products.

Transportation Improvement Program (Metropolitan Planning Organization)

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

The TIP case study also is applicable to the **State Transportation Improvement Program (STIP)**, which is the State short-range program for the State Long-Range Transportation Plan and is required to include all TIP projects.

Intelligent Transportation System Architecture and Operations Plan (State)

The United States Department of Transportation (U.S. DOT) requires that States and regions deploying intelligent transportation systems (ITS) projects funded from the Highway Trust Fund

develop a Statewide/regional ITS architecture and operations plan based on the National ITS Architecture.

The project's case study focuses specifically on Statewide ITS Architecture and Operations Plans, but the analysis also is applicable to **regional ITS Architecture and Operations Plans**.

Bicycle and Pedestrian Planning (Metropolitan Planning Organization)

Federal legislation requires MPOs to include bicycle and pedestrian elements in the Metropolitan Transportation Plan and the TIP, such as: policy statements and goals related to bicycle and pedestrian transport; bicycle/pedestrian projects and programs; and financial resources.

The project's case study focuses specially on MPO bicycle and pedestrian planning, but the analysis also is applicable to **State bicycle and pedestrian planning**.

Long-Range Metropolitan Transportation Plan (Metropolitan Planning Organization)

MPOs develop Long-Range Metropolitan Transportation Plans (MTP) to 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.

MTPs also are sometimes referred to as Regional Transportation Plans (RTP) or Regional Long-Range Transportation Plans. The MTP case study also is applicable to the **State Long-Range Transportation Plan**.

Transportation Asset Management Plan (State)

Transportation Asset Management Plans (TAMP) inventory transportation system assets, conditions, and strategies to maintain/improve assets and system performance. Each State Department of Transportation (DOT) is required to developed a TAMP for the National Highway System (NHS). 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.

Strategic Highway Safety Plan (State)

As part of the Federal Highway Safety Improvement Program (HSIP), State DOTs are required to develop, implement, evaluate, and update a Strategic Highway Safety Plan (SHSP). An SHSP identifies the State's greatest safety needs, and guides investment decisions regarding strategies with the greatest potential to save lives and prevent injuries. In general, C/AV will impact SHSPs by introducing new cost effective data that can supplement the crash, traffic, and vehicle data used in the SHSP. Certain types of crashes also are 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.

State Implementation Plan (State)

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). A 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.

Transit Development Plan

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

Public Involvement Plan (State and Metropolitan Planning Organization)

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

The PIP case study covers both the State and MPO scope.

Freight Plan (State)

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 also are 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.

Financial Plan (Metropolitan Planning Organization)

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 an MPO's MTP and 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. 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 financial plan case study focuses on financial plans as they relate to the MTPs of MPOs, however, the discussion also is relevant to **other planning products (MPO and Statewide) that include a financial plan**.

Additional Transportation Planning Products

The process of selecting planning products for case studies intentionally chose a set of planning products that represent the broad spectrum of planning products developed by States, MPOs, and local agencies and illustrate the variety of potential impacts that C/AV technologies are expected to have on the transportation planning process and related activities. It is worth noting, however, the planning products that were considered but ultimately not selected for case studies. These planning products are listed below, although not explicitly covered in the desk reference tables in section 4.0. The case studies most relevant to the products below are listed in parentheses:

- MPO Long-Range Visioning Plan (Long-Range Transportation Plan).
- MPO Five-Year Plan (TIP, Financial Plan).
- MPO Congestion Management Plan (CMP) (TIP, ITS Architecture/Strategic Plan, Bicycle-Pedestrian Plan, Transit Development Plan).
- State DOT Highway Safety Improvement Plan (HSIP) (Strategic Highway Safety Plan).
- MPO Transportation Demand Management Plan (Bicycle-Pedestrian Plan, Transit Development Plan).
- State DOT Corridor Study (Long-Range Transportation Plan, Transit Development Plan).
- Unified Planning Work Plan (TIP).

Transportation Planning Steps and Processes

The case studies of each transportation planning product were organized around three to eight planning steps or processes. For each case study, the project determined that these planning steps were the key steps involved in most planning products of that type. However, depending on the context additional steps may be included—or certain steps may be deemed unnecessary—in each planning product. To facilitate cross-referencing, this desk reference has condensed the steps across all case studies into 12 categories of essential, common planning steps. These categories are listed and briefly described below, along with references to the alternative names given to the steps in the project's case study analysis. Not every planning product-specific step from the case studies is a perfect fit for the overall category, but there is significant overlap in terms of purpose or planning activities. Many of the descriptions across different planning products are similar; for example Goals and Objectives do not vary greatly across the different products. However, in order to provide a completed and consistent reference, all key steps and products are specifically mentioned.

Goals and Objectives

This planning step develops high-level goals, objectives, and vision statements through the engagement of stakeholders and the public. In the project's case studies of transportation planning products, Goals and Objectives fell under the following planning steps:

- **Bike Pedestrian—Vision, Goals, and Performance Measures:** Develop high-level vision statements, measurable goals, and performance measures.
- **MTP—Establish Goals and Objectives:** Engage the public and stakeholders to establish goals and objectives.
- **TAMP—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.
- **SHSP—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.
- **SHSP—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.
- **TDP—Goals, Objectives, and Standards:** Establish and describe goals, objectives, and performance standards.
- **PIP—Set Goals and Objectives:** Set goals and objectives derived from the specific circumstances of a given transportation plan, program, or project.
- **Freight—Goals and Performance Measures:** Develop strategic goals and measures of condition and performance. Assess the condition and performance of the freight transportation system.

Current Conditions

This planning step inventories and collects baseline information on the current transportation system. In the project's case studies of transportation planning products, Current Conditions fell under the following planning steps:

- **ITS Architecture Plan—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.
- **Bicycle and Pedestrian Planning—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.
- **MTP—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.
- **TAMP—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.

- **SHSP—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.
- **TDP—Overview of Transit System:** Provide a brief overview of the transit system, ITS program, and public outreach.
- **Freight Plan—Baseline Freight System:** Create an inventory of freight transportation assets. Identify significant freight system trends, needs, and issues.
- **Financial Plan—Funding Streams:** Indicate and describe funding streams from public and private sources at the Federal, State, and local levels.

Assessment of Needs

This planning step builds upon the Current Conditions step. It compares available data on the current system to projections and regional goals in order to identify key needs in the transportation system. In the project's case studies of transportation planning products, Assessment of Needs fell under the following planning steps:

- **ITS Architecture Plan—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.
- **TAMP—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.
- **SHSP—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.
- **TDP—Service and System Evaluation:** Evaluate route-level and systemwide performance against current performance standards for each mode and/or type of service.
- **Freight Plan—Baseline Freight System:** Create an inventory of freight transportation assets. Identify significant freight system trends, needs, and issues.

Development of Performance Measures

This planning step determines the performance measures and targets used to track progress towards the transportation plan's objectives and goals. In the project's case studies of transportation planning products, Development of Performance Measures fell under the following planning steps:

- **MTP—Develop the Performance Measures and Targets:** Determine the performance measures (PM) and targets used to track progress toward objectives.
- **TAMP—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.
- **SHSP—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.

- **Freight Plan—Goals and Performance Measures:** Develop strategic goals and measures of condition and performance. Assess the condition and performance of the freight transportation system.

Stakeholder Relationships and Agreements

This planning step identifies all stakeholders related to the transportation plan's objectives, goals, processes, and potential impacts. It outlines stakeholder outreach, engagement, and education as well as details any necessary relationships or agreements that will need to be built. In the project's case studies of transportation planning products, Stakeholder Relationships and Agreements fell under the following planning steps:

- **ITS Architecture Plan—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.
- **ITS Architecture Plan—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.
- **SIP—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.
- **PIP—Identify the Public Audience:** Identify and analyze the individuals and groups who are directly and indirectly affected.
- **Freight Plan—Policies, Strategies, and Institutions:** Discuss freight-related funding programs, regional planning activities, and infrastructure owners that will guide the freight improvement strategy.

Alternatives Analysis

This planning step analyzes and compares the alternatives available to move the transportation system towards the transportation plan's objectives and goals. It typically employs life-cycle costs and risk analysis to aid its comparison. In the project's case studies of transportation planning products, Alternatives Analysis fell under the following planning steps:

- **MTP—Analyze Alternatives:** Identify system needs and analyze the alternatives that will move the system toward established targets.
- **TAMP—Alternative Investment Plans:** Use life-cycle cost and risk assessment analysis to develop alternative investment plans; define both programmatic and system risks.
- **Freight Plan—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.

Development of Strategies

This planning step identify strategies that will help the transportation system move towards the stated objectives and goals in the transportation plan. These strategies can include project evaluation metrics, policies, educational efforts, etc. In the project's case studies of transportation planning products, Development of Strategies fell under the following planning steps:

- **TIP—Project Selection Criteria:** Develop a set of evaluation metrics, such as "scoring techniques" or other quantitative approaches to rank projects.
- **Bicycle and Pedestrian Planning—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.
- **TAMP—Investment Strategy:** Compare investment plans and develop a fiscally constrained investment strategy.
- **SHSP—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.
- **PIP—Develop General Strategies:** Develop strategies to meet established goals and objectives and to involve the targeted audience(s).
- **Freight Plan—Improvements Strategy:** Analyze and prioritize improvements, including analysis of how each improvement will advance the strategic goals.
- **Financial Plan—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.

Programming of Capital Projects, Operations, Policies, Initiatives, etc.

This planning step develops a program of specific capital projects, operations programs, policies, services, techniques, initiatives, etc. that constitute the activities that the transportation plan intends to implement. In the project's case studies of transportation planning products, Programming of Capital Projects, Operations, Policies, Initiatives, etc. fell under the following planning steps:

- **TIP—Project List:** Prioritize a list of projects and strategies to be programmed over the next four years.
- **MTP—Perform Transportation Planning and Programming:** Assess funding sources, prioritize alternatives, and select the most cost effective solutions.
- **SHSP—Action Plans:** Identify specific action steps for each countermeasure, assign responsibility to stakeholder(s), and document time lines.
- **SIP— Ambient Monitoring Program:** Establish and describe the system and methods to monitor data on ambient air quality.
- **TDP—Service Expansion Project Descriptions:** Summarize each proposed service expansion project, including estimates of ridership, cost, and funding
- **TDP—Operations Plan:** Describe the fixed route and demand response services the operator intends to provide over the plan period.
- **TDP—Capital Improvement Program:** Describe the capital programs required to carry out the operations and services set out in the operating plan.

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

Implementation Plan

This planning step documents the intended approach to implementing the transportation plan's program of projects and activities. In the project's case studies of transportation planning products, Implementation Plan fell under the following planning steps:

- **ITS Architecture Plan—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.
- **Bicycle and Pedestrian Planning—Inclusion in the MTP and TIP:** Incorporate the identified strategies into the MTP and TIP, following the timeframe and update cycle.
- **MTP—Implement and Monitor:** Implement the transportation plan and monitor the performance measures.
- **SHSP—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.
- **Freight Plan—Implementation Plan:** Develop short-term and medium- to long-term strategies and a timeline for proposed freight improvements, taking into account funding considerations.

Financial Plan

This planning step can consist of a variety of financial information depending on the context, including assessments of funding sources, funding priorities, and forecasts of funding levels and/or budgets. In the project's case studies of transportation planning products, Financial Plan fell under the following planning steps:

- **TIP—Financial Plan:** Determine the funding sources and match to projects and strategies.
- **MTP—Develop a Financial Plan and Investment Priorities:** Assess funding sources, prioritize alternatives, and select the most cost effective solutions.
- **TAMP—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.
- **TDP—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.

Maintenance Plan

This planning step provides guidelines on how the transportation plan's program will be updated and maintained over time. In the project's case studies of transportation planning products, Maintenance Plan fell under the following planning steps:

- **ITS Architecture Plan—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.

Monitoring and Evaluation

This planning step details the transportation plan's approach to monitoring and evaluating progress towards its goals and objectives, typically through the plan's performance measures and targets. In the project's case studies of transportation planning products, Monitoring and Evaluation fell under the following planning steps:

- **TIP—Monitoring and Evaluation:** Monitor funded projects and strategies and evaluate their effectiveness in supporting performance targets established in the long-range transportation plan.
- **Bicycle and Pedestrian Planning—Evaluation of Progress:** Monitor progress toward identified vision and goals and update strategies accordingly.
- **MTP—Implement and Monitor:** Implement the transportation plan and monitor the performance measures.
- **SHSP—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.
- **TDP—Monitoring and Evaluation:** Describe the process to monitor and evaluate progress towards implementation of plan.
- **PIP—Monitor and Evaluate:** Assess the impact of the selected strategies and techniques on public involvement, and update as needed.

Expected Impacts of Connected-Automated Vehicles

An important part of the project's foundational work was to develop an impact typology for how the impacts of C/AV can be considered across a range of transportation planning processes and environments (this complete analysis is documented in the associated project report entitled *Memorandum #2: Connected Vehicle Planning Processes and Products and Stakeholder Roles and Responsibilities*.) This work revealed that there are six primary categories for the impacts of C/AV on transportation planning:

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

The case study analysis then mapped out which impacts applied to each transportation planning products and—more specifically—to each planning step within the given planning product. To better facilitate cross-reference between the impacts and the studied planning products and planning steps, this section lists and briefly describes the impacts as they apply to the planning steps described in section 3.2.

Goals and Objectives—Impacts

1. C/AV will impact goals and objectives related to a wide range of issues—including mobility, reliability, safety, sustainability, social equity, data privacy, and security. Planners will need to ensure that current goals and objectives adapt to the anticipated impacts of C/AV.
2. C/AV will likely significantly increase safety and reduce crashes and, therefore, reduce the level of resources needed for safety investments in the long term. This would allow agencies to focus more on other goals and objectives.
3. C/AV applications may require the involvement of new stakeholders in the visioning of objectives and goals, such a private C/AV equipment providers.

Current Conditions—Impacts

1. Agencies should document existing assets related to C/AV to create a baseline for measuring the impacts of C/AV deployment.
2. Agencies will need to evaluate how C/AV will impact their current system, ITS program, and outreach program.
3. C/AV will introduce more precise and cost effective data sources and collection methods for obtaining information on current conditions; for example, C/AV probe applications.

Assessment of Needs—Impacts

1. Agencies should clearly define the functional requirements of C/AV and work to gain consensus on the services that these functional requirements provide.
2. Agencies should identify existing infrastructure that will need to be upgraded and/or integrated in order to support C/AV applications.
3. Continuous C/AV data will allow performance gap assessments to be performed more frequently, enabling dynamic adjustment for changing traffic patterns.
4. Agencies should consider potential needs created by C/AV investments, particularly any resources needed to store/analyze increased volumes of C/AV data.
5. Estimates of regional C/AV market penetration will be needed to identify needs in the transportation planning process.
6. Agencies should evaluate the potential impact of C/AV on travel demand, ridership forecasts, etc.

Development of Performance Measures—Impacts

1. C/AV is projected to reduce crash rates over time and, therefore, impact safety performance measures and targets.
2. C/AV technology will likely enable agencies to adopt more ambitious performance measures and targets.
3. Real-time information collected by C/AV will allow agencies to identify poor performing assets sooner and take proactive actions to increase performance.

4. Private fleets will track changes in performance as they deploy C/AV technology; they will want to protect this information for competitive reasons but may be willing to provide "scrubbed" data to agencies.

Stakeholder Relationships and Agreements—Impacts

1. Agency personnel with significant knowledge of C/AV applications will be needed to steer C/AV aspects of transportation planning and to engage stakeholders.
2. Agencies will need to broadly educate an array of internal and external C/AV stakeholders, such as traffic engineers, planners, emergency response personnel, and private companies providing C/AV services.
3. C/AV applications will require the involvement of new stakeholders in transportation planning, such a private C/AV equipment providers.
4. Many C/AV projects will likely be implemented through public-private partnerships; agreements and standards related to information exchange, data-ownership, and right-of-way will need to be established.
5. Agencies should identify the private and public organizations that can pilot C/AV deployment for a variety of purposes, such as reducing emissions.
6. 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.
7. U.S. DOT places great importance on involving groups that traditionally experience barriers in participating (i.e., low-income groups, minorities, persons with disabilities, and non-native English speakers); C/AV presents both opportunities and challenges to these groups.
8. C/AV deployment will likely trigger more intensive public involvement than similar technology advancements have in the past (i.e., ITS) because of the broad range of impacts and issues related to physical infrastructure, daily operations, data privacy, security, etc.

(ITS) State DOTs should clearly define the functional requirements of C/AV and work to gain consensus on the services that these functional requirements provide.

Alternatives Analysis—Impacts

1. C/AV will 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.
2. C/AV will increase the level of uncertainty inherent in the alternatives analysis in the foreseeable future.
3. 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).
4. Planners will need to track C/AV research so agencies can quickly address issues in alternative analyses such as: will platoons need to be limited to inside lanes to allow other vehicles to safely exit?

Development of Strategies—Impacts

1. Strategic project selection criteria will need to be able to identify C/AV technologies that can 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.
2. C/AV impacts that shift the needs and requirements of the transportation system (e.g., reducing required widths of vehicle travel lanes, parking requirements, and crashes) will create opportunities to strategically redirect resources.
3. Region-specific prototype installations are recommended for assessing the opportunities and challenges of C/AV adoption and developing C/AV planning and deployment strategies.
4. 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. Agencies will need to develop public involvement strategies related to C/AV, such as pursuing C/AV pilots could provide an effective opportunity to educate the public on C/AV technology.
6. Private companies will likely have data that can inform C/AV strategies, but may be reluctant to share due to competition concerns. Agencies should work with the private sector to address these concerns in order to access as much information as possible.
7. As 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.

Programming of Projects, Investments, Policies, Initiatives, etc.—Impacts

1. Agencies should look for opportunities to incorporate C/AV projects into capital projects or replacements for ITS investments.
2. Public involvement in selecting early C/AV projects should accommodate the general public's likely limited awareness of C/AV by providing educational components.
3. As C/AV advances, C/AV applications identified in long-range planning should be re-evaluated for any short-term applications bundles ready to be programmed.
4. Programming of C/AV investments should consider replacement cycles for existing ITS investments, as well as whether C/AV can replace current ITS investments.
5. C/AV program plans will need to identify the skills required to implement C/AV strategies, from planning to design to deployment.
6. Flexibility will be needed in development of C/AV action plans since both the technology and estimates of market penetration levels will change; recognition of this by leadership will be key.
7. 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.
8. Many agencies will have a limited number of spare vehicles that can be utilized for C/AV testing; this will need careful planning so existing operations are not disrupted.
9. As C/AV develops, the public will become increasingly connected to the transit system through smart phones as ITS, provide agencies the opportunity to implement a wider range of C/AV applications.

Implementation Plan—Impacts

1. The process of integrating C/AV elements into larger, existing ITS systems can enhance the linkage between operations and planning through involvement of a wider array of stakeholders.
2. To help include C/AV projects in the MTP, TIP, and STIP—State, regional, and local agencies (DOTs, MPOs, transit agencies, etc.) will need to collaborate.
3. C/AV is expected to evolve quickly, as are the impacts of C/AV on the current programs and planned capital investments; these projects should be reevaluated regularly in light of C/AV advancements and market penetration.
4. To motivate future C/AV-related safety investments, it will be critical to evaluate how effectively implemented C/AV investments support performance targets.
5. Public C/AV implementation will consist primary of field infrastructure (e.g., roadside units), agencies should coordinate with private companies to schedule infrastructure deployment with upgrades/purchases, to ensure compatibility of devices, and to put data collection/sharing agreements in place.

Financial Plan—Impacts

1. Financial plans should identify new funding program eligibility for C/AV investments
2. Financial plans should include any early benefit/cost analysis of alternative C/AV investment options and strategies where possible (including the “do-nothing” alternative). There will significant limitations and uncertainty associated with early estimates.

Maintenance Plan—Impacts

1. Agencies should identify the entity that can lead the maintenance effort related to C/AV, and develop a C/AV maintenance plan.

Monitoring and Evaluation—Impacts

1. 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.
2. Early on, published final reports on the monitored impacts of C/AV-enabled data collection will lag behind deployment of the technology. Agencies should share information about their works in progress.
3. Smartphone applications and other new sources of data will provide an opportunity to collect information that monitors C/AV projects and programs, although privacy concerns would need to be addressed.
4. To motivate future C/AV-related safety investments, it will be critical to continuously evaluate how effectively C/AV investments support performance targets.

Applications of Connected and Automated Vehicle Technology

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

As detailed below, the C/AV applications relevant to transportation planning fell within four main categories: safety, mobility, environment, and agency data. The desk reference refers to C/AV applications using the names developed by the U.S. DOT Connected Vehicle Pilot Deployment Program; however, these names are subject to change over time as C/AV technology and research evolves.

Safety

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

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

C/AV applications are expected to offer some of the most promising opportunities for crash reduction. Research conducted by the National Transportation Systems Center for the National Highway Traffic Safety Administration (NHTSA) estimates that V2I and V2V systems can potentially address up to 81 percent of vehicle crashes.[4]

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

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4 "Frequency of Target Crashes for IntelliDrive Safety Systems," National Highway Traffic Safety Administration, DOT HS 811 381, June, 2010.

Mobility

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

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

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

Environment

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

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

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

Agency Data

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

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

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

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

Section 4.0—Reference Tables

The reference tables in this section are intended to help understand and plan for the connections between the four categories of key elements that are essential to understanding the impacts of connected-automated vehicles (C/AV) on transportation planning: 1) the transportation planning products impacted by C/AV (hereafter "planning products"); 2) the transportation planning steps and processes *within* these planning products that are impacted by C/AV (hereafter "planning steps"); 3) the expected impacts of C/AV on planning products and planning steps (hereafter "impacts"); and 4) the potential applications of connected and automated vehicle technology relevant to transportation planning ("applications").

The three reference tables below illustrate these connections and impacts:

- The **Planning Steps versus Planning Products** reference table provides the framework used in this desk reference to map out the impacts of C/AV across a broad range of transportation planning products and processes.
- The **Impacts versus Planning Steps versus Planning Products** reference table maps out the impacts of C/AV across a broad range of transportation planning products and processes by vertically listing the expected impacts of C/AV under the planning steps that each impact will most influence. The table then maps out horizontally the planning products that are expected to be influenced by the given impact.
- The **Planning Products versus Applications** reference table maps out which C/AV applications will be relevant to which planning product to provide planners with examples of how C/AV can be incorporated into each type of planning product.

Planning Steps versus Planning Products

The planning steps versus planning products reference table provides the framework used in this desk reference to map out the impacts of C/AV across a broad range of transportation planning products and processes. The 12 categories of essential, common planning steps detailed in section 3.2 are listed vertically in the table; the planning products analyzed in the project's case studies are listed horizontally. Planning products that typically include a given planning step are marked with a check in the appropriate cell. As previously discussed, depending on the context transportation planning products may include additional steps or deem certain steps unnecessary, but the steps shown were determined to be essential to that transportation planning product.

Table 1. Relevance of common planning steps to the planning product case studies.

Planning Step	Description	Planning Product—Transportation Improvement Program (TIP)	Planning Product—Intelligent Transportation System (ITS) Architecture	Planning Product—Bike Pedestrian	Planning Product—Metropolitan Transportation Plan (MTP)	Planning Product—Transportation Asset Management Plans (TAMP)	Planning Product—Strategic Highway Safety Plan (SHSP)	Planning Product—State Implementation Plan (SIP)	Planning Product—Transit Development Plan (TDP)	Planning Product—Public Involvement Plan (PIP)	Planning Product—Freight	Planning Product—Finance
Goals and Objectives	Develops high-level goals, objectives, and vision statements through the engagement of stakeholders and the public.			✓	✓	✓	✓		✓	✓	✓	
Current Conditions	Inventories and collects baseline information on the current transportation system.		✓	✓	✓	✓	✓		✓		✓	✓
Assessment of Needs	Compares data on the current transportation system to projections/ regional goals to identify key needs.		✓	✓		✓	✓		✓		✓	
Development of Performance Measures	Determines the performance measures and targets needed to track progress towards objectives/goals.				✓	✓	✓				✓	
Stakeholder Relationships and Agreements	Identifies all relevant stakeholders; outlines outreach, engagement, and education; details any relationships or agreements that will need to be built.		✓					✓		✓	✓	
Alternatives Analysis	Analyzes and compares available alternatives to move the transportation system towards objectives and goals.				✓	✓					✓	
Development of Strategies	Identifies strategies to move the transportation system move towards objectives and goals.	✓		✓		✓	✓				✓	
Programming of Capital Projects, Operations, Policies, Initiatives, etc.	Develops a program of specific capital projects, operations programs, policies, services, techniques, initiatives, etc. that the transportation plan intends to implement.	✓			✓		✓	✓	✓			

Table 1. Relevance of common planning steps to the planning product case studies (Continuation).

Planning Step	Description	Planning Product—Transportation Improvement Program (TIP)	Planning Product—Intelligent Transportation System (ITS) Architecture	Planning Product—Bike Pedestrian	Planning Product—Metropolitan Transportation Plan (MTP)	Planning Product—Transportation Asset Management Plans (TAMP)	Planning Product—Strategic Highway Safety Plan (SHSP)	Planning Product—State Implementation Plan (SIP)	Planning Product—Transit Development Plan (TDP)	Planning Product—Public Involvement Plan (PIP)	Planning Product—Freight	Planning Product—Finance
Implementation Plan	Documents the approach to implementing the transportation plan's program of projects and activities		✓	✓	✓		✓				✓	
Financial Plan	Documents financial information—including funding sources, funding priorities, and forecasts of funding levels and/or budgets.	✓			✓	✓			✓			✓
Maintenance Plan	Provides guidelines on how the transportation plan's program will be updated and maintained over time.		✓									
Monitoring and Evaluation	Details the approach to monitoring and evaluating progress towards goals and objectives, typically through performance measures and targets.	✓		✓	✓		✓		✓			

Source: Cambridge Systematics, Inc.

Impacts versus Planning Steps versus Planning Products

A series of potential C/AV impacts were identified in *Technical* and *Memorandum #2: Connected Vehicle Planning Processes and Products and Stakeholder Roles and Responsibilities*[5] of this project. Impacts included general societal impacts, impacts on the transportation system and impacts relevant to specific planning activities. These impacts were further defined in *Technical Memorandum #5: Case Studies,*[6] which featured 11 case studies of specific planning products. Each case study walks through a set of planning steps normally used to develop the specific product. In the reference table lists the C/AV impacts anticipated under each planning step. While each product may have slightly different steps, these have been combined into 12 of the more common steps used in the planning process. Impacts generally apply to multiple planning products and these relationships are shown in the table below using a "high," "medium," or "low" designation to indicate relevance. A "high" designation indicates that the impact is very significant to the planning product/activity and should be considered in the next cycle of product development. The "**high**" designations shown in bold point the reader to the case studies which have the most extensive discussion of the impact and in many cases, provide specific actions for agencies to take in addressing the impact. For example, a number of the safety-related impacts are covered in Case Study #6, Strategic Highway Safety Plan, but also impact other products such as the TIP, the Bicycle-Pedestrian plan and the ITS Architecture and Strategic Plan. A "medium" designation indicates that the impact might be relevant but is less urgent and/or more peripheral for the specific product. Those applications with limited or no relevance to the specific plans are classified as "low." These impacts and their relevance to specific products will become clearer as technology progresses and new plans and projects are developed. It also should be noted that new products and processes are likely to emerge as a result of the technology. Thus, tracking of peer agency activities and Federal/State guidelines related to C/AV in planning is important. Table 3 summarizes the results of table 2 by identifying the planning products that are most associated with each impact (those in which the "high" designation is bolded in table 2) and providing a brief description of the key issue that links that impact and the product(s).

[5] Technical Memorandum #1 was an interim document that was incorporated into Technical Memorandum #2.
[6] Technical Memorandum #4 was an interim document that was incorporated into Technical Memorandum #5.

Table 2. Relevance of the expected impacts of connected-automated vehicles (C/AV) to the planning product case studies.

Impacts	Transportation Improvement Programs	Intelligent Transportation System Architecture	Bike Pedestrian	Metropolitan Transportation Plan	Transportation Asset Management Plans	Strategic Highway Safety Plan	State Implementation Plan	Transit Development Plan	Public Involvement Plan	Freight	Finance
Goals and Objectives—C/AV will impact a wide range of goals and objectives.	High	Medium	High	High	Medium	High	High	High	Medium	High	Medium
Goals and Objectives—C/AV will likely improve safety allowing agencies to redirect resources to other goals and objectives.	Medium	Medium	High	**High**	Medium	**High**	Low	Low	Medium	High	High
Goals and Objectives—C/AV may require the involvement of new stakeholders in the visioning of objectives and goals (e.g., private C/AV equipment providers).	High	High	High	High	Low	High	Low	High	**High**	High	Low
Current Conditions—Agencies should document existing assets related to C/AV to create a baseline for measuring the impacts of C/AV deployment.	Medium	High	Low	High	**High**	High	High	High	Medium	High	Medium
Current Conditions—Agencies will need to evaluate how C/AV will impact their current system, ITS program, and outreach program.	Medium	**High**	Medium	High	High	High	Medium	High	**High**	High	Medium
Current Conditions—C/AV will introduce more precise/cost effective sources and methods for collecting information on current conditions (e.g., probe applications).	High	**High**	Medium	High	**High**	High	High	Medium	Low	High	Medium
Assessment of Needs—Agencies should clearly define C/AV functional requirements and services provided.	Low	**High**	Medium	High	High	High	Medium	High	Low	Medium	Medium
Assessment of Needs—Agencies should identify existing infrastructure that will need to be upgraded and/or integrated in order to support C/AV applications.	**High**	**High**	Medium	Low	High	High	Low	High	Low	High	Medium
Assessment of Needs—Continuous C/AV data will allow performance gap assessments to be performed more frequently, enabling dynamic adjustment for changing traffic patterns.	Low	**High**	Medium	Medium	Low	Medium	High	Medium	Medium	Medium	Low
Assessment of Needs—Agencies should consider potential needs for resources to store/analyze increased volumes of data.	Medium	**High**	Medium	High	**High**	High	High	Medium	Low	Medium	High
Assessment of Needs—Estimates of regional C/AV market penetration will be needed to identify needs in the transportation planning process.	Medium	High	Medium	**High**	High	High	Medium	Medium	Medium	High	Medium
Assessment of Needs—Agencies should evaluate the potential impact of C/AV on travel demand, ridership forecasts, etc.	High	Medium	Medium	**High**	Low	Low	Medium	High	Medium	High	Medium
Development of Performance Measures—C/AV is projected to reduce crash rates over time and, therefore, impact safety performance measures and targets.	High	Medium	High	**High**	Low	**High**	Low	Low	Medium	High	High
Development of Performance Measures—C/AV technology will likely enable agencies to adopt more ambitious performance measures and targets for mobility, environmental and economic measures.	**High**	High	High	High	Medium	High	High	High	Medium	High	Medium
Development of Performance Measures—Real-time information collected by C/AV will allow agencies to identify poor performing assets sooner and take proactive actions to increase performance.	Medium	Medium	Low	Medium	**High**	Medium	Low	High	Low	Medium	High

Table 2. Relevance of the expected impacts of connected-automated vehicles (C/AV) to the planning product case studies (Continuation).

Impacts	Transportation Improvement Programs	Intelligent Transportation System Architecture	Bike Pedestrian	Metropolitan Transportation Plan	Transportation Asset Management Plans	Strategic Highway Safety Plan	State Implementation Plan	Transit Development Plan	Public Involvement Plan	Freight	Finance
Development of Performance Measures—Private fleets will track changes in performance as they deploy C/AV technology; they will want to protect this information for competitive reasons but may be willing to provide "scrubbed" data to agencies.	Medium	**High**	Low	High	**High**	High	Medium	High	Low	**High**	High
Stakeholder Relationships and Agreements—Agency personnel with significant knowledge of C/AV applications will be needed to steer C/AV aspects of transportation planning and to engage stakeholders.	High	High	Medium	High	Medium	Medium	Medium	Medium	**High**	High	Low
Stakeholder Relationships and Agreements—Agencies will need to broadly educate an array of internal and external C/AV stakeholders, such as traffic engineers, planners, emergency response personnel, and private companies providing C/AV services.	High	**High**	Medium	**High**	High	High	Medium	Medium	Medium	High	Medium
Stakeholder Relationships and Agreements—C/AV applications will require the involvement of new stakeholders in transportation planning, such a private C/AV equipment providers.	Medium	**High**	Low	Medium	High	Medium	Low	High	**High**	High	Medium
Stakeholder Relationships and Agreements—Many C/AV projects will likely be implemented through public-private partnerships; agreements and standards related to information exchange, data-ownership, and right-of-way will need to be established.	**High**	High	Low	High	High	High	Medium	Medium	Medium	High	High
Stakeholder Relationships and Agreements—Agencies should identify the private and public organizations that can pilot C/AV deployment for a variety of purposes, such as reducing emissions.	High	High	Medium	High	Medium	Medium	**High**	High	Low	High	Medium
Stakeholder Relationships and Agreements—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.	**High**	High	High	High	Medium	High	Medium	Medium	High	High	Medium
Stakeholder Relationships and Agreements—U.S. Department of Transportation (DOT) places great importance on involving groups that traditionally experience barriers in participating (i.e., low-income groups, minorities, persons with disabilities, and non-native English speakers); C/AV presents both opportunities and challenges to these groups.	**High**	Medium	High	High	Low	High	Low	High	**High**	Low	Medium
Stakeholder Relationships and Agreements—C/AV deployment will likely trigger more intensive public involvement than similar technology advancements have in the past (i.e., ITS) because of the broad range of impacts and issues related to physical infrastructure, daily operations, data privacy, security, etc.	High	High	Medium	High	Low	Medium	Low	Medium	**High**	High	Medium
Alternatives Analysis—Collect and apply new sources of data, such as travel times and pavement conditions, in the alternatives analysis.	Medium	High	Medium	**High**	High	Medium	Low	Medium	Low	Medium	High
Alternatives Analysis—Increase the level of future uncertainty inherent in the alternatives analysis requiring more sophisticated scenario analysis.	Low	Medium	Low	**High**	Medium	Medium	Low	High	High	High	High

Table 2. Relevance of the expected impacts of connected-automated vehicles (C/AV) to the planning product case studies (Continuation).

Impacts	Transportation Improvement Programs	Intelligent Transportation System Architecture	Bike Pedestrian	Metropolitan Transportation Plan	Transportation Asset Management Plans	Strategic Highway Safety Plan	State Implementation Plan	Transit Development Plan	Public Involvement Plan	Freight	Finance
Alternatives Analysis—New tools and personnel needed to process and analyze large amounts of C/AV data	Medium	High	Low	High	**High**	High	Medium	Medium	Low	Medium	Medium
Alternatives Analysis—Need to track C/AV research related to operations such as truck platooning impacts.	Low	Medium	Low	High	Low	High	High	Medium	Medium	**High**	Medium
Development of Strategies—Need project selection criteria that can accommodate C/AV projects and investments	**High**	High	Medium	High	Medium	High	Low	High	High	High	Medium
Development of Strategies—Evaluate opportunities created by C/AV impacts to shift the needs and requirements of the transportation system such reduce vehicle travel lane widths.	Low	Medium	**High**	High	Medium	High	Low	High	High	High	High
Development of Strategies—Region-specific prototype installations are recommended for C/AV investments and developing C/AV planning and deployment strategies.	**High**	High	Medium	Medium	**High**	High	Medium	Medium	Low	High	Medium
Development of Strategies—Foster realistic expectations for short-term impacts of C/AV applications, as initial applications will be modest in terms of scope, geography, and capabilities.	High	High	Medium	Low	Medium	**High**	Low	Medium	High	Medium	Low
Development of Strategies—Need public involvement strategies related to C/AV, such as pursuing C/AV pilots could be used to educate the public on C/AV technology.	High	High	Medium	Low	Medium	High	Medium	Medium	**High**	Medium	Low
Development of Strategies—Need to work with the private sector to address data ownership issues in order to access as much information as possible.	High	High	Medium	Medium	**High**	High	Medium	Low	Low	**High**	Medium
Development of Strategies—Tools needed to rank C/AV projects using traditional metrics such as benefit-cost ratio, which will depend on factors such as market penetration, industry competition, and regional coordination.	Medium	Low	Medium	**High**	Medium	High	Medium	High	Medium	**High**	High
Programming of Projects, Investments, Policies, Initiatives, etc.—There will be opportunities to incorporate C/AV projects into capital projects or replacements for ITS investments.	**High**	High	Medium	Medium	High	High	Low	Medium	Low	Medium	Medium
Programming of Projects, Investments, Policies, Initiatives, etc.—Public involvement in selecting early C/AV projects should include educational components given limited public awareness.	**High**	Medium	Medium	Low	Low	High	Low	Medium	**High**	Low	Low
Programming of Projects, Investments, Policies, Initiatives, etc.—As C/AV advances, C/AV applications identified in long-range planning should be re-evaluated for any short-term applications bundles ready to be programmed.	**High**	High	Medium	Low	High	High	Medium	Medium	Low	Medium	Low

Table 2. Relevance of the expected impacts of connected-automated vehicles (C/AV) to the planning product case studies (Continuation).

Impacts	Transportation Improvement Programs	Intelligent Transportation System Architecture	Bike Pedestrian	Metropolitan Transportation Plan	Transportation Asset Management Plans	Strategic Highway Safety Plan	State Implementation Plan	Transit Development Plan	Public Involvement Plan	Freight	Finance
Programming of Projects, Investments, Policies, Initiatives, etc.— Programming of C/AV investments should consider whether C/AV can replace current ITS investments as these investments reach the end of life cycle.	High	**High**	Low	Low	High	High	Low	High	Low	Medium	Medium
Programming of Projects, Investments, Policies, Initiatives, etc.— C/AV program plans will need to identify the skills required to implement C/AV strategies, from planning to design to deployment.	Low	High	Medium	**High**	Medium	Medium	Low	Medium	Low	Medium	Medium
Programming of Projects, Investments, Policies, Initiatives, etc.— Flexibility will be needed in development of C/AV action plans since both the technology and estimates of market penetration levels will change.	Medium	High	Medium	**High**	High	**High**	Medium	Medium	Low	High	Medium
Programming of Projects, Investments, Policies, Initiatives, etc.— Region-specific prototype installations can be used to evaluate C/AV adoption, develop agency internal professional capacity.	High	High	Medium	Medium	High	High	Medium	Medium	Low	High	Medium
Programming of Projects, Investments, Policies, Initiatives, etc.— Planning will be needed to make spare vehicles available for C/AV testing; without disrupting operations.	Low	Medium	Low	Low	Medium	Medium	Low	**High**	Low	Low	Medium
Programming of Projects, Investments, Policies, Initiatives, etc.— Leverage opportunities provided by smart phones and other technologies to implement a wider range of C/AV applications.	High	High	**High**	Low	High	High	Medium	**High**	High	High	Low
Implementation Plan—C/AV can be used to enhance the linkage between operations and planning through involvement of a wider array of stakeholders.	Medium	**High**	Medium	Medium	Low	Medium	Low	Low	**High**	Medium	Low
Implementation Plan—State, regional, and local agencies (DOTs, Metropolitan Planning Organizations (MPO), transit agencies, etc.) will need to collaborate in order to include C/AV projects in transportation plans.	**High**	High	High	Medium	Low	High	Medium	Medium	Medium	Medium	Low
Implementation Plan—C/AV projects should be reevaluated regularly in light of C/AV advancements and market penetration.	High	High	Medium	**High**	High	High	Medium	High	Medium	High	Medium
Implementation Plan—To motivate future C/AV-related safety investments, it will be critical to evaluate how effectively implemented C/AV investments support performance targets.	Medium	High	Medium	High	Medium	**High**	Medium	Medium	Low	High	Medium
Implementation Plan— (Freight) Agencies should coordinate with private companies to schedule infrastructure deployment with upgrades/purchases, to ensure compatibility of devices, and implement data collection/sharing agreements.	Medium	High	Medium	Medium	High	Medium	Low	High	Low	**High**	High
Financial Plan—Financial plans should identify new funding program eligibility for C/AV investments.	**High**	High	Medium	Medium	Medium	High	Medium	High	Low	Medium	**High**

Table 2. Relevance of the expected impacts of connected-automated vehicles (C/AV) to the planning product case studies (Continuation).

Impacts	Transportation Improvement Programs	Intelligent Transportation System Architecture	Bike Pedestrian	Metropolitan Transportation Plan	Transportation Asset Management Plans	Strategic Highway Safety Plan	State Implementation Plan	Transit Development Plan	Public Involvement Plan	Freight	Finance
Financial Plan—Financial plans should include any early benefit/cost analysis of alternative C/AV investment options and strategies where possible.	**High**	High	Low	High	Medium	High	Low	High	Medium	High	**High**
Maintenance Plan—(ITS) Agencies should identify the lead entity for C/AV maintenance, and develop a C/AV maintenance plan.	High	**High**	Low	Medium	High	Medium	Low	High	Low	Low	High
Monitoring and Evaluation—Agencies should be prepared to assess these C/AV-based data collection opportunities as well as track the system benefits and costs	**High**	High	Medium	High	High	High	Medium	High	Medium	High	**High**
Monitoring and Evaluation—Agencies should share information about their works in progress since evaluation reports will lag technology developments.	**High**	**High**	Medium	High	High	High	High	High	Low	High	Medium
Monitoring and Evaluation—New sources of data will provide an opportunity to collect information that monitors C/AV projects and programs, although privacy concerns need to be addressed.	High	**High**	**High**	High	High	High	High	Low	High	High	Medium
Monitoring and Evaluation—It will be critical to continuously evaluate how effectively C/AV investments support performance targets.	High	High	Medium	**High**	Medium	**High**	Medium	High	Medium	High	High

Source: Cambridge Systematics, Inc.

Table 3. Planning product case studies most relevant to connected-automated vehicle (C/AV) impacts.

Impacts	Case Studies	Key Points
C/AV will impact a wide range of goals and objectives.	ALL	
C/AV will likely improve safety, allowing agencies to redirect resources to other goals and objectives.	MTP, TAMP	This is a likely long-range impact on investment decisions, with life cycles of existing equipment an important consideration.
C/AV may require the involvement of new stakeholders in the visioning of objectives and goals (e.g., private C/AV equipment providers).	PIP	New stakeholders, mainly from the private sector, will be providing some services related to C/AV. Security and data science are examples.
Agencies should document existing assets related to C/AV to create a baseline for measuring the impacts of C/AV deployment.	TAMP	A good asset management program is key to measuring C/AV benefits.
Agencies will need to evaluate how C/AV will impact their current system, ITS program, and outreach program.	ITS, PIP	C/AV technology may replace much of the ITS infrastructure. Communicating these changes to the public and decisionmakers will be important.
C/AV will introduce more precise/cost effective sources and methods for collecting information on current conditions (e.g., probe applications).	ITS, TAMP	Probe data obtained from vehicles will be useful for both traffic operations and asset management.
Agencies should clearly define C/AV functional requirements and services provided.	ITS	C/AV requirements need to be incorporated into ITS architecture and plans.
Agencies should identify existing infrastructure that will need to be upgraded and/or integrated in order to support C/AV applications.	TIP, ITS	C/AV-related investments may be developed through ITS architecture and plans but must be funded through the TIP.
Continuous C/AV data will allow performance gap assessments to be performed more frequently, enabling dynamic adjustment for changing traffic patterns.	ITS	Opportunities to improve operational performance will be developed in ITS plans.
Agencies should consider potential needs for resources to store/analyze increased volumes of data.	ITS, TAMP	Assets needed to collect, store and analyze data will be developed through the ITS plans and the TAMP.
Estimates of regional C/AV market penetration will be needed to identify needs in the transportation planning process.	MTP	Long-term planning needs to consider market penetration rates for C/AV technology, particularly automated vehicles.
Agencies should evaluate the potential impact of C/AV on travel demand, ridership forecasts, etc.	MTP	Impacts of C/AV on travel demand will be a key element in long-range planning.
C/AV is projected to reduce crash rates over time and, therefore, impact safety performance measures and targets.	MTP, SHSP	Safety-related targets will change and impact investments in both the SHSP and MTP.
C/AV technology will likely enable agencies to adopt more ambitious performance measures and targets for mobility, environmental and economic measures.	TIP	Changes in performance targets will impact the TIP in the short term.
Real-time information collected by C/AV will allow agencies to identify poor performing assets sooner and take proactive actions to increase performance.	TAMP	C/AV can greatly improve the quality of asset management data.
Private fleets will track changes in performance as they deploy C/AV technology; they will want to protect this information for competitive reasons but may be willing to provide “scrubbed” data to agencies.	ITS, TAMP, Freight	Data from private fleets will be useful for several planning products but will require partnerships to overcome privacy and ownership issues.
Agency personnel with significant knowledge of C/AV applications will be needed to steer C/AV aspects of transportation planning and to engage stakeholders.	PIP	Staff knowledge of C/AV technology will be important in keeping the public informed.
Agencies will need to broadly educate an array of internal and external C/AV stakeholders, such as traffic engineers, planners, emergency response personnel, and private companies providing C/AV services.	ITS, MTP	Educational activities will be key to many products but especially important in ITS and long-range planning.
C/AV applications will require the involvement of new stakeholders in transportation planning, such a private C/AV equipment providers.	ITS, PIP	New stakeholders with interest in C/AV are likely to be identified first through ITS plans but will impact overall public involvement activities as well.

Table 3. Planning product case studies most relevant to connected-automated vehicle (C/AV) impacts (Continuation).

Impacts	Case Studies	Key Points
Many C/AV projects will likely be implemented through public-private partnerships; agreements and standards related to information exchange, data-ownership, and right-of-way will need to be established.	TIP	Costs to obtain data will be identified initially in TIPs.
Agencies should identify the private and public organizations that can pilot C/AV deployment for a variety of purposes, such as reducing emissions.	SIP	Through the SIP process planning agencies will work with environmental agencies and other interested parties to identify the impact of C/AV on emissions reduction.
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.	TIP	C/AV pilots should be incorporated into the TIP; the process will be critical when initial funding is exhausted.
U.S. DOT places great importance on involving groups that traditionally experience barriers in participating (i.e., low-income groups, minorities, persons with disabilities, and non-native English speakers); C/AV presents both opportunities and challenges to these groups.	TIP, PIP	Equity impacts of C/AV on mobility and economic opportunity need to be addressed in the PIP and mitigation activities in the TIP.
C/AV deployment will likely trigger more intensive public involvement than similar technology advancements have in the past (i.e., ITS) because of the broad range of impacts and issues related to physical infrastructure, daily operations, data privacy, security, etc.	PIP	C/AV, especially automation, will change the way agencies address public concerns and will involve new stakeholders. For example, security of automated vehicles will need to be addressed in public forums.
Collect and apply new sources of data, such as travel times and pavement conditions, in the alternatives analysis.	MTP	C/AV data has the potential to help set long-term investment priorities.
Increase the level of future uncertainty inherent in the alternatives analysis requiring more sophisticated scenario analysis.	MTP	Multiple scenarios related to the transportation system impacts of C/AV, as well as land use and economic impacts will need to be analyzed for long-range plans. New techniques will be needed.
New tools and personnel needed to process and analyze large amounts of C/AV data	TAMP	Large amounts of data generated will require new tools and techniques.
Need to track C/AV research related to operations such as truck platooning impacts.	Freight	The freight industry is likely to be an early adopter of C/AV technology. Valuable information can be gained by tracking their experience.
Need project selection criteria that can accommodate C/AV projects and investments	TIP	
Evaluate opportunities created by C/AV impacts to shift the needs and requirements of the transportation system such reduce vehicle travel lane widths.	Bike Pedestrian	In the long-term automated vehicles may require less roadway space, providing opportunities to implement new bicycle, pedestrian or transit facilities.
Region-specific prototype installations are recommended for C/AV investments and developing C/AV planning and deployment strategies.	TIP, TAMP	Asset management and operational benefits may be gained in the short term through C/AV investments.
Foster realistic expectations for short-term impacts of C/AV applications, as initial applications will be modest in terms of scope, geography, and capabilities.	TIP, SHSP	Goals and objectives of early deployments must be clearly defined and communicated, especially with regard to safety impacts.
Need public involvement strategies related to C/AV, such as pursuing C/AV pilots could be used to educate the public on C/AV technology.	PIP	Pilot projects provide a good opportunity to educate the public on C/AV.
Need to work with the private sector to address data ownership issues in order to access as much information as possible.	TAMP, Freight	Much of data may be owned by private sector, including freight industry. Agencies will need to identify partnership opportunities early on.
Tools needed to rank C/AV projects using traditional metrics such as benefit-cost ratio, which will depend on factors such as market penetration, industry competition, and regional coordination.	MTP, Freight	Tools being developed by the Federal Highway Administration (FHWA) need to be adopted by agencies. Some may develop their own. Benefits/cost tools are key.
There will be opportunities to incorporate C/AV projects into capital projects or replacements for ITS investments.	TIP	C/AV technology may be able to replace some ITS investments.
Public involvement in selecting early C/AV projects should include educational components given limited public awareness.	TIP, PIP	Pilot projects provide a good opportunity to educate the public on C/AV.
As C/AV advances, C/AV applications identified in long-range planning should be re-evaluated for any short-term applications bundles ready to be programmed.	TIP	An incremental approach to deployment will allow impacts to be identified and adjustments to be made going forward.

Table 3. Planning product case studies most relevant to connected-automated vehicle (C/AV) impacts (Continuation).

Impacts	Case Studies	Key Points
Programming of C/AV investments should consider whether C/AV can replace current ITS investments as these investments reach the end of life cycle.	ITS	C/AV technology may be able to replace some ITS investments as they reach the end of their life cycle. ITS plans are a good place to conduct this analysis.
C/AV program plans will need to identify the skills required to implement C/AV strategies, from planning to design to deployment.	MTP	Future MTP documents may have a section addressing C/AV needs and issues.
Flexibility will be needed in development of C/AV action plans since both the technology and estimates of market penetration levels will change.	MTP, SHSP	Updates or amendments to MTP and SHSP documents may be required more frequently as C/AV technology moves forward.
Planning will be needed to make spare vehicles available for C/AV testing; without disrupting operations.	TDP	Transit Development Plans need to identify key resources for implementation of C/AV technologies.
Leverage opportunities provided by smart phones and other technologies to implement a wider range of C/AV applications.	Bike Pedestrian, TDP	Agencies should be aware of the full range of technologies that can be applied to improve bicycle, pedestrian and transit modes.
C/AV can be used to enhance the linkage between operations and planning through involvement of a wider array of stakeholders.	ITS, PIP	The ITS and PIP should both be used to promote closer ties between operations and planning that will be necessary to support C/AV.
State, regional, and local agencies (DOTs, MPOs, transit agencies, etc.) will need to collaborate in order to include C/AV projects in transportation plans.	TIP	Through the TIP process agencies need to educate member communities at all levels on C/AV technology.
C/AV projects should be reevaluated regularly in light of C/AV advancements and market penetration.	MTP	Long-term planning needs to consider market penetration rates for C/AV technology, particularly autonomous vehicles.
To motivate future C/AV-related safety investments, it will be critical to evaluate how effectively implemented C/AV investments support performance targets.	SHSP	The SHSP process should consider revised safety targets based on C/AV deployment and provide a mechanism to measure performance.
Agencies should coordinate with private companies to schedule infrastructure deployment with upgrades/purchases, to ensure compatibility of devices, and implement data collection/sharing agreements.	Freight	Freight industry adopters of C/AV can provide useful data to agencies. Process and agreements should be defined in the freight plan.
Financial plans should identify new funding program eligibility for C/AV investments.	TIP, Finance	Agencies will need to track funding eligibility for C/AV projects through both their TIPs and Financial Plans.
Financial plans should include any early benefit/cost analysis of alternative C/AV investment options and strategies where possible.	TIP, Finance	Financial plans should incorporate benefit/cost analysis for alternative technology investments, including C/AV. This should help drive the TIP process as well.
(ITS) Agencies should identify the lead entity for C/AV maintenance, and develop a C/AV maintenance plan.	ITS	ITS plans, with the support of operational agencies need to identify resources for C/AV infrastructure maintenance.
Agencies should be prepared to assess these C/AV-based data collection opportunities as well as track the system benefits and costs	TIP, Finance	Financial plans should incorporate benefit/cost analysis for alternative data collection opportunities provided by C/AV. The analysis should be reflected in the TIP process.
Agencies should share information about their works in progress since evaluation reports will lag technology developments.	TIP, ITS	ITS plans will need to incorporate new research on the impacts of C/AV technologies.
New sources of data will provide an opportunity to collect information that monitors C/AV projects and programs, although privacy concerns need to be addressed.	ITS, Bike Pedestrian	ITS and Bike/Ped plans can be improved by new data. Privacy concerns must be addressed however, particularly for bike/pedestrian users.
It will be critical to continuously evaluate how effectively C/AV investments support performance targets.	MTP, SHSP	The SHSP process should consider revised safety targets based on C/AV deployment and provide a mechanism to measure performance. The MTP must address a wider range of measures.

Source: Cambridge Systematics, Inc.

Planning Products versus Applications

The Federal Highway Administration (FHWA) has identified a series of applications that can help meet planning goals by linking connected vehicle technology with the infrastructure. These applications could be implemented using dedicated short-range communications (DSRC) technology, but other communications technologies could be used as well. Ten applications are identified in the case studies to help illustrate the potential uses of C/AV technology. However many of the applications are relevant to multiple planning products as illustrated in the table below. A "high" designation indicates that the application is directly relevant to the planning product/activity and should be considered during development. For example, the Probe-Based Pavement Maintenance Application clearly has direct relevance to the Transportation Asset Management Plan, as a potential replacement for current data collection and analysis methods. A "medium" designation indicates that the application might be relevant in certain cases; for example the Red Light Violation Warning may not be prioritized in a bicycle/pedestrian plan, but bicyclists and pedestrians will likely benefit from implementation. Those applications with limited or no relevance to the specific plans are classified as "low."

While these applications should be of interest to planners, they will evolve and change over time as C/AV technologies are more established. Increased automation with more sophisticated navigation will likely bring many of these applications fully into the vehicle. Therefore, the applications below are more generally relevant to short-term planning products and it is important that planners track ongoing developments in both the private and public sectors.

Table 4. Relevance of connected-automated vehicle (C/AV) applications to planning product case studies.

Application	Description	Planning Product—Transportation Improvement Program	Planning Product—Intelligent Transportation Systems Architecture	Planning Product—Bike Pedestrian	Planning Product—Metropolitan Transportation Plan	Planning Product—Transportation Asset Management Plans	Planning Product—Strategic Highway Safety Plan	Planning Product—State Implementation Plan	Planning Product—Transit Development Plan	Planning Product—Public Involvement Plan	Planning Product—Freight	Planning Product—Finance
Safety—Red Light Violation Warning (RLVW).	SPaT information from a signal controller, along with vehicle position and speed, is used to determine if a warning to the driver is needed.	High	High	Medium	Low	Low	High	Low	Low	Medium	Low	Low
Safety—Reduce Speed/Work Zone Warning (RSWZW).	Information is provided to the vehicle to enable warnings relating to the specific situation, such as warning drivers to reduce speed, change lanes, or come to a stop within or approaching work zones.	High	High	Low	Medium	Low	High	Low	Low	Low	Low	Low
Safety—Pedestrian in Signalized Crosswalk (PSCW).	An application that warns vehicles of a potential conflict with pedestrians that are within the crosswalk of signalized intersection.	Medium	Medium	High	Low	Low	High	Low	Medium	Medium	Low	Low
Safety—Curve Speed Warning (CSW).	Geometric information is provided to the vehicle to enable a warning that the speed of the vehicle is too high to safely negotiate the curve.	High	High	Low	Low	Low	High	Low	Low	Low	High	Low
Mobility—Emergency Vehicle Preemption (PREEMPT).	Traffic signal controllers detect oncoming emergency vehicles and change desired direction to green.	Medium	High	Low	Low	Low	High	Low	Medium	Low	Low	Low

Table 4. Relevance of connected-automated vehicle (C/AV) applications to planning product case studies (Continuation).

Application	Description	Planning Product—Transportation Improvement Program	Planning Product—Intelligent Transportation Systems Architecture	Planning Product—Bike Pedestrian	Planning Product—Metropolitan Transportation Plan	Planning Product—Transportation Asset Management Plans	Planning Product—Strategic Highway Safety Plan	Planning Product—State Implementation Plan	Planning Product—Transit Development Plan	Planning Product—Public Involvement Plan	Planning Product—Freight	Planning Product—Finance
Mobility— Transit Signal Priority (TSP).	Transit vehicles request an extended green from traffic signals.	Medium	Medium	Low	Medium	Low	Low	Medium	High	Low	Low	Medium
Mobility— Freight-specific Dynamic Planning and Performance (FSDPP).	Applications provide enhanced freight-related travel information, such as wait times at ports, road closures, work zones, and route restrictions.	Medium	Medium	Low	Low	Low	Medium	Medium	Low	Low	High	Low
Mobility— Mobile Accessible Pedestrian Signal System (PED-SIG).	An application that allows for an automated call from the smartphone of a visually impaired pedestrian to the traffic signal, as well as audio cues to safety navigate the cross.	Medium	Medium	High	Low	Low	High	Low	Medium	Low	Low	Low
Environment— Eco-Approach and Departure at Signalized Intersections (EADSI).	SPaT information is used to provide speed advice, allowing the driver to adapt in order to pass the next signal on green or to decelerate to a stop in the most eco-friendly manner.	Medium	High	Low	Medium	Low	Medium	High	Low	Medium	Medium	Low
Agency Data— Probe-based Pavement Maintenance (PBPM).	This technology detects vertical wheel movement and/or body acceleration to measure road quality, such as pothole location and size and surface roughness.	Medium	Low	Low	Medium	High	Medium	Low	Medium	Low	Medium	Medium

Source: Cambridge Systematics, Inc.

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