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Policies and Design Guidelines to Plan for Connected and Autonomous Vehicles

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16. Abstract

This report chronicles the work undertaken by researchers at the University of Illinois Urbana Champaign to identify policies and design guidelines to plan for connected and autonomous vehicles (CAVs) in mid-sized regions in Illinois. The report starts with the goals of this work followed by a review of existing literature. The review addresses CAV technologies and scenario planning, including academic research articles, policies and guidance documents from federal and state agencies, and recent long-range transportation plans. The review findings are organized into three categories—drivers, levers, and impacts—to facilitate scenario-based planning and included key factors and trends in technology development and adoption (drivers), mechanisms that planners and policymakers may employ to intervene in or prepare for CAV futures (levers), and community-level outcomes of different plausible CAV futures (impacts). Primary research was undertaken first by interviewing practitioners in six mid-sized regions of Illinois to collect inputs about their needs and obstacles to planning for CAVs, as well as to understand their sense of their community's preparedness for CAVs. The research team then conducted a detailed survey of over 700 residents from the Greater Peoria region to understand their would-be travel behavior and residential location decisions in a CAV future and general attitude toward self-driving cars. These inputs helped identify the key drivers, levers, and impacts to be employed in creating scenarios, a list of selected policies and design, and a framework to select appropriate responses based on the needs and desires of a community. The detailed scenarios are as follows: (1) continuation of the status quo, (2) private multimodal future, and (3) shared multimodal future. The policies and design guidelines are identified for each scenario and are categorized into six sets of action items: general, data and digitization, mobility and traffic, street design, infrastructure, and planning. Specific details of each action item are organized in a format that allows the user to consider each item carefully and to assess its feasibility in a specific region or city. The appendices include background documents related to primary research and, importantly, a handbook for practitioners.

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EXECUTIVE SUMMARY

This report chronicles the work undertaken by researchers at the University of Illinois Urbana Champaign to identify policies and design guidelines to plan for connected and autonomous vehicles (CAVs). The research and findings documented in this report and the attached appendices, especially the practitioner's handbook, aim to guide mid-sized regions in Illinois toward well-considered decisions to achieve a favorable future under a range of CAV-related uncertainties. The introduction (Chapter 1) summarizes the rationale and goals of this work.

Chapter 2 presents a review of the existing literature on CAV technologies and scenario planning, including academic research articles, policies and guidance documents from federal and state agencies, recent long-range transportation plans, and other scholarly and practice-based resources. The research team used the review to develop a preliminary list of key factors and trends in technology development and adoption (drivers), mechanisms that planners and policy-makers may employ to intervene in or prepare for CAV futures (levers), and community-level outcomes of different plausible CAV futures (impacts).

Chapter 3 discusses our primary research and engagement activities. Following the literature review, the research team engaged with practitioners in six mid-sized regions of Illinois to collect inputs about their needs and obstacles to planning for CAVs, as well as to understand their sense of their community's preparedness for CAVs. The research team then conducted a detailed survey of over 700 residents from the Greater Peoria region, one of the mid-sized regions of Illinois, to understand their would-be travel behavior and residential location decisions in a CAV future and general attitude toward self-driving cars.

Chapters 4 and 5 present the scenario framework and the policies and design guidelines framework, respectively. Chapter 4 describes how the key scenarios for CAV futures are constructed. It identifies the main drivers that according to our research will influence the rates of CAV adoption and usage, such as advancement in infrastructure and vehicular technologies; acceptance and willingness of residents to use CAVs; and state endorsement and effective planning by related stakeholders. It also identifies a short list of frequently studied impacts, such as safety (cyber and physical), travel (congestion and mileage), and the economy (property value and job market), as well as the most commonly studied policy levers, such as traffic management strategies, incentives for shared transportation, and pursuing complementary land use and urban design policies. From this list of factors, the key dimensions for constructing scenarios are selected and their main would-be impacts are identified. The constructed scenarios are as follows: (1) continuation of the status quo, (2) private multimodal future, and (3) shared multimodal future. The scenarios are discussed in more detail in Appendix D: Planning for Connected and Autonomous Vehicles: Practitioner's Handbook.

Chapter 5 discusses how policies and design guidelines are identified and organized as well as how practitioners can navigate the range of conditions and choices using a scenario approach. The policies and design guidelines are categorized into six sets of action items: (1) general, (2) data and digitization, (3) mobility and traffic, (4) street design, (5) infrastructure, and (6) planning. Specific details of each action item are organized in a format that allows the user to consider each item carefully and to assess its feasibility in a specific region or city. The format includes a detailed description of each action item, category(ies), key stakeholders to engage, the right scale of implementation, potential barriers, costs, anticipated impacts, and time horizon. For a subset of these dimensions—namely, category, costs, and impacts—we provide a series of matrices that allow practitioners to navigate and compare the action items by these critical characteristics. A full list of action items with detailed characteristics can be found in the separate practitioner handbook deliverable for this project (entitled “Planning for Connected and Autonomous Vehicles: Practitioner’s Handbook,” also included in Appendix D of this policy report).

Chapter 6 documents the stakeholder workshops, two events attended by planners and experts to review the proposed scenario framework, and a preliminary list of action items. The report discusses the feedback that was collected and how it validated and informed the research findings and recommendations.

Chapter 7 includes a brief conclusion and directions for future research. Appendices A–D include the interview instrument, survey questionnaire, workshop results, and handbook, respectively.

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CHAPTER 1: INTRODUCTION

Connected and autonomous vehicles (CAVs) promise to dramatically alter future mobility landscapes in Illinois and beyond and will have profound social, economic, and environmental impacts (Kockelman et al., 2016). However, a lot remains uncertain about the nature and impact of CAVs. Key uncertainties include the pace of technological change and adoption of CAVs, as well as their potentially transformative impact on driving demand, safety, roadway design, jobs, and the broader urban form. Furthermore, these uncertainties may vary by type of travel (freight vs. passenger), geography (highways vs. local), and socioeconomic context (low-income or elderly riders). Communities need to anticipate how the trajectories of possible changes could affect them and make plans that can help them achieve favorable outcomes (Litman, 2020).

Scenario planning is a tool for decision-making under uncertainty, and it is commonly employed by many metropolitan planning organizations (MPOs) in developing long-range transportation plans (LRTPs) (Zegras et al., 2004). Since Portland's Land Use, Transportation and Air Quality plan, many metropolitan areas have used scenario planning in exploring alternative futures and in identifying a course of action (Chakraborty, 2011). In Illinois, the Chicago Metropolitan Agency for Planning (CMAP) relied on scenario planning in their Go to 2040 and On to 2050 plans (CMAP, 2019). Champaign County Regional Planning Commission also used a scenario process called Big.Small.All in 2007 and has since attempted to implement many of its recommendations through its long-range transportation plans.

Scenario planning is a suitable approach for MPOs to identify policy and design guidelines to plan for CAVs. Scenario planning can help identify important external drivers of change, such as new technologies and extent of adoption, as well as uncertainties due to varying rates of technological change and adoption (Guerra, 2016). Scenario planning can help transportation planners organize complex information, engage stakeholders, analyze possible impacts of uncertainties, and make choices that can help communities reach a favorable future. Finally, scenario planning can help identify possible short- medium-, and long-term impacts and offers a path to track and adjust policies based on their performance.

While a number of resources already exist for scenario analysis in transportation planning, little guidance exists in the area of CAVs, particularly for mid-sized MPOs. The Federal Highway Administration (FHWA) maintains a robust resource page for basic techniques and noteworthy practices in scenario planning. The Association of Metropolitan Planning Organizations maintains a resource page on CAVs directed at MPOs and state departments of transportation (DOTs), as does FHWA. Yet, none of these resources adequately guide transportation planners to systematically navigate the various uncertainties associated with CAVs, nor do these sufficiently assist in formulating policy and design guidelines that can help communities reach favorable outcomes. This is further challenged due to the greater focus of available information on large urban regions at the expense of smaller regions.

In this project, we address this gap by identifying policies and design guidelines for mid-sized MPOs in Illinois. We start with a review of existing literature on CAV technology and scenario planning, including academic research articles, agency policy and guidance documents, long-range transportation plans, and other scholarly and practice-based resources. We then engage with practitioners and residents through interviews and surveys to assess and analyze the current trends, resident perceptions and expectations, and obstacles faced when planning for CAVs. Based on these inputs, we develop a scenario framework that captures the most critical CAV-related uncertainties from a planning perspective and an action items framework that identifies and organizes a list of policies and design guidelines suitable for mid-sized regions. Finally, we work with state, regional, and local stakeholders to refine and validate these frameworks and further develop the list of actions items along six important categories: (1) general, (2) data and digitization, (3) mobility and traffic, (4) street design, (5) infrastructure, and (6) planning. The full description of CAV scenarios and list of action items are included in Appendix D: Planning for Connected and Autonomous Vehicles: Practitioner's Handbook, which is intended to be a practice-oriented companion document to this report.

CHAPTER 2: LITERATURE REVIEW

The transformative potential of CAVs and other changes in technology and travel behavior are expected to have profound consequences. For example, the annual energy consumption of private vehicles is expected to decrease by 15% (from 88.8 to 75.5 billion gallons of gasoline equivalent) and individual time cost is expected to decrease by 38% [Taiebat et al., 2019]). However, it is also expected that CAVs will significantly decrease user costs of private cars, which could cause urban hinterlands to attract more residents and development. This will have detrimental impacts on land use and sprawl by straining transportation demand and infrastructure capacity (Szimba & Hartmann, 2020).

Despite their transformative potential, effective planning for CAVs remains a challenge due to the novelty of these technologies and uncertainties surrounding their impact on communities. Some communities in the U.S. are currently testing CAVs on public roads or developing engineering and technology standards. For example, New York, Boston, and Arlington have either a CAV pilot program or a trial in which citizens are exposed to these technologies and their reliability is tested and enhanced. New York, for example, has started CAV testing by equipping more than 10,000 vehicles and buses with connectivity abilities to communicate with each other and the infrastructure. Boston has been testing autonomous vehicles in South Boston along with adaptable parking in different locations. Arlington has initiated and financed programs that digitalize infrastructure, facilitate acceptance of CAVs, and test autonomous vehicles and their performances.

Large-scale active planning for CAVs is still in its early stages, though. Most planning and transportation agencies as well as private sector companies are uncertain of the pace of technological change and adoption of CAVs, as well as the extent of their impact on driving demand, safety, roadway design, jobs, and the broader urban form. Furthermore, these uncertainties may vary by type of travel (freight vs. passenger), geography (highways vs. local), and socioeconomic context (low-income or elderly riders). As a result, regulations and policies that can promote desirable outcomes remain undefined or unclear. Communities need to anticipate how the trajectories of possible changes vis-à-vis CAVs could affect them and devise plans that can help them achieve favorable outcomes not just in terms of mobility and urban form, but also the broader economy, environment, and society. In this project, we aim to identify policies and design guidelines that can help planners navigate these uncertainties, especially for mid-sized MPOs in the state of Illinois.

Toward that end, this literature review synthesizes available knowledge from practice and research that address planning for CAVs. We employ a scenario analysis framework to organize the available knowledge into three categories—drivers, levers, and impacts. These categories refer to key factors and trends in technology development and adoption (drivers), mechanisms that planners and policy-makers may employ to intervene in or prepare for CAV futures (levers), and community-level outcomes of different plausible CAV futures (impacts). A scenario planning lens allows us to organize uncertainties associated with these categories systematically and is expected to guide our subsequent work on identifying policies and design guidelines. Our review covers a wide range of document types from researchers and practitioners, as well as guidance from leading organizations in the public and private sector, with the goal of understanding the state of the art of CAV-related efforts and their implications for planning practice. The review synthesizes 1) drivers, levers, and impacts related to CAV technology and deployment; 2) planning organizations' reaction toward CAVs and their planning methods; 3) and pertinent regulations and policies adopted or proposed in other communities.

In this literature review, we used scenario planning principles to organize the different dimensions of uncertainty related to CAVs. These dimensions include drivers, i.e., CAV technology developments and trends; levers, i.e., critical considerations for planning, including policies and design strategies that MPOs could use to proactively plan for favorable future outcomes; and impacts, i.e., potential implications of CAVs for communities. This approach allows planners to organize the identified drivers and levers, account for their critical uncertainties, formulate future scenarios, and analyze and compare scenarios based on their potential impacts. For example, drivers and levers can be organized along two primary axes of a matrix, and the combined future outcomes of the interaction between drivers and levers can be seen as scenarios, which are then compared on their impacts (for a detailed discussion of this approach, please see Chakraborty et al., 2011). Beyond this literature review, we use this scenario approach in subsequent steps of our research to conduct workshops that helped us identify recommendations for key action items. Figure 1 presents a conceptual illustration of a scenario framework.

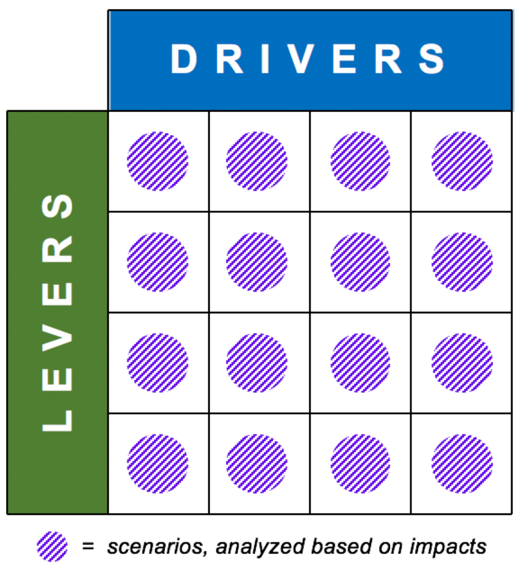


Figure 1. Conceptual illustration of scenario framework.

TYPES OF DOCUMENTS REVIEWED

This review scans the existing knowledge on relevant CAV technologies, trends, and planning efforts. The types of documents reviewed include academic journal articles, published studies and white papers from public and private sector agencies, recent long-range transportation plans, and other scholarly and practice-based resources. We specifically looked at the different drivers, impacts, and levers (Table 2). Table 1 summarizes the number of documents by each category. A full list of reviewed documents is included in the References section of this report.

Table 1. Number of Documents Reviewed by Category

Type of document	Number of documents reviewed
Academic journal articles	60
White papers/agency reports	6
Long-range transportation plans	25
Other documents/studies	24

Table 2. List of Selected Drivers, Impacts, and Drivers

Drivers	Impacts	Levers
– Technological change – Consumer preferences – Demographic shifts – Actions by other agencies	– Safety – Vehicle miles traveled – Congestion – Emissions – Urban form – Accessibility – Equity – Economic shifts	– Infrastructure investment – Travel pricing – Parking policy – Multimodal transportation investment – Land use planning

SELECTION METHODS FOR LRTPS AND OTHER MPO DOCUMENTS

Reviewing what and how metropolitan planning organizations are currently investigating and planning for CAVs is essential for this project. We have divided our review into two categories: large MPOs and mid-sized MPOs. Although our project is specifically oriented toward mid-sized MPOs, it was important to first review what and how larger cities and areas are tackling this emerging technology. Larger cities might have access to more resources and are up to date with technology advances due to private investment and availability of funding and skills. This allows us to assess the extent of planning activities taking place in denser areas that are expected to be impacted more than less dense areas and what parameters were being considered. We reviewed plans and CAV-related documents from 15 large MPOs and 10 mid-sized MPOs.

CURRENT STATE OF THE RESEARCH

Overview

Scholarly articles and technical reports are our main sources for understanding ongoing trends in CAVs and their implications for cities. Many of these documents also provide a set of recommendations that can be adopted by planning agencies to accommodate or prepare for CAV technologies and their impacts at different scales. In this section, we summarize this literature using the previously described dimensions of drivers, impacts, and levers. With CAV technologies continuing to develop, the uncertainties remain high, and, in many cases, their implications remain unclear. To capture this evolving landscape, our synthesis records the likelihood and range of uncertainty associated with the various drivers, levers, and impacts, when possible. The aim of this section is also to highlight the most critical uncertainties; the interactions among different drivers, impacts, and levers; and the lessons emerging from these connections.

Drivers

Drivers for CAVs are the key external factors that may affect the development and adoption of autonomous vehicles in communities. Drivers have been widely studied and are summarized mainly under three categories: technological change, consumer preferences, and actions/policies by different agencies other than the planning sector. Understanding the nature of these drivers and their influence on CAV deployment outcomes may help MPOs in planning for CAVs. However, there remains considerable uncertainty about drivers. For example, while the "which" and "how" of each of these factors are getting clearer, the "when" and "how much" are yet to be known. This uncertainty affects which decisions to make and when to make them.

Technological Change

Most agencies, scientific reports, and other documents note the need for further technological advancements to push and accelerate CAV penetration. The rate and magnitude of how technology will advance is one of the prominent influencers on how the rollout of CAVs might look and its potential impacts. Regardless of the type of technology change (vehicular versus infrastructural), more optimistic studies suggest that fully automated vehicles will be available as soon as year 2025 or by year 2035 at the latest (Underwood et al., 2014; Zmud et al., 2015). More conservative speculations project a longer timeline where a considerable amount of time is required for CAVs to become more common and affordable. In such a scenario, it is expected that autonomous shared services, self-driving taxis, and ride-hailing will be available during the 2030s and 2040s (Litman, 2020).

In order to understand these projected timelines, it is vital to point out which specific technological advancements could have the greatest impact on deployment of autonomous vehicles. There are two main types of technology: autonomous vehicles and the infrastructure to support them. With regards to vehicles (private as well as shared and freight), real-time map updating, wireless CAV software updates, localization techniques, and dedicated short-range communications are yet to be further developed to have a possible transition into fully automated vehicles (Anderson et al., 2016). For infrastructure, the continuous enhancement of big data analysis for incident forecasting (Payalan & Guvensan, 2020), development of computer vision and sensor algorithms (environment, degradation, vehicle-to-vehicle [V2V]/vehicle-to-infrastructure [V2I] communication) (Anderson et al., 2016) and improvement of V2V and V2I communication (Fagnant & Kockelman, 2015) are most important.

Many of the basic technological advancements required for CAVs have already been identified. The rollout and complete realization of these advancements is still uncertain due to many factors such as cost, feasibility, reliability, and standardization. It is not clear if one technological advancement is prioritized over another or if their magnitude on CAV penetration will vary substantially. Although there are many unknowns, it is almost certain that these advancements are essential for driving CAVs forward. Consequently, some cities and states have actually started investing in infrastructural updates and endorsing research efforts working on enhancing CAV technology (North Central Texas Council of Governments, 2018b).

Consumer Preferences

Along with technological changes, it is important to understand how consumers will receive CAV technology and how this reception will influence CAV rollout. Given that CAVs come with many uncertainties and possible vulnerabilities, speculating the rate of acceptance can be difficult. It is also important to note the cultural and contextual differences from one place to another. For example, a survey conducted in Switzerland found that 61% of commuters prefer to use shared forms of CAVs (Stoiber et al., 2019). This might not apply to all U.S. cities given differences in lifestyle and car ownership rates. According to our research, consumer preference and acceptance rates are being driven by three types of factors, examined more closely in the sections that follow:

- Demographic features and shifts
- Job accessibility and residential location (suburban vs. urban)
- Consumer trust and awareness

Demographics

According to a 2019 survey (Nodjomian & Kockelman, 2019), men are more likely than women to shift toward owning or riding an autonomous vehicle. However, this is contingent upon their residential location and commute times. For example, people with poor job accessibility using automobiles are highly interested in AVs (Nodjomian & Kockelman, 2019). Younger people are also more willing to use autonomous vehicles. Car ownership plays a decisive role on the type of CAV a consumer is willing to adopt. People with lower incomes or who are unable to drive and rely heavily on public transportation are more prone to use shared AVs (Burghard & Dütschke, 2019; American Public Transportation Association, 2016). Even though CAVs are projected to be ready and available by the 2030s/2040s, they might not become common and affordable until the 2050s to 2060s (Litman, 2020). However, CAV accessibility might not benefit those who do not have access to payment methods due to lower incomes or technological difficulties (Litman, 2015).

Job Accessibility and Residential Location (Suburban vs. Urban)

Most research agrees that individuals with longer commutes and lower job accessibility are more likely than others to rely on CAVs. According to Nodjomian and Kockelman (2019), people living in the suburbs are more likely to use CAVs than their peers living in the city. On the other side, individuals commuting to downtown/urbanized areas are more accepting of using shared autonomous vehicles (EERE, 2017). Dense areas are expected to attract more shared autonomous vehicles (Duarte & Ratti, 2018), whereas single-use developments are likely to see CAVs before those with multiple uses (Nodjomian & Kockelman, 2019).

Consumer Trust and Awareness

Consumers express a greater willingness to own, ride in, or otherwise use CAVs when they understand its capabilities, benefits, and limitations (KPMG, 2015). However, trust in CAVs can be one of the challenges to its greater acceptance (Zhang et al., 2019). Significant advances in CAV cybersecurity and greater evidence of physical safety, as well as perceived ease of use and usefulness, are expected to increase public acceptance toward autonomous vehicles (Lim & Taeihagh, 2018; Zhang et al., 2019).

While the above factors may increase *acceptance*, factors influencing *actual adoption* may be somewhat different. Some research has shown that the most important factor to adoption is cost effectiveness, especially in the case of a shared model (shared autonomous vehicles): If prices are competitive with other modes, drivers may be willing to overcome privacy concerns and inconvenience (Anderson et al., 2016). Another uncertainty in this area is identifying the types of drivers who will adopt CAVs first, and their rate and timing of adoption. As a result, planning agencies are not able to map the possible layout of CAV evolution in their respective cities or predict growth locations. For the time being, MPOs are focusing on spreading awareness about CAVs and informing the public about this technology (The Houston-Galveston Area Council, 2019).

Other Drivers

Several other drivers might affect the rate of growth in CAVs. These include federal and state regulations and incentives, investments in the private sector, and streamlining of business logistics, especially in the freight sector. Funding provisions as well as CAV proactiveness by the state may play a positive role in advancing deployment (Fagnant & Kockelman, 2015). Resolving liability concerns and assigning a clear legal CAV framework will also promote more trust in CAV and further adoption (Taeihagh & Lim, 2019; Zmud et al., 2015). Additionally, positive results from private sector investments in research and development can significantly push forward CAV proliferation rates (Zmud et al., 2015).

Impacts

Along with investigating the factors that drive the availability and spread of CAVs and their timelines, it is important to understand and assess the impacts of CAVs on our future cities and regions. One of the main reasons several entities such as DOTs or planning agencies are investing in CAVs is the promise of greater safety, both for drivers and for pedestrians, through reduction in crashes and more efficient traffic and mobility. However, impacts of CAVs are highly uncertain in other aspects such as congestion levels and vehicle miles traveled (VMT). In addition to the direct impact on mobility and safety, CAVs will also have indirect impacts on greenhouse gas emissions, energy consumption, car ownership, and travel behavior, leading to changes in the built environment and urban form, which, ultimately, may affect equity and accessibility in our communities.

Expected impacts of CAVs are commonly discussed in the literature about autonomous mobility. Whether using scenarios, simulations, or qualitative methods, most research studies have something to say about the possible impacts and their magnitude. In addition, impacts are an essential element for introducing effective levers and understanding their possible application. With that being said, impacts just like drivers, vary in uncertainty and likelihood ratios. Some impacts, although clearer in terms of their possible direction, are yet uncertain in their magnitude and secondary consequences. Impacts of CAVs are also tightly related to and dependent on drivers. As long as drivers are highly uncertain, many impacts stay uncertain. Such uncertainties may hinder MPOs from taking a proactive action toward adopting and planning for CAVs.

Safety

CAVs affect two areas of safety: traffic safety and cybersecurity. Most of the conducted research states that CAVs will provide higher safety to passengers, pedestrians, and cyclists. According to a study conducted by the Jackson Area MPO, cyclists and pedestrians reported that they would feel safer walking or biking along with CAVs, as they are more attentive and cautious than human drivers (Jackson MPO, 2018). However, CAVs may negatively affect other aspects of safety, such as individual privacy, data hacking, vehicular hijacking, and cybersecurity concerns (Fredericksburg MPO, 2018).

Physical Safety

Even the conservative projections estimate a reduction in accident percentage at approximately 80% (Kockelman et al., 2016; KPMG, 2015), whereas optimistic numbers predict a 90% reduction in road incidents, saving around one million lives each year globally (Anderson et al., 2016; Arena & Ticali, 2018; Fagnant & Kockelman, 2015). Given the self-learning ability of CAVs, it can be expected that safety performance will improve as larger numbers of CAVs are deployed on the road, which provides them with training and real-world experience (Taeihagh & Lim, 2019). Projected improvements in safety are largely based on expectations regarding the elimination of human error, which according to Shay et al. (2018) could one day even facilitate unrestricted pedestrian movement.

Cybersecurity

Cybersecurity is considered one of the highest vulnerabilities of CAVs. Any cyberattacks on CAVs or malware/fault in the software could lead to more crashes, violation of individual privacy, and other unanticipated results (Lim & Taeihagh, 2018). Additionally, cyber-attackers could get access to highly sensitive data that breach privacy and security thresholds (Lim & Taeihagh, 2018).

Vehicle Miles Traveled

Most research is still uncertain about potential changes in VMT. However, many believe that VMT will increase due to the increased number of CAV taxis and shared autonomous vehicles (SAVs), greater affordability, and increased access to mobility for elderly, disabled, and underage populations. Increase in sprawl as a result of greater mobility may also increase VMT (Anderson et al., 2016; Soteropoulos et al., 2019). According to Soteropoulos et al. (2019), new users will bring an approximately 14% increase in VMT. It is expected that the value of travel time savings in commuting trips will be reduced by 41% (Kolarova et al., 2019). This does not apply to leisure or shopping trips. Some also expect an impact on VMT due to zero-occupancy (or passenger-less) CAV and SAV trips either roving to pick up passengers or avoiding parking fees. This could eventually have secondary repercussions on congestion and energy consumption.

However, studies generally agree that VMT impacts may be dramatically influenced by consumer preference and market penetration rates. At lower market penetration rates, such as closer to 10%, increase in VMT is estimated to be 20% more than in a non-CAV environment. When market penetration is boosted to 90%, the VMT number decreases by 10% (Fagnant & Kockelman, 2015). Likwise, “consumers’ perceived travel time cost” will have a high impact on VMT increase/decrease rates (Stephens et al., 2016).

Although CAVs may increase VMT, the net benefits may still be higher due to gains in safety and time (Fagnant & Kockelman, 2015). Additionally, it may be possible to reduce VMT outcomes through increased ride-hailing and shared vehicles (Tirachini & Gomez-Lobo, 2020). VMT outcomes may be more controlled or mitigated in communities where travelers are more willing to use SAVs and where development patterns are supportive.

Congestion

Like VMT, the potential impact of CAVs on congestion is highly uncertain, and therefore, trying to map and predict congestion rates is challenging (Anderson et al., 2016). Changes in congestion are highly dependent upon VMT rates, which are uncertain. Additionally, changes in congestion will depend on other factors such as consumer preferences, policies and regulations, and technological decisions. More specifically, the congestion associated with CAVs will be influenced by the number of vehicles owned by consumers (depending on acceptance/preference rates), the amount of empty CAV/SAV trips taken or allowed by regulation, CAV market penetration rates, and proximity of vehicles to each other. It also predicted that road capacity and throughput will most likely increase regardless of how congestion rates unfold. Studies are estimating doubled or tripled road capacities (Anderson et al., 2016; Fraedrich et al., 2019; Underwood et al., 2014). This is attributed to the ability of CAVs to potentially drive safely at close intervals and, in some cases, vehicle platooning.

However, several studies also highlight the role of road pricing in significantly reducing congestion (Gurumurthy et al., 2019). Likewise, according to Fagnant and Kockelman (2015), CAV market penetration and higher usages (i.e., 90% penetration) should at least decrease congestion in highways by 60%.

Emissions

Most research suggests that greenhouse gases (GHG), pollution, and carbon emissions from CAVs will most likely decrease, although some uncertainties remain (Anderson et al., 2016; Underwood et al., 2014). Emissions are influenced by energy usage rates, fuel efficiency, and total VMT (Anderson et al., 2016). Gross amount of emissions might not reduce given that CAVs provide higher accessibility to driving and riding vehicles. However, emission ratios per vehicle could be reduced based on fuel efficiency and source of energy.

The decrease in emissions could be partially due to lower congestion (Wadud et al., 2016), which reduces the stop-and-go frequency. However, since congestion estimates come with high uncertainty, related aspects of emission impacts are consequently uncertain.

The potential decrease in emissions, regardless of congestion forecasts, is mainly attributed to electric charging. CAVs are designed to use electric charging instead of fuel-based charging. GHG emissions might reduce by half or increase up to double based on CAV levels, CAV features and types, and policy interventions, as cited by Faisal et al. (2019). Penetration of shared AVs even if VMT increases most likely lowers GHG emissions between 16.8% and 42.7% (Faisal et al., 2019; Jones & Leibowicz, 2019). As with other factors, the overall impact of autonomous vehicles on reducing GHG emissions seems more impactful and tangible in the distant future rather than near- to mid-term (Liu et al., 2019).

Urban Form

Another area of research examines potential changes to the built environment, which arise indirectly from CAVs as households adapt via changes in travel behavior and residential location. The main urban form features that are expected to be influenced by CAV penetration are parking, density, right-of-way and road/lane widths, and land use changes.

Parking

The potential for reduced parking may be the most prominent impact of CAVs on urban form. Due to CAVs' self-driving capability, vehicles are no longer required to be close to drivers or passengers when parked. As less parking space (parking spots, lots, and dimensions) is needed, parking garages, parking lots, and land use–based parking requirements are expected to change and fall dramatically by up to 90% (Zhang et al., 2015). It is also expected that SAV systems can reduce parking land by 4.5% in Atlanta at a 5% market penetration level (Zhang & Guhathakurta, 2017). An estimated $250 in parking savings (approximately $1 per working day) will be realized per each new CAV (Fagnant & Kockelman, 2015). Additionally, side parking may become supplementary and drop-off areas may become a required feature. Vacant parking lots will offer the opportunity for other developments that might invite higher densities. However, there are many "uncertainties about the spatial and temporal distribution of parking demand after AVs are introduced and used" (Stead & Vaddadi, 2019).

Density

Most studies show that CAVs will influence density in both directions: an increase in density as well as increase in sprawl and suburbanization. It is expected that metropolitan areas will become denser if parking spaces are converted to other land uses (Anderson et al., 2016; Faisal et al., 2019; Stead & Vaddadi, 2019). On the other hand, due to decreased travel time value, households may be willing to live farther. If shared modes of AVs are to be used, it may encourage denser, urban developments and reduce further development in greenfields (UITP, 2017).

Right-of-Way and Road/Lane Widths

As parking is reduced dramatically, drop-off areas will have to be introduced as part of building code requirements and road design. As such, it is expected that rights-of-way and travel lanes will also be affected along with infrastructure (signage, wayfinding, road intersections, etc.) (Fraedrich et al., 2019). Lane widths may also be reduced due to ability of CAVs to communicate with one another, potentially opening space for alternative uses.

Land Use Changes

Based on results generated from scenario simulations, Kang and Kim (2019) state that agricultural areas are to decrease whereas residential and commercial land use are to expand. Due to the significant decrease in parking requirements and even obsolete parking structures, communities may expect more opportunities for mixed use development, resulting in the potential to densify urban areas. This line of reasoning suggests mutually reinforcing trends in higher-density developments and shared autonomous vehicles and autonomous delivery vehicles (Anderson et al., 2016; Fraedrich et al., 2019). Additionally, a large share (up to 80%) of the space freed up from vehicles (i.e., extra lanes/side parking) could be transformed into green and open spaces (Yadan, 2019), inviting more social activities and interactions. An alternative outcome, however, could be starkly different, with worse conditions for pedestrians and cyclists as priority is given to CAVs, resulting in environments that are less friendly for active transportation modes (Bosch et al., 2018; Cohen & Cavoli, 2019; Fraedrich et al., 2019).

Another important land use change could result from redistribution of charging stations. It is expected that the CAV system will be viable with fewer refueling stations (Anderson et al., 2016). Having charged parking spaces might encourage parking demand to move from downtown to close-by low-income neighborhoods, which might also have potential social equity problems (Zhang & Guhathakurta, 2017).

Apart from parking reduction due to CAV penetration, many of the urban form changes are still under research and speculation. This high level of uncertainty prevents MPOs from actively making any land use changes or zoning ordinances. Indeed, even in the case of parking—for which anticipated impacts are relatively clear and agreed upon—planning agencies generally have not taken significant action toward preparing for CAVs.

Accessibility

According to current research, the impacts of CAVs on accessibility are likely to vary by location and setting. In low-density rural areas, places with higher street connectivity will continue to have higher accessibility, as they provide more opportunities compared to traditional, non-CAV environments (Meyer et al., 2017). This is not necessarily the case in urban and higher-density areas, where the accessibility impacts depend on how CAVs are used and for what purposes. For instance, CAVs could increase accessibility if they are used as a first-/last-mile solution for public transportation. On the other hand, alternative trends in autonomous vehicle development may favor urban sprawl and significantly reduce public transportation use (Meyer et al., 2017). As a result, public transportation and other current shared transportation modes may become obsolete (Anderson et al., 2016; Soteropoulos et al., 2019), which could severely reduce accessibility of people who are particularly dependent on public transportation or non-CAV mobility options.

Equity

As with other impacts, the equity impacts of CAVs are highly uncertain. CAVs are likely to bring mobility opportunities to non-drivers such as the elderly, people with disabilities, children, and others who are unable to drive. However, if CAVs lead to further reductions in public transportation services, low-income and other vulnerable communities may be negatively affected due to lower access to mobility options. As such, CAVs may lead to an inequitable distribution of CAV-based benefits and opportunities, further widening the non-equity gap (Vassallo & Manaugh, 2018).

Economic Shifts

Once CAV adoption rates are high, economic shifts are expected to occur. Some job sectors, such as taxis and the trucking industry, may become obsolete. Other sectors, however, may gain temporarily or in the long run. For instance, employment gains are estimated at 15% in construction related to parking lot conversion and highway modification during the transition phase, whereas IT products and services sectors are expected to have sustained gains (Faisal et al., 2019; Pettigrew et al., 2018).

At a more local level, if parking decreases in prime locations and is rarely used by CAVs, parking revenues will also decline heavily. Likewise, if public transportation ridership also decreases, fare revenues will also be negatively affected. Both shifts jeopardize a key source of income upon which cities depend for maintenance and capital projects (Anderson et al., 2016).

Broader economic shifts are also expected in domains related to transportation. Safety enhancements may reduce employment in the insurance industry, while a popular SAV future may reduce the need for car dealerships (Anderson et al., 2016). As with most impacts, economic gains or losses are highly dependent on autonomous vehicle penetration levels. Fagnant and Kockelman (2015) estimate a total of $450 billion dollars in net economic benefits at 90% penetration of CAVs. More optimistic estimates suggest that the U.S. economy would increase by 1.3 trillion dollars due to CAVs (Arena & Ticali, 2018).

Levers

Within the context of the present study, levers are the actions and decisions made by an agency that could (1) guide or regulate local preparations for and/or adoption of CAVs, (2) attempt to mitigate possible negative impacts of CAVs, or (3) endorse or support positive CAV outcomes. Based on the literature review, the levers that could be adopted and deployed by metropolitan planning organizations and related agencies generally fall under three categories:

1. Infrastructure-related levers (e.g., infrastructure investments)

2. Transportation-related levers (e.g., travel pricing and multimodal investments)

3. Land use/urban form levers (e.g., land use planning and parking policies)

The impacts of these levers, however, remain uncertain. In this section, we describe the major types of levers identified through the literature review and discuss corresponding recommendations for better planning for CAVs.

Infrastructure Investment

Providing a CAV-friendly environment is one of the essential requirements of an effective CAV rollout. Many studies emphasize that cities should prepare their infrastructure first to successfully receive autonomous fleets. This is more likely to ensure that AVs are not infected by malware or are vulnerable to cyberattacks (Vassallo & Manaugh, 2018) and that the built environment and existing modes of transportation can adjust more effectively. The two main infrastructure types are physical and data/communications.

Physical Infrastructure

AVs depend on camera vision and wireless data communication to maneuver without the assistance of a driver. As such, signage, wayfinding boards, lane markings, and pavements should be installed at the right locations and be clearly marked/painted for successful detection by autonomous vehicles (Faisal et al., 2019). In some cases, specific signs and markings should be updated to accommodate CAV technology (Faisal et al., 2019; Kockelman et al., 2016). Road intersections and traffic signals should shift toward smart applications and speed limits; traffic signal locations and timing are then adjusted accordingly (Faisal et al., 2019).

Another way of utilizing existing infrastructure is by assigning high-occupancy vehicle lanes exclusively to CAVs. This allows continuous lines of platooning CAVs that are well coordinated to reduce time and energy consumption and improve network performance (KPMG, 2015). Since CAVs project new traffic dynamics and behavior, it is suggested that specific lanes are dedicated to autonomous vehicles to improve network performance and vehicle throughput (Faisal et al., 2019).

Data/Communications Infrastructure

Given that CAVs depend heavily on connection to infrastructure (V2I; i.e., traffic signals, traffic conditions, etc.) and connection to other vehicles (V2V), cities' digital infrastructure should be adaptable to such requirements. To facilitate centralization of data and optimize network operations, V2V and V2I communication should be developed and deployed (Cohen & Cavoli, 2019). Wireless communication and public free Wi-Fi could be expanded to allow for better real-time public transportation information (Golub et al., 2019). Traffic signal and road intersections should also convert to smart mechanisms such as prioritizing dedicated short-range communications locations that would further enhance V2V infrastructure (Faisal et al., 2019). This also includes adjusting speed limits as well as traffic signal locations and timing (Faisal et al., 2019).

Transportation Investment

Travel Pricing

As previously noted, the impacts of CAVs on congestion, VMT, and related outcomes come with high uncertainty. However, these impacts are also highly influenced by regulations and policies targeting travel and transportation behavior. Travel pricing is one of the most commonly suggested strategies to mitigate the potential for increased VMT and congestion. New policies could employ VMT-based pricing to substitute for the current fuel taxation, especially if energy sources shift toward electricity (Faisal et al., 2019). It is recommended to move from fixed prices to variable charges applied by distance (price per kilometer) and time of the day, as this will have impactful results on traffic (Hensher, 2018). According to a charging reform (non-CAV based) proposed by Hensher (2018), applying a distance-based charge of 5c/km during the peak period only (in addition to decreasing registration fees) reduced traffic by 6%–10% in the Sydney Metropolitan Area. Furthermore, increasing the charge by 10% had a 1.6% reduction in vehicle usage (Brent & Gross, 2018).

Travel pricing, although identified as a useful solution for managing negative impact of CAVs, is most effective when shared autonomous vehicles are used widely. Road pricing reinforcement during peak hours reduces VMT, especially when coupled with SAVs (Gurumurthy et al., 2019). Therefore, to encourage use of shared mobility modes, priority groups and SAV rides could be subsidized or allowed to travel free of charge (Cohen & Cavoli, 2019). Introducing congestion pricing is also a viable solution to control travel demand and traffic and reduce congestion. However, congestion pricing can be no different in terms of its efficacy when compared to traditional control methods with the exception of bringing higher economic gains (Gurumurthy et al., 2019). Cohen and Cavoli (2019) also suggest the regulating of passenger-less AVs to control the increase in VMT, whereas UITP (2017) suggests thinking about potential “measures to avoid empty private AVs idling on the road.”

Parking Policy

As discussed previously, the parking scene is likely to change dramatically as CAVs become commonly used. As such, parking regulations pertaining to building codes and parking pricing/policies should be reassessed and studied. According to Cohen and Cavoli (2019), the first course of action could be to “reduce parking stock.” Parking spaces could either be reduced or eliminated, and more drop-off/pick-up locations may be introduced, especially at transportation hubs. This could be achieved through reclaiming on-street and off-street parking facilities, especially ones located in the city center or dense area, and potentially replacing them with other types of development. Subsequently, the parking spaces removed from downtown and denser areas could be replaced by rebuilding multistory garages in suburban and less dense areas (Faisal et al., 2019). Potential social equity problems can possibly be alleviated by combining charged-parking policies with additional regulations. This includes providing opportunities for new in-fill development in lower income neighborhoods and indirect improvement of mobility through accessibility to SAVs (Zhang & Guhathakurta, 2017).

Multimodal Transportation Investment

To reduce the impact of increased vehicle ownership, which leads to higher VMT rates and, as a result, higher probability of congestion, shared vehicle usage provides a good alternative. Many studies emphasize that CAVs and SAVs can work hand-in-hand with a multimodal transportation network. This possibility is often examined with respect to public transportation, as CAVs are efficient at providing first-/last-mile connectivity (Gurumurthy et al., 2019; Kolarova et al., 2019). If AVs are well integrated into the overall public transport network, the efficiency and range of public transportation could increase with usage levels of public transport reaching 138% (Booth et al., 2019). However, if autonomous vehicles are available at competitive prices and provide faster options, usage levels of public transport are expected to drop by 75%.

To ensure that CAVs are compatible with other modes of transportation, policies should make sure that shared/collective CAVs are prioritized and subsidized. On the other hand, public transportation and active transport should also be prioritized and well connected with autonomous vehicles, especially shared autonomous vehicles (Booth et al., 2019). This may require providing high-quality mass transportation, increasing the frequency of service lines, improving the cycling and pedestrian network and quality, and providing complementary services (Cohen & Cavoli, 2019). Additionally, by requiring and endorsing location and timing decisions that favor use of public transportation, it is expected that public transportation remains a vital mode for mobility (Cohen & Cavoli, 2019). If such improved transportation services (public transportation and active transportation) are achieved with a reduction in prices, it is expected that equity increases (Golub et al., 2019). Also, making sure that SAVs are integrated with public transportation will be important to reducing VMT and allowing for high street reclaiming (UITP, 2017).

Land Use Planning

CAVs are predicted to influence how land use is planned and distributed. Parking requirements are estimated to decrease dramatically; the traffic performance (i.e., VMT and congestion) would change with self-driving cars, existing road space might become abundant, and cities might grow further outward with improved accessibility due to CAVs. As a result, zoning, density requirements, bonuses, and funding should all be revaluated (Cohen & Cavoli, 2019). Since autonomous vehicles will have an impact on road design and parking requirements, land use policies and planning efforts should fully consider how to proactively plan for a CAV future. Ideas include reconfiguring zoning, changing density requirements, and providing bonuses/funding for CAV-aware developments (Cohen & Cavoli, 2019).

Vacant/Unused Spaces

As many street parking spaces, parking lots, and vehicle travel lanes become unused, they can be either converted to new developments or utilized for other activities. The resulting freed-up space may be repurposed to serve pedestrians and cyclists (Staricco et al., 2019) or converted to open spaces that serve the public: “pavements to parks” (Stead & Vaddadi, 2019). Through this strategy, right-of-way can be reclaimed to serve pedestrians, cyclists, and other modes of multimodal transportation. This synergy between different transportation modes is essential for a sustainable provision of CAVs. Unused land could also be planned to new links that are dedicated to transportation modes that are most space-efficient or that benefit those with the poorest accessibility (Cohen & Cavoli, 2019).

Vehicle Charging

New parking locations can be used for parking as well as charging stations. Nodjomian and Kockelman (2019) advise MPOs to expect prompt impacts on suburban before urban and dense areas, and therefore parking and street infrastructure in the suburbs should be reviewed and updated. Since it is anticipated that CAVs will be more electricity based than fuel based, the distribution of charging stations and charging mechanisms may have to dramatically change and increase. As such, street parking in suburb locations can also be used as electric charging stations since the downtown area in a CAV future may have fewer parking spaces (Faisal et al., 2019).

Summary

With all the uncertainties and varying probabilities, most research seems to expect the CAV future to be safer and to provide even greater access to automobile transportation, but this future may also potentially result in higher VMT, greater congestion, and greater disparity in access. Active transportation opportunities may also be reduced unless such opportunities are carefully planned and integrated with CAVs. There is general agreement that the introduction of and investment in shared vehicles as a multifaceted solution is recommended to combat many of the likely negative consequences of CAVs. Studies on suggested levers provide some guidance on what policies and design guidelines should be adopted for attaining a more desirable CAV future; however, this guidance does not yet translate to actions for MPOs. In the next section, as we discuss the efforts of selected MPOs, their awareness of these issues becomes clearer, as do many of their challenges to take tangible action. This can be attributed partly to the uncertainties surrounding drivers and impacts, as well as to our limited understanding of the ultimate effectiveness of many levers suggested in research.

CURRENT STATE OF THE PRACTICE

The purpose of this section is to review how transportation planning agencies are currently addressing CAVs in practice, noting how the drivers, impacts, and levers described in the previous section are being framed and included in actual plans, policies, and programs. We begin by reviewing three reports that have provided general scans of CAV-related practices at the regional and local levels. We then summarize the findings of our own review of long-range transportation plans and other studies for a set of 15 large MPOs and 10 mid-sized MPOs across the U.S. This review illustrates how CAV research is being translated into practice, providing a foundation for key takeaways and recommendations relevant to the context of Illinois MPOs.

General Scans of Practice

As CAV development has progressed, so has interest in how regional and local agencies have responded to this development and the corresponding uncertainties. Guerra (2016) provides one of the earliest snapshots of CAV-related planning efforts at the regional level, reviewing LRTPs and conducting surveys and interviews with practitioners at 25 large MPOs in the U.S. At the time of Guerra's (2016) review, none of the MPOs examined had incorporated CAVs into their LRTPs. However, the surveys and interviews with planners and engineers revealed that transportation practitioners were acutely aware of CAV technology, and that some were taking actions outside of the LRTP framework—such as expert focus groups, scenario planning, travel behavior modeling, technology testing, and assessment of regional investment priorities—to prepare for the arrival and growth of CAVs. Guerra (2016) finds that the uncertainties associated with CAVs, particularly surrounding their potential impacts on communities and regions, were the most important factors preventing planners from fully considering CAVs in their LRTPs. Other barriers to addressing CAVs in the LRTP framework included the presence of other transformative technologies and the notion that CAVs and their impacts are "too far removed from decisions about whether and how to invest in and maintain transportation infrastructure" (Guerra, 2016, p. 214).

Two more recent studies have extended this early snapshot, providing information on how regional and local agencies have adapted during the four relatively transformative years since Guerra's (2016) work. Freemark et al. (2019) do this by examining comprehensive and transportation-specific plans in the 25 largest U.S. cities and surveying transportation planning practitioners in 120 U.S. municipalities. This work finds that while several years have passed since Guerra's analysis, the prevailing approach to CAV planning remains similar: CAVs were only addressed in 36% of the plans reviewed, but the survey results indicated a growing awareness of CAVs and their impacts. Among the plans that mentioned CAVs, the majority did so at a high level only, "[using] language that prioritizes 'innovation' and 'flexibility' rather than concrete regulatory strategies" (Freemark et al., 2019, p. 139). Key barriers to proactive planning included uncertainty and a lack of guidance from state and federal transportation agencies. Outside of formal planning documents, survey respondents were largely aware of potential CAV impacts and believed that CAV rollout would happen quickly, but most described their cities as unprepared and lacking a clear division of responsibility for CAV planning. Along with the findings of Guerra (2016), these results suggest that planners are aware of the transformative potential of CAVs but struggle to include them in their long-range planning efforts due to the considerable uncertainties surrounding their development trajectory and community impacts.

Departing somewhat from the approach of previous researchers, Chatman and Moran (2019) do not conduct a broad scan of planning practice, but rather focus in-depth on the actions of regions and municipalities considered to be “CAV-advanced.” The authors interviewed representatives from cities, transit agencies, MPOs, and technology companies in regions where CAV testing is underway and/or CAV-related policies have been adopted. Similar to previous research, this work finds that “there is little consensus in terms of what cities *should* do regarding AVs, and … the vast majority of municipalities have not carried out planning for AVs” (Chatman & Moran, 2019, emphasis in original, p. iii). Among agencies that have already adopted CAV policies, specific approaches have included regulations for testing, partnerships between transit agencies and CAV companies to plan for first-/last-mile connectivity, reduced parking requirements, and consideration of taxing CAV trips. Chatman and Moran (2019) also find that these efforts are constrained by uncertainty and by a lack of federal guidance. Through their focus on regions in which CAV testing and/or planning is already underway, they also add to the existing literature an understanding of how data-sharing agreements with private CAV companies can be obstacles to proactive planning. Although the approaches taken by CAV-advanced cities have varied considerably, they provide snapshots into how “local and regional public agencies [are] attempting to shape AV activity in order to improve existing and future transportation and livability” (Chatman & Moran, 2019, p. v).

Taken together, these existing scans of CAV practice demonstrate that while awareness and knowledge of CAVs are fairly strong, planning efforts to date have been limited and varied. This lack of translation between awareness and action can be explained by many factors, but most likely results from the considerable uncertainties surrounding CAV rollout and impacts and from a lack of clear guidance from higher levels of government. We add to these existing scans of CAV practice through a review of LRTPs and other types of documents in large and mid-sized MPOs across the U.S., as summarized in the section that follows.

Plans of MPOs

A long-range transportation plan is a long-range strategy and capital improvement program with 20- to 30-year horizons. The plan is aimed at guiding the effective investment of public funds in improving regional mobility and transportation facilities. The plan is usually prepared by MPOs to address their vision and plans for transportation in their respective metropolis and updated every four or five years to reflect occurring changes (Miami Valley RPC, 2016). Based on an assessment of LRTPs in terms of their readiness to CAVs conducted by Guerra (2015), the majority of cities five years ago were not planning for or envisioning a future with CAVs yet. Today, based on our LRTP assessment, the status has changed and many regions, regardless of their population size, have indeed started discussing CAVs in their planning for emerging technology.

For this research, we assessed LRTPs for 15 of the largest MPOs (populations greater than 3,000,000) and 10 mid-sized MPOs (populations less than 300,000). From reviewing the LRTP documents, we found that most MPOs are widely aware of CAV technologies, including the advancements and possible consequences associated with this forthcoming change. However, we also found that responses in the form of CAV planning have been limited and uneven. The majority of the LRTPs had dedicated subsections or a mention of CAVs in the "Technology" section. However, in many cases it was limited to a mention of the technology in general with no contextualization or a broader discussion on the technology's impact on long-range planning objectives. We also learned that many of the metropolitan CAV-related initiatives are not necessarily covered in the LRTPs but are often discussed in separate studies, white papers, and agency reports. Since LRTPs are not always sufficient to determine whether an MPO is proactive, we searched for these types of documents that are either prepared by the MPO itself, a third party (consultant), or the department of transportation of the respective state. For example, the MPO of Chicago has an additional document (Emerging Transportation Technologies) specifically published to address planning for autonomous vehicles. Likewise, the city of Boston has issued a supplementary document to their LRTP (Boston MPO, 2017).

The main source of varying reactions toward planning for CAVs is the uncertainty and timeline of this technology. MPOs have expressed how difficult it is to make concrete decisions and act given the high uncertainties and varying opinions about the drivers and possible impacts of autonomous vehicles. For example, according to Merced County (2018), "[the MPO will] continue to monitor this technology because the schedule for its adoption and implementation, and its implications remain highly uncertain." In general, we have concluded that MPOs are most uncertain about three aspects of CAVs: 1) pace of technological advancement, 2) degree and pace of adoption (consumer acceptance), 3) and potential impacts of CAVs on traffic (e.g., VMT, congestion).

In this section we briefly present how MPOs describe the various drivers and impacts of CAVs on planning. We also list the different levers suggested by these organizations, although these levers are not necessarily being implemented at the current time. Our organization employs the same scenario-based drivers/levers/impacts framework used in the previous chapter.

Drivers

CAV drivers have been discussed in several transportation plans. Although none of the MPOs have conducted their own temporal projection of CAV deployment, several planning documents cite existing references, especially the National Highway Traffic Safety Administration, as to what the CAV timeline might look like. The Houston-Galveston Area Council (2019) states that "key challenges that could potentially slow down widespread use of autonomous vehicles include: testing and approval; development of a regulatory framework; affirmative demonstrations of reliability, security and safety; affordability; and public acceptance."

Technological Advancement

Progress in vehicle technology is moving at a rapid pace. The LRTPs emphasize the development of car sensors, localization abilities, 3D printing, image recognition, wireless communication, adaptive cruise control, cybersecurity of information, etc. All of these features have an indirect impact on people's acceptability and trust in this technology. As a result, when drivers' concerns are addressed, along with assured affordability (Houston-Galveston Area Council, 2019), it expected that the ratio of CAV penetration will increase.

Infrastructure technology that is yet to be further developed and deployed includes 5G technology, Internet of Things, data storage, centralization of database, data integration, big data, drones (unmanned aerial vehicles), online platforms, information sharing, live streaming of signal / intersection data. Additional technology that is yet to be further developed and deployed includes upgrades to the telecommunications technology, fiber, and intelligent transportation systems (Miami-Dade MPO, n.a; Miami-Dade MPO, 2016). Building an infrastructure that reinforces communication abilities between vehicles and the city's physical system enables an efficient deployment of connected and autonomous cars. Based on the assessment of many LRTPs, most cities are not there yet in terms of preparedness (KPMG, 2019). NYMTC (2017), however, has started an initiative of testing connectivity between vehicle and infrastructure by supporting 10,000 vehicles, including city buses. The initiative investigates the efficiency of live data sharing from and to the infrastructure/vehicles (traffic data, intersection status, etc.). Arlington (Texas) has also started updating their traffic signals and data communication infrastructure (North Central Texas Council of Governments, 2018b).

Consumer Acceptance

One of the most important drivers for CAV proliferation (after assuring the technology is safe) is consumers accepting this technology (North Central Texas Council of Governments, 2018a). People are still hesitant about autonomous vehicles. Palm Beach in Florida has shown in their transportation plan that approximately 40% of their respondents are willing to ride a fully autonomous vehicle (Palm Beach Transportation Planning Agency, 2019), while other resources have shown that acceptance rates are increasing (Missouri DOT, 2018). Acceptance rates vary based on demographics, prior experience with autonomous technology, and trust. Several locations such as Georgia DOT are aware of this, which encouraged some of the agencies to increase efforts in marketing and educating their residents about CAVs. Considering any possible demographic shifts, perspectives, and desires for using CAVs highly affects acceptability rates. According to Nashua's MPO, with their current high population of drivers it is expected that as the driving population ages, the need for CAVs will increase (Nashua Region MPO, 2019).

Impacts

Just like the drivers, most MPOs with both larger and smaller populations are exposed to many of the impacts mentioned in the research. They are in fact encouraged to endorse this technology given its positive impacts. Some of the large MPOs show a progressive assessment of impacts by contextualizing several of the expected impacts to their respective areas. San Francisco assessed the opportunities and risks of CAV impacts to their metropolitan area and provided a list of recommended policies and action items accordingly. Opportunities include reduced cost of transportation, reduce parking allowing for housing development, as well as increased accessibility to housing and employment (Horizon, 2018). Similarly, Southeast Michigan MPO projected the possible impacts based on their demographics and state of infrastructure.

Safety

Passenger safety is one of the most certain impacts of CAV technology. The technology is promised to reduce human error close to 80% (Delaware Valley MPO, 2017), resulting in minimal crashes and less fatal accidents. According to a research study conducted by the Jackson Area MPO, cyclists and pedestrians feel safer walking or biking along with CAVs, as they are more attentive and cautious than human drivers (Jackson MPO, 2018). However, virtual safety (cybersecurity) is highly jeopardized and prone to more cyberattacks (Fredericksburg MPO, 2018).

Congestion and Travel

Connected and autonomous vehicles, according to the literature, will have higher efficiency, as they can plan trips and communicate with other vehicles and the infrastructure. Most studies point out that although CAVs might resolve the problem of congestion and increase equitable mobility, it will lead to higher vehicle miles traveled. As a result, experts recommend that extended research should be conducted on potential policies and regulation to control VMT increase (Hunter et al., 2018).

Emissions

If CAVs are to be based on electric charging rather than fuel/gasoline, this results in less vehicle and GHG emissions as well as air pollution (Fredericksburg MPO, 2018; Miami-Dade MPO, 2016; Montachusett MPO, 2017). However, these conclusions are not definite anymore, given that VMT rates are to increase with CAV penetration, and the difficulty of having freight/trucks that are electricity based (due to battery size).

Urban Form and Parking

The size of parking spaces is assumed to reduce since there is no need to accommodate human activity (open/close doors). It is predicted that the decrease in parking spaces will reach up to 80% if CAVs are shared 100% (Nygarrd & Will, 2018). The reduced lane widths and elimination of side parking provides more open spaces and encourages human scale redevelopment (North Central Texas Council of Governments, 2018). Based on these changes, building design is also affected due to less parking requirements and inclusion of more drop-off areas (North Central Texas Council of Governments, 2018).

Levers

Given that LRTPs are comprehensive documents at a regional scale, levers are often discussed at a very high or abstract level, which may make it very difficult to translate into actionable policies or regulations. The most proactive levers discussed in many MPO plans are those related to pilots or testing programs. This "lever" in fact is an action toward understanding the implications of CAVs rather than endorsing/combating possible impacts and driving factors. In some cases, more detailed levers were found in other documents and studies, white papers, and agency reports. These documents often include some guidance for preparing the physical and virtual (data) infrastructure of the city. Additionally, some MPOs encouraged collaborations and working with different stakeholders in order to better plan for CAVs.

Infrastructure Investment

In addition to technology, physical infrastructure itself is influential for CAV deployment such as road markings, road surfaces, road signs, and electric charging stations. LRTPs often talk about the need for investing in the existing infrastructure and updating roads and traffic lights to be smart and well connected to receive and transmit data.

Travel Pricing

Pricing strategies are suggested as a form of controlling endless roaming of CAVs, as they might cause congestion and inefficient traffic flows (Chicago Metropolitan Agency for Planning, 2019; Seattle MPO, n.d.). There has not been any optimal strategies or methods proposed yet. Some travel pricing methods suggested using VMT taxation, cordons, and variable tolls (DFML, 2017).

Parking Policies

Reduction of parking is one of the certain impacts that most literature agree upon. Therefore, it is the most common "aspect" studied with actionable items to be deployed. Many agree on reducing minimum parking requirements (Horizon, 2018), getting rid of side parking (APA, 2019), shifting parking garages to the peripheries, and reducing the size of parking (Shaver, 2019). The city of Chandler in Arizona has already deployed a regulation by reducing parking requirement by 40%.

Multimodal Transportation Investment

Uncertainty can be tackled by designing transportation programs that have access to all modes (flexible and adaptable in the future). Investing in public transportation infrastructure and facilitating the connection between different modes of transportation encourages the use of shared CAVs/SAVs and minimizes private vehicle ownership (Side Walk Labs, 2018; DFML, 2017).

Land Use Planning and Housing Policies

Urban form and land use implication are very uncertain, and as a result, levers are vague as well. However, recommended regulations try to regulate sprawl by using geofencing techniques (Missouri DOT, 2018) and rethinking Euclidean zoning (APA, 2019). There is also a focus on urban design aspects such as developing livable streets, reducing lane widths, and up zoning.

CONCLUSIONS

This literature review has examined the drivers (external forces), impacts (community outcomes), and levers (agency actions) associated with planning for CAVs. With respect to drivers, the propagation and use of CAVs is contingent upon the enhancement of infrastructural technology and vehicular technology, which in turn affect the pace and timeline of CAV rollout. Additionally, the pace of CAV rollout in a specific area is determined in large part by the acceptance and willingness of its residents to use and own CAVs. Based on the literature review, the pace and extent of technological advancement appears to have the strongest magnitude as a driver of CAVs, since it also influences consumer trust/acceptance and provides opportunities for cities to actively install infrastructure changes. The role of technological development as a key driver is well reflected in the LRTPs of both large and mid-sized MPOs, many of which emphasize that technologies such as 5G, 3D printing, and digitalization of infrastructure are essential for better reception of CAVs.

The potential impacts of CAVs on communities are multifaceted and associated with considerable uncertainty. While CAVs are generally expected to be beneficial in terms of traffic safety, their impacts on VMT and congestion are less certain and are highly dependent on rates of CAV adoption, SAV usage, vehicular ownership, driving behavior, number of trips, and other critical elements of travel behavior. CAVs are also likely to have impacts on the built environment by either increasing core densities, expanding suburbanization, or both. Although CAVs are likely to provide greater mobility and accessibility for non-drivers such as the elderly and people with disabilities, CAVs might also have negative impacts on active transportation, social equity, and the environment.

The ultimate impacts of CAVs are also highly influenced by the actions taken by MPOs. While the literature on CAV levers is currently less robust than the literature on CAV drivers and impacts, some levers are addressed. Suggested levers found in CAV research and by MPOs can be translated into traffic control strategies (e.g., VMT-based taxation, congestion pricing, etc.), infrastructural changes (e.g., road markings, signage, adjustment of speed limits, smart intersections, etc.), commuting incentives (e.g., usage of SAVs, usage of public forms of transportation, improvement of multimodal transportation), and design guidelines (e.g., parking policies, reduce right-of-way, charging stations, incentivize denser developments, etc.).

Although there is extensive discussion about possible levers, research falls short in providing a detailed layout of how, when, and where to implement these recommendations. It is difficult for planners to take these levers and translate them into policies and guidelines without knowing which levers to prioritize and which would have the greatest impacts. Additionally, many of the levers are conveyed in a general manner where no contextualization or a critical understanding of the area is reflected. This is where scenario planning would play a valuable role in trying to contextualize these drivers, impacts, and levers, providing the detailed information and direction that are needed for MPOs to plan accordingly.

Most of the mid-sized MPOs included in this review tend to follow a “wait-and-see strategy” (Hunter et al., 2018). However, in order to better plan for CAVs, MPOs could be better served by assessing CAVs in relation to their planning objectives. One of the essential parts of CAV planning is understanding the future impacts of CAVs on delivering improved quality of mobility services, equity provisions, higher accessibility and mobility, and time-travel reliability on their specific metropolitan areas. More importantly, having a grasp of these contextualized impacts allows MPOs to deconstruct what impacts they are able to control, mitigate, or endorse. Since the majority of mid-sized MPOs have not provided a concrete strategy for levers yet, and given the limited budgetary for pilot/testing programs, scenario planning frameworks allow for constructing a better understanding of the desired future based on the organization’s planning objectives.

CHAPTER 3: RESEARCH AND ENGAGEMENT

This chapter summarizes two of the activities undertaken for Task 2, practitioner interviews and resident surveys, and highlights the major activities and key takeaways. We worked with MPO representatives and other stakeholders (1) to understand local preparedness for CAV planning, (2) to refine the basis of our follow-up scenario development exercise, and (3) to generate and narrow the list of relevant impacts of alternative future scenarios.

DEVELOP THE BASIS OF OUR SCENARIO FRAMEWORK

Accounting for all combinations of the multi-layered and uncertain factors would lead to an unnecessarily complex analysis. Thus, our work in this subtask was to focus on developing "packages" of drivers and, separately, levers that can be used to create meaningful scenarios. To do this, we worked on answering two sets of questions:

- Which drivers are most important, and what are the critical uncertainties associated with these drivers?
- Which levers are most relevant to the work of mid-sized MPOs in Illinois, and how are these strategies likely to be coordinated with one another in practice?

We answered these questions through a combination of MPO interviews and household surveys. We conducted interviews with representatives of six MPOs (16 participants), seeking their perspectives on critical drivers, the way these drivers are likely to unfold in mid-sized regions, and the strategies they view as most relevant to their work in preparing for CAVs. The interviews focused on questions about trends and MPO strategies specifically related to passenger transport.

Additionally, we conducted a household survey in the Greater Peoria Region (>700 responses) to gauge consumer preferences concerning a set of future uncertainties such as automobile ownership models (personal vs. fleet), automobile use (single occupancy vs. shared ride), residential location (dispersed vs. compact), and other relevant behaviors. These responses helped us assign more specific, context-appropriate ranges on critical uncertainties for each driver. We also included survey questions that gauged attitudes toward the CAV impacts (e.g., safety, congestion, emissions, job shifts) that were used later to evaluate scenarios. Finally, we asked general questions about location (e.g., suburban, urban), travel behavior, and sociodemographic characteristics to allow stated preferences to be analyzed along these dimensions.

Taken together, the results of the MPO interviews and household surveys helped us identify the critical driver uncertainties and MPO levers around which the scenario framework should be based. Using this information, we identified two packages of critical drivers/levers and two packages of secondary drivers/levers to populate the axes of a refined scenario framework. We used this framework to define four scenarios that capture a range of plausible futures.

PRACTITIONER INTERVIEWS

We interviewed practitioners from mid-sized regions in Illinois to gain their input and perspectives on CAVs and to review local efforts that relate to CAV planning. In particular, we interviewed staff of MPOs, municipalities, and other transportation agencies. The interview list included individuals who worked at any level on technology, transportation, and land use planning. The interview guide for this process is provided in Appendix A.

Goal

The goal of the practitioner interviews was to gather perspectives on critical drivers, the way these drivers are likely to unfold in mid-sized regions, and the strategies viewed as most relevant to planning for CAV rollout. The results of the interviews informed our survey questions as well as our workshop scenarios.

Methods

This effort included interviewing representatives of six mid-sized regions in Illinois. A total of 16 individuals were interviewed from MPOs, municipalities, and other transportation agencies across the following regions: Peoria, Carbondale, Rockford, Springfield, Bloomington-Normal, and Champaign-Urbana.

Interviews were conducted on Zoom for about an hour each. The participants were sent an executive summary and the questions before the interview. The interviews were transcribed and synthesized to then be used for developing the household survey and workshop sessions.

Summary of Results and Observations

Awareness

In general, interviewees were well aware of CAV technology. Some reported attending conferences, joining committees related to CAV planning and technology, and/or incorporating CAVs in their long-range transportation plans. Some regions have also conducted scenario planning efforts and included the results in their transportation modeling process.

Uncertainties

Interviewee comments on critical CAV uncertainties are summarized in Table 3. These comments suggest critical unknowns ranging from CAV technology itself and its development timeline to the role of government and the private sector in steering and managing this technology.

Table 3. Summary of Perceptions on CAV Uncertainties

Topic	Uncertainties
Consumer preferences	- Public engagement, reaction, and awareness - Consumer acceptance - Cost
Land use and mobility	- Extent of sprawl - Car ownership and ridesharing model - Implications of CAV on VMT and traffic
Technology	- CAV definitions - Data - Timeline - Safety - Digital infrastructure readiness
Government and private sector	- Funding and support - Engagement and awareness of government - Extent of private sector penetration - Regulation and liability
Planning	- Extent of infrastructure needs and readiness - Equity concerns - Long-term planning - Implementation challenges

Consumer Preferences

One of the most common themes raised by interviewees was uncertainty of how residents and communities would react to CAV technology. Several participants noted that based on regional demographic and socioeconomic characteristics, there is considerable uncertainty surrounding the adoption and use of CAVs. As one interviewee stated, "the majority of the residents don't know about CAVs. There are people who have electric vehicles which might be more aware of CAVs; however, that's a smaller population."

Others emphasized the importance of trust and safety in influencing CAV adoption. One interviewee noted "the sheer anxiety of people being tracked, and their privacy taken away" as a critical barrier, while another saw public acceptance as paramount in CAV development: "Regardless of the technology's progress, the public's acceptance and adoption will drive and steer the layout and projection of this technology."

Along with public trust and perceived safety, interviewees expressed the influence of cost and return on investment from the consumer perspective. If CAV costs are prohibitively high (as with current CAVs already on the market), this will alter adoption models and have a detrimental effect on who can use this technology.

Land Use and Mobility

Most interviewees expressed concerns about sprawl, but usually as an inevitable outcome rather than an uncertainty. However, one participant expressed doubt about whether people would choose to live further away from work and everyday destinations. Another interviewee brought up the opposite direction of influence—that is, existing patterns of sprawl may influence the extent and layout of CAV adoption.

Most participants also described uncertainties about CAV adoption and use, including who will use CAVs and how. These considerations will influence congestion, commuting patterns, miles traveled, infrastructure needs, and overall mobility. Some explained the challenges that these uncertainties create for land use, urban design, and planning for other modes such as public transportation, noting that the extent of uncertainty often prevents agencies from considering CAVs in a meaningful way.

Technology

Two aspects define technology in this context: CAV technology and digital infrastructure technology. For infrastructure technology, some interviewees expressed concerns about how current infrastructure investments might not suit CAVs in the near future. Most importantly, they are uncertain of what has to be done in terms of preparing the data infrastructure for CAVs. Interviewees noted a limited understanding about what types of data and data infrastructure would be needed, and how the data would be managed and used in intelligent transportation systems. As one participant noted, "what will happen to the enormous amount of data collected and extracted? And how [will] data [be] accessed and secured?"

Another critical uncertainty is the timeline of CAV development. Several interviewees mentioned that the timeline is important because different stakeholders plan for different time horizons; for instance, MPOs usually plan for 20 years and update their plans every three to five years, which can be detrimental if CAVs are not considered while they are evolving quickly. On the other hand, municipal entities such as public works departments plan and implement on much shorter time horizons, which could jeopardize the swift adoption of CAVs.

One interviewee asked: "What is CAV? Is it a car that I buy that I don't have to drive? A car that nobody is in? You send it around alone? What's the technological level?" Along with the timeline, how the Society of Automotive Engineers (SAE) levels will rollout and what are their capabilities are also very uncertain, which hinders planners and decision-makers from foreseeing a clear CAV future.

The extent of safety of the technology is mentioned by several entities, especially that their current planning concern is enhancing active transportation infrastructure. In fact, most infrastructure development and policies recommend prioritizing protection of pedestrians and cyclists. Therefore, one respondent noted the importance of having a mature CAV technology: "its ability to detect pedestrians and cyclists especially in lighting and bad weather condition." Not only are they concerned about CAVs' performance with active transportation, but also their interaction with typical automobiles. One respondent asked: "how safe will it be to introduce a CAV especially in a place that already has enough accidents?"

Government and Private Sector

Financial funding and support seem to be the most unknowns to many regions. CAVs will require a source of funding for preparing the infrastructure, subsidizing transit, and spreading awareness. One respondent inquired, “Who would be best to pay for technologies to happen?” The uncertainty of funding persists even throughout CAV deployment. One responded asked, “What about retrofitting and maintaining the road infrastructure. It’s already challenging to use the funds for current problems which are non-CAV related.”

Government engagement and endorsement are vital for the successful planning of CAVs. However, according to several MPO and city staff, in many cases elected officials might have no buy-in or understanding for this technology, which makes it difficult to even study CAVs in a contextualized matter: “for example, our public works department was led by a traffic engineer who was concerned with traffic problems only.” According to one interviewee: “in some cities, due to the pandemic, many leaders and employees are retiring which might affect the outlook on CAVs due to the loss of institutional knowledge.” However, it is not enough that the government endorses this technology, but there should be alignment between the visions of the governments and residents.

Long-term planning requires a good grasp of many factors influencing transportation and land use in the long run. Given that this technology is mostly developed, enhanced, and steered by the private sector, it is very challenging to drive and control CAV rollout. According to one interviewee: “this might be a private sector initiative; maybe wait for General Motors to come and bring the fund and start/push for CAVs. However, cities with more CAV private sector funding will make it tough on us.”

There are many unknowns in the managerial and logistic aspects of CAVs such as the regulation and liability of CAVs: “Liabilities? Who is responsible when it comes to accidents? Is there a threshold of CAV users?” Cities, therefore, should not only look at infrastructural and community preparedness, but also “legal and policy preparedness.” Since CAVs have a vague understanding of their functioning and liability, one interviewee is concerned: “[Who has] the responsibility of planning in overlapping jurisdictions? How do you make sure that the roads CAVs drive in Illinois standards will be able to make sure CAVs drive on other roads from different states?”

Planning

Planning (specifically urban planning) for CAVs has been brought up several times during our interviews. Due to the extent of uncertainties, some interviewees expressed how difficult it is to plan for CAVs when there is no clear guidance. How would regions know if their infrastructure is ready to receive CAVs? And how are research and technical reports applied on a day-to-day basis? One of the interviewees mentioned it is not enough to know about the details of technology and its updates only; stakeholders must also know how to implement that in road infrastructure, building codes, and road design. One interviewee specifically stated: “How will we move from normal cars to CAVs?” Planners and agencies emphasized how much uncertainty hinders long-term planning: “It’s difficult to plan for things that are not very clear yet.”

Also, the readiness of cities to receive such a technology was brought up during interviews. One interviewee stated: “Are we socially and governmentally ready?” Not knowing the extent of a region’s readiness for accepting such a technology creates additional obstacles for regions to start planning for these technologies. One region mentioned that maybe one proxy to assessing CAV readiness is through evaluating the level of electric-mobility readiness.

One of the biggest unknowns and uncertainties of CAVs is their impact on equity. Since this technology has been mostly steered by the private sector, the positive impacts on the economy and community are not necessarily part of the private sector discussion. One interviewee mentioned that the COVID-19 pandemic has exposed several social inequities, which should encourage planners to rethink all the possible inequities of CAVs and how residents might react: “[CAVs might] exacerbate the transportation equity problem. How do we meet required CAV demands especially if the affluent will exceed in adoption in relative to poorer communities.”

Impacts

In many cases, the interviewees have expressed their biggest unknowns as the possible impacts of CAVs. Therefore, their concerns are related to how the technology might influence their cities and to what extent. Land use and mobility implications are the two most discussed topics. Table 4 presents a summary of interviewees’ perceptions on the possible impacts of CAVs.

Table 4. Summary of Perceptions on the Possible Impacts of CAVs

Topic	Impacts
Land use	- Land use - Parking and curbs - Sprawl
Mobility	- Congestion - Commute - Public transportation - Ownership model - Mobility as a service
City revenue	- Gasoline tax - Parking revenue
Social equity	- Losing a source of income - Reduced access to mobility

Land Use

Since CAVs might facilitate more vehicular ownership and facilitate mobility, sprawl is often cited as a highly occurring consequence of CAVs. Both MPO and city staff expressed concern about sprawl since CAVs will encourage people to spread away and increase VMT. CAVs causing sprawl is not only an unsustainable model of growth, but is also unstainable from an economic perspective: “Sprawl can’t continue because this will require maintaining (potholes, signage, etc.) streets even more.”

Land uses according to a city staff member will not be impacted that much by CAVs. However, today’s COVID-19 pandemic has impacted different land uses such as the shift toward a “home/office type of work.” This might induce acquiring larger homes and apartments.

With CAVs requiring less parking, planners and engineers are thinking about what might happen to parking demands as well as vacant parking spaces. They are aware that curb management becomes a necessity and might require further studies of how to incorporate CAVs as part of their planning and design. On the other hand, one interviewee stated that their region might require additional parking given the older housing stock.

Mobility

The concept of moving from one place to another will change dramatically. However, according to several interviewees, much of this is unclear yet: "CAVs will affect the ownership model and vehicle adoption rates. Here it is more about safety rather than transportation." One region expected that more people are to use mobility as a service. On the other hand, another region stated: "public transportation might be negatively impacted causing less ridership." Given these uncertainties, one planner suggests that it is impossible to learn more about the impact of CAVs on mobility without testing them on real roads: "The primary impact we should monitor is about traffic volumes, especially VMT increases and how the CAVs will be used."

City Revenue

Tariffs collected from the city's parking spaces and gasoline taxes will have a hefty impact as governments are dependent on such incomes. One interviewee asked: since these are legacy tax mechanisms, how will the government deal with electric-based vehicles that require much less parking? If CAVs are to be electricity-dependent, who will take charge of such energy sources, and how will they be charged in the case of shared mobility scenarios?

Social Equity

Based on the interviews, CAVs will impact both drivers and riders and will raise social equity problems specifically related to access to mobility and economic status. The introduction of CAVs will take away some income from individuals who are using vehicles as a source of income such as Uber and Lyft or any other delivery serivces. One interviewee asks: "What about people who can't afford shared riding? What will happen to people heavily depending on transit if it is negatively impacted?"

Therefore, the suggested solutions were that cities have to make sure that CAVs "help all parts of the society" to be equitable. However, if the market will be left to lead the rollout and adoption of CAVs, equity problems are sure to arise.

Levers

Levers suggested by MPO and city staff are not necessarily directly tied to CAV technology but rather the requirements to move forward with planning for this technology. Therefore, one of the most important steps is to assess each lever and assign a responsible entity to carry out each of these action items and internal decisions. Table 5 presents a summary of interviewees' perceptions on various action items to be adopted by their entities or other agencies to prepare for CAVs in the region.

Table 5. Summary of Perceptions on Various Action Items to Be Adopted by Their Entities or Other Agencies to Prepare for CAVs in the Region

Topic	Levers
Communication	- Consider autonomous vehicles in upcoming projects - Education of people/staff and planners/engineers - Synergy between stakeholders
Policy	- Technical/policy guidance - Standardization - Subsidize mass transit
Planning	- Control sprawl
Action items	- Update infrastructure - Start testing - State support

Communication

Almost all of the regions stated that there must be a mechanism for sharing knowledge and better communication between the different stakeholders, including community members. But before that, it is important to spread awareness and educate staff, planners, and engineers about the future of autonomous transportation and mobility. The reception of CAVs varies from one region to another, depending on how much knowledge residents and staff have about CAVs. Therefore, “MPOs should have more forums to discuss CAVs,” according to one respondent. According to a few regions, “thinking about CAVs” should be further encouraged in planning departments and people should be surveyed so they are made aware of the technology and the city is more conscious about residents’ reactions. This “thinking” can start with studying connected vehicles that are not autonomous first and then gradually upgrade to connected and autonomous vehicles.

Communication indicates that all involved staff from the different regions and various entities communicate with each other and collectively “engage in the discussion to choose the vision(s) and collect data.” One interviewee stated that there should be “inter-MPO cooperation regardless of region size,” as this would allow more coherence and effective planning for CAVs at a state level. One region stated the importance of coordination between MPOs, agencies, academia, city, etc., when creating local standards.

Policy

According to several interviewed staff, although as regions they are enthusiastic about CAVs, it is difficult to plan for these technologies without any guidance at the policy level and technical level: “There are very broad and loose guidelines by the state. For example, do we have to do any changes on the street, signals, current guidelines?” This guidance extends to the types and levels of automation (SAE levels), the minimum requirements in the physical infrastructure (e.g., fiber optics, 5G, etc.), and how to start preparing the digital infrastructure. One interviewee stated that it is important to start “thinking of the Intelligent Trasnportation Systems (ITS) network/Internet Enhanced Service (IES) architecture from now to be able to plan long term.”

Standardization of policies or design guidelines is vital for an effective rollout of CAVs. According to one respondent, “Design guidelines and policies are mainly going to be driven by the technology.” Therefore, according to any planning employee, it is vital to make sure that whatever guidelines are developed align with other states/jurisdictions. This includes regulatory factors and liabilities. CAVs are expected to have a negative impact on transit, so one of the policies to be assessed and introduced is subsidizing mass transit. One respondent noted that to assure an equitable future for mobility, it is important to “reduce costs due to people who don’t have access to mobility.”

Planning

Sprawl is expected to grow in a CAV-dominated future; however, “there is less funding on maintaining suburb infrastructure,” acccording to one respondent. Planners have suggested that sprawl should be controlled, otherwise we are looking at an infrastructure crisis.

Action Items

Several interviewees stated that the state has to provide adequate support for CAVs at the planning level: “We need additional state resource[s] that can fund/support such as energy programs, fiber programs that can be captured.” This includes guidance and funding expertise and staff by Illinois Department of Transportation and other stakeholders.

According to many of the planners, especially those with substantive experience in technology, updating the infrastructure can start as soon as now. This can simply start with “transferring to single-channel fiber” to support faster bandwidth instead of the legacy communication/network systems. This can also be extended to improving traffic lights (smart signals connected to the digital network). Electric charging stations should be thought of as well since this requires a special infrastructure (i.e., power generators). Other infrastructural updates include enhancing pedestrian and cycling lanes, as these will exist along with CAVs. Additionally, parking codes can be updated to allow for more off-street parking.

Along with infrastructural updates, CAV testing should start taking place: “[We should] utilize MPOs to begin pilot programs from planning to implementation.” The only way to visualize and quantify the impact of CAVs on each region is by testing CAVs on the road.

Obstacles

One of the recurring themes during our discussions with our interviewees is the hurdles and obstacles they face as they think about CAVs. These obstacles are related to procedures and processes of planning rather than the CAV technology itself. These can be related to state guidance, funding, and lack of expertise. Table 6 presents a summary of perceived obstacles faced by practitioners when preparing for CAVs.

Table 6. Summary of Perceived Obstacles Faced by Practitioners When Preparing for CAVs

Topic	Obstacles
External	- Timeline - Adoption rates - Lack of guidance - Funding - Difficulty to engage with the private sector - Planning like bigger cities
Internal	- Lack of expertise - Lack of education - Lack of resources (staff and monetary) - Data - Continuous updates/learning

External

There are external forces that hinder cities from being able to effectively plan for CAVs. The most important external force is the timeline of CAV development. Interviewees expressed how the uncertainty of CAV timelines might provide some difficulty when updating their long-range transportation plans. Just like the vague timeline of CAVs, the adoption rates of CAVs delays planners from imagining different futures. One interviewee stated that it is "impossible to manage adoption rates through mandates, which will influence maintenance standards."

Also, the lack of funding and guidance imposes MPO and city planners to take a slower pace on planning for CAVs: "funding for CAVs is very doubtful and would be minor." As stated previously, since the private sector is taking the lead on this, engaging with them seems very difficult and "infeasible anytime in the foreseeable future."

Usually bigger cities are more prone to plan for CAVs due to their density, abundance of resources, and engagement with the private sector. However, smaller regions should be aware that mid-sized and larger metropolitan regions are inherently different. This means that these MPOs "cannot plan like bigger cities."

Internal

For internal forces (factors that a region can control and make decisions), the lack of expertise and resources also presents an obstacle for planning for CAVs. Lack of education, whether for residents or staff, hinders regions from moving forward and planning for CAVs: "It comes from the unknown and lack of education. NIMBYism, classism, racism, we lack political support." However, to resolve this issue, we need "effective education. Marketing and social media to help with that and understand human behavior."

Data also places an obstacle on current planners. Whether this data is collected from smart road networks or retrieved from other resources, region planners are not sure how to handle this "sheer amount of data" and, most importantly, how to utilize/analyze it for better CAV planning. Another data obstacle that these regions stated was the access to data from other cities and vendors (e.g., the truck industry).

Finally, the continuous and fast updates on CAVs might cause obstacles as they are fluctuating and changing every day. This requires planners to be up to date with the latest advancements in technology; however, the nature of long-term planning is less rigorous toward fast-paced changes like the development of CAVs.

Differences between Mid-sized and Large Regions

Most interviewees agreed that there are differences between CAVs' impacts and rollout in larger cities versus smaller cities. However, one interviewee stated: "I don't see a big difference in our town." The interviewee supported their stance by stating that CAVs' impact is highly connected to congestion, which exists in their respective town as well.

Time

Most interviewees agreed that CAVs will require more time to penetrate mid-sized regions: "demographic status might not need CAVs; maybe after 10–20 years." As a result, MPOs and cities in mid-sized regions might not have to plan for CAVs as early.

Mobility

Interviewed planners stated that the conversation about commuting is much more impacted in cities. Cities already have a larger number of transit users, and "hyper commuters might be increased in larger cities." CAVs will have a larger impact in larger cities, because the technology mostly impacts the transit system. One interviewee stated that "CAVs will have an immediate impact in areas with more congestions and higher interactions between vehicles and pedestrians." The interviewee concluded that regardless of the size of the region, the impact of CAVs depends on the extent of congestion. One planner supported this by saying: "it's about the extent of urbanism and number of cars rather than the region itself."

People

Larger regions "have more density to support pilot programs as people are more willing to share rides in cities." Also, the reason behind adopting CAVs is different from one place to another. "Here it's more about safety rather than transportation," said one of the interviewees.

City

- Larger cities have more authority on how CAVs (Google/Uber/Lyft) might shape their future.
- Smaller cities are more vulnerable since the private sector is leading it, and they do not have much influence on its rollout.
- CAVs influence not only mobility, but also fiscal projections, parking revenues, and reduction of businesses. Therefore, regions will witness different impacts based on their size.

- Infrastructure maintenance and development of smaller regions is lengthier by nature, which impacts the CAV adoption and deployment curve in these regions and cities.
- Funding is a shared problem regardless of the size of the region, as stated by interviewees.

Key Takeaways

Through our interviews, we found that most practitioners are aware of CAVs as a future technology. Many expressed that they look forward to this technology reducing VMT and congestion rates along with assuring higher safety impacts, especially for pedestrians and cyclists. However, each region's reaction and consideration of CAVs within their planning processes and projects varied. Most regions have not had any direct consideration for CAVs in their current or future projects. There are entities, however, that conducted some studies to contextualize the drivers and impacts of CAVs and tried to incorporate the consequent findings in their planning procedures and efforts.

Interviewees expressed many uncertainties related to CAVs. The most prominent ones were related to consumer preferences and adoption rates, state support and funding, as well as issues related to equity and accessibility. This uncertainty also extends to the action items and the extent of their scope when planning for CAVs.

Regardless of how much these regions believe they are ready for this technology, practitioners recommended the following steps to plan for CAVs more effectively. First, there must be a spread of CAV knowledge and clear and extensive communication between the various stakeholders, including DOTs, MPOs, private sector, city staff, and decision-makers. Second, any infrastructural updates must incorporate CAV requirements such as 5G and fiber-optic channels as well as consideration for data generation and storage. Third, some practitioners suggested having pilot programs and CAV testbeds for assessing this technology at a local level.

When asked about potential obstacles for planning for CAVs, interviewees expressed how the uncertainty of CAV timelines might create difficulty when updating their long-range transportation plans. Additionally, the lack of expertise and resources presents an obstacle to planning for CAVs. Finally, the continuous and fast updates on CAVs might cause difficulties, as they fluctuate and change every day.

Finally, practitioners and experts expressed that there is a difference between planning for CAVs in larger cities versus smaller regions. This is because larger cities have higher density, greater penetration of transit, and stronger authority over the private sector. Many projected that CAVs will require more time to penetrate mid-sized regions. However, they stated that funding is a shared problem regardless of the region's size.

HOUSEHOLD SURVEYS

To cross-validate results from our literature review and stakeholder interviews, we conducted a household survey. Surveys were sent to over 5,800 households in the Peoria region. We received 733 responses, which is twice the conservative response rate of 6.2% we were expecting. These surveys provided us with information about respondents' current use of different forms of transportation, their attitudes toward CAVs, how they might use CAVs in the future, as well as their basic personal and household characteristics.

Goal

The goals of the survey are to identify the major impacts of self-driving cars on communities in Illinois and the factors that planners and policy-makers should keep in mind as they plan for the future. This includes understanding how individuals and households in mid-sized MPOs perceive CAVs and might adapt to their proliferation. Assessing these results and understanding the perception of residents will allow us to assign a specific, context-appropriate range on critical uncertainties for each driver and lever. The primary research questions for the household survey were as follows:

1. How willing are residents of mid-sized regions to adopt CAVs in varying formats, and why? (Overall willingness, willingness to share rides [vs. single-occupancy travel], willingness to participate in shared fleet [vs. personal vehicle ownership])

2. How might their travel behaviors/preferences change in response to CAV availability?

3. How might their residential location choices/preferences change in response to CAV availability?

4. What are their attitudes toward the types of impacts that CAVs may have on their communities?

Please see Appendix B for the full list of questions.

Methods

We first shared our survey content with the project's Technical Review Panel members to seek their feedback and comments. After incorporating their feedback in our survey draft, we applied for Institutional Review Board approval at the University of Illinois Urbana Champaign and received it.

We contracted with a third-party consultant for printing the surveys and sending out mail. The survey was distributed to more than 5,800 randomly selected households in the mid-sized Greater Peoria metropolitan region. The population of Greater Peoria is 406,883 (U.S. Census Bureau, 2019). The survey was distributed between May and June 2021, where our response rate was 12%. A total of 735 household representatives, aged 18+ years old, completed the survey. Although the survey was distributed through mail, the respondents had the option to complete the survey online through Qualtrics.com (https://go.illinois.edu/Self-driving-cars-survey). Less than 20% of those who responded opted for the online option.

Summary of Results and Observations

Demographics and Context Analysis

Most of our respondents were male (59%), whereas 37% were female. Likewise, most respondents (87%) identified as "white" for their ethnicity/race. The mean age of our respondents was 60 years old, and 74% of respondents ranged between 50 and 80 years old (Figure 2). Most of the surveyed respondents (86%) indicated they had a college degree or above, suggesting our survey sample was educated to a high degree. More than 58% of respondents specified their household income was above $75,000 annually (Figure 3), and 74% stated that their household size is between two or less. Approximately half (47%) of respondents identified as retired for their employment status. A total of 74% have rated their health as either *good* or *very good.*

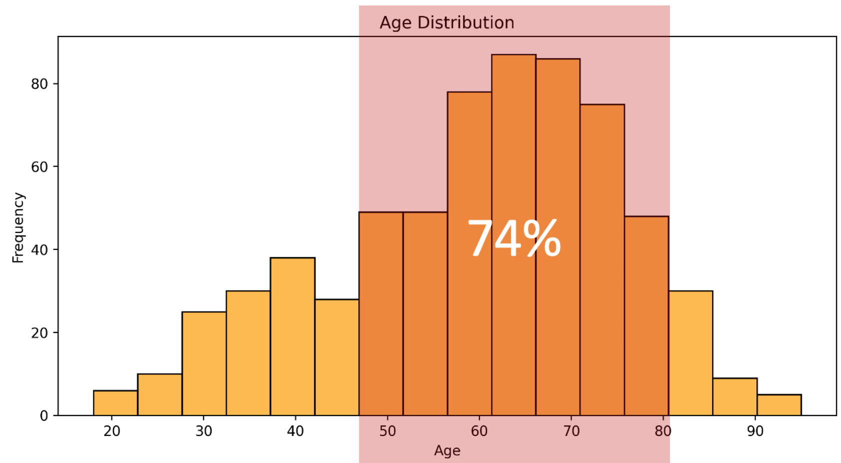


Figure 2. Age distribution.

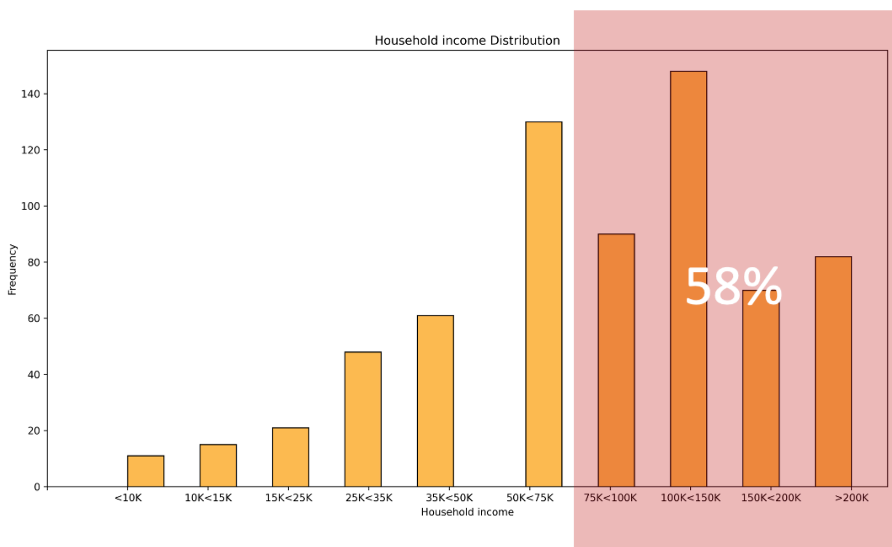


Figure 3. Household income.

Figure 4 presents the respondents' driving habits and living context. Most respondents (95%) stated that they use a car predominantly for daily trips and travel to work. The second most used mode of transportation is walking (1.2%) and less than 4% used other methods or a combination. Also, the majority indicated that they either live in a suburb (56%) or a rural (25%) setting. Only 19% said they live in urban neighborhoods.

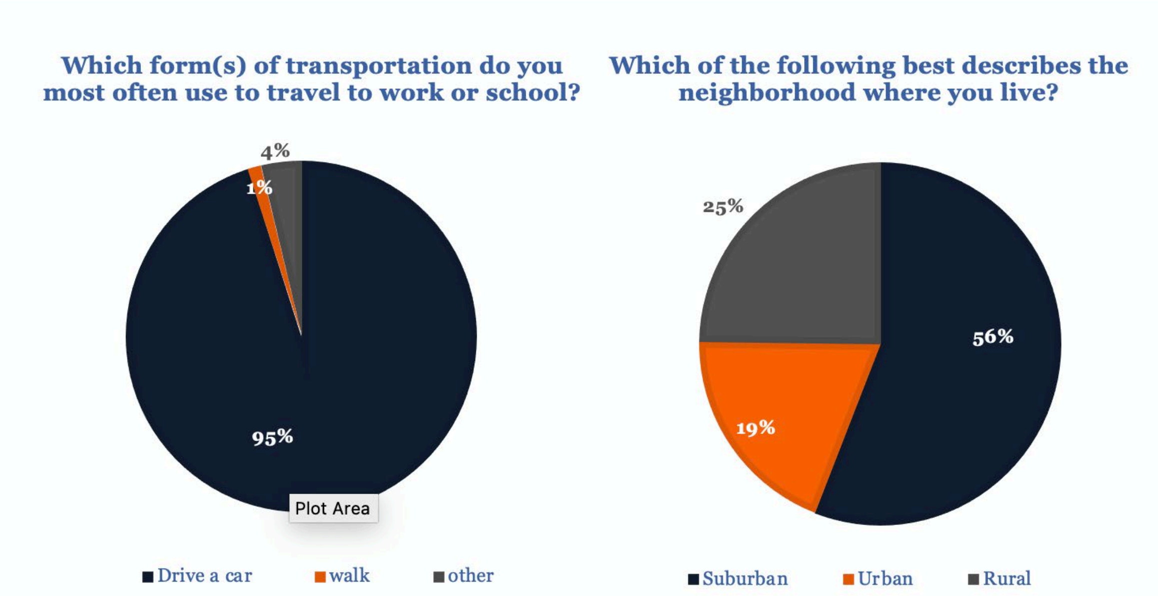


Figure 4. Driving habits and living context.

Perception of CAVs

Figure 5 presents respondents' general perceptions on CAVs. Although the majority (98.5%) stated that they have at least heard about CAVs, only 20% believed that CAVs might become affordable. In addition, 74% believed that CAVs will be available in the next 20 years; however, only 40% of respondents thought CAVs will be safer. However, from a hacking and privacy perspective, more than 50% believed that CAVs will not be safer. Only 36% believed that CAVs will be better for the environment. However, 34% said they are unsure/undecided for this question, which implies their potential lack of knowledge about the environmental impacts of CAVs. Finally, more than 55% believed that CAVs will not help them reach places faster.

Adoption of CAVs

Less than a quarter believed that they would travel more. Although CAVs promise passengers will be able to conduct other tasks during their commute, about 50% stated that they would still mind the time spent in the car. CAVs do not seem to impact the respondents' living preferences, since 82% stated that they do not expect to live farther from work and 84% do not expect to live farther from their daily destinations.

Travel Behavior with CAVs

Less than 30% shared that they will use or own CAVs. However, more than 65% stated that they will not subscribe to CAV-based ride-sharing/ride-hailing services. Only about 50% said they might be open to sharing rides with people they know (i.e., fleet-sharing). However, 83% were completely against sharing rides with strangers (i.e., ride-hailing). Car ownership was deemed so important that 87% stated that they do not expect to forgo their cars. In fact, the majority (65%) mentioned that they do not expect to even reduce cars per household when CAVs are available.

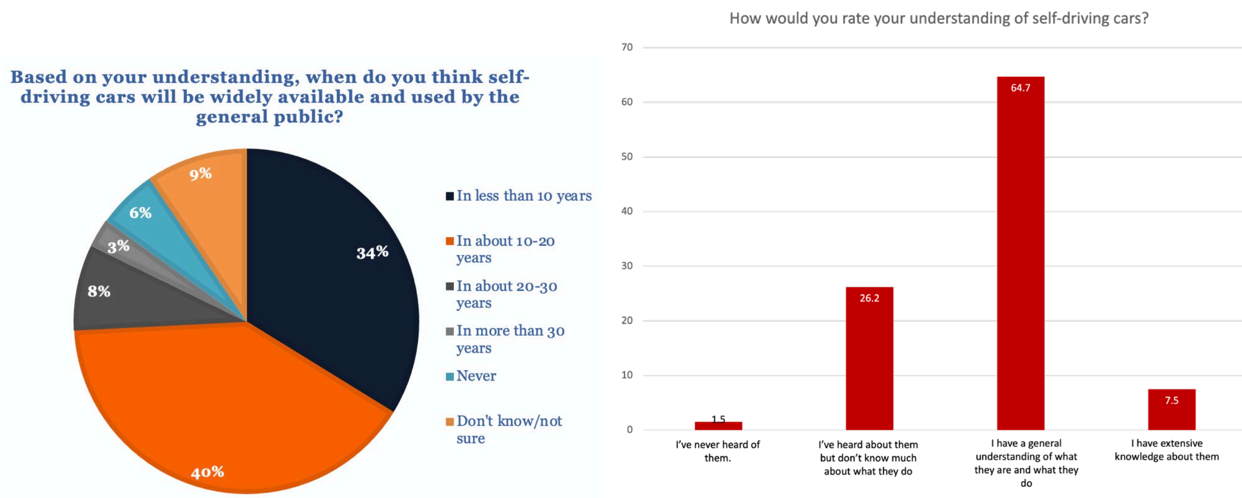


Figure 5. General perceptions on CAVs.

Cross Tabulation

Our analysis investigates the impact of sociodemographic characteristics on CAV perception, adoption, and behavior. We use the chi-squared test to investigate the significance of the relationship and Kendall's tau to identify any categorical correlations.

Perception

We cross tabulated the perception results by sociodemographic and highlighted factors that had p-values ≤ 0.05.

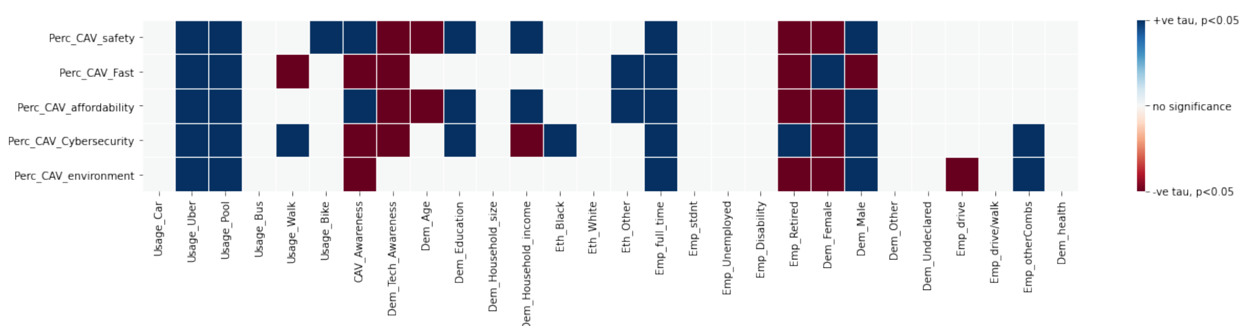


Figure 6. Relationship between demographics and CAV perception.

Figure 6 is a matrix visualizing the significance and direction of the relationship (positive/red or negative/blue) between demographic metrics and perception of CAVs. We can, for example, see a positive and significant relationship between gender, employment, age, and CAV/tech awareness. We found that males are more prone to believe that CAVs are safer, affordable, and environmentally friendly. On the other hand, females were exactly the opposite. They perceived CAVs to be faster but not safer, affordable, or environmentally friendly. Fully employed individuals are more optimistic about CAVs' safety, emissions, efficiency, and affordability. Retired respondents were pessimistic about CAVs' impacts, except for their cybersecurity. Finally, awareness of CAVs did not always mean positive views on CAVs, as some respondents expect them to be inefficient and vulnerable from a cybersecurity standpoint.

Adoption

We cross tabulated the adoption results by sociodemographic and highlighted factors that had p-values ≤ 0.05.

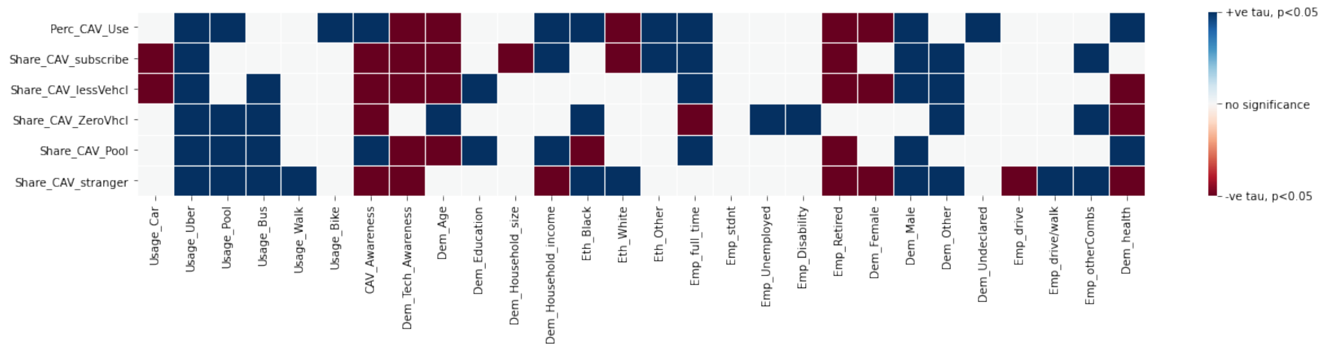


Figure 7. Relationship between demographics and CAV adoption.

Figure 7 is a matrix visualizing the significance and direction of the relationship (positive/red or negative/blue) between demographic metrics and CAV adoption metrics. We can, for example, see a positive relationship between CAV awareness and willingness to use all modes of CAV sharing. People who use modes other than driving (Uber, bike, bus) are more willing to own fewer vehicles, share rides, and subscribe to sharing services. On the other hand, people with more CAV awareness are willing to use CAVs but are less willing to share rides and subscribe to sharing services. Age is negatively correlated with vehicle ownership, where older adults are more unaccepting of giving up on their cars. Retired individuals are less willing to use and subscribe to sharing service (rides or fleets). Males are more willing to use and share CAVs, whereas females are less willing to share rides. That might be related to females feeling less safe and secure when with strangers.

Behavior

We cross tabulated the results of CAV expected behavior by sociodemographic and highlighted factors that had p-values ≤ 0.05.

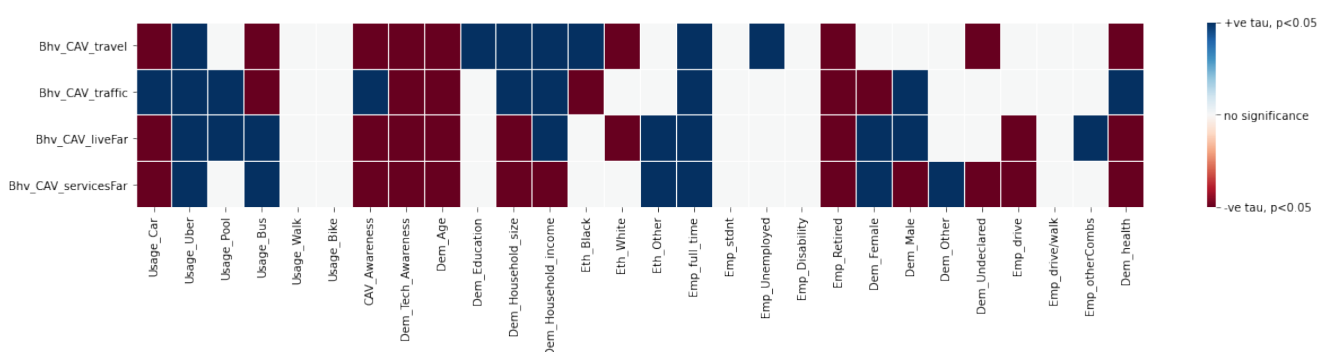


Figure 8. Relationship between demographics and CAV behavior.

Figure 8 is a matrix visualizing the significance and direction of the relationship (positive/red or negative/blue) between demographic metrics and CAV adoption metrics. We can, for example, see a positive relationship between future behavior and age. Retirees are expected to travel less and live farther from employment centers. Fully employed respondents are the opposite. Those who drive frequently for school/work do not expect to relocate farther or travel more. However, they would not mind spending more time in the car. People who currently use ride-hailing or car-pooling expect to live further in a CAV future. Higher income households expect to travel more, spend more time on trips, and live farther. Respondents who were more aware of CAV technologies and their impact generally do not expect to travel more or live farther. This might be due to their awareness of CAVs' negative impacts such as increased VMT, emissions, and congestion.

Key Takeaways and Policy Implications

Overall, we found that the majority of respondents are aware of CAVs and their capabilities, but CAV awareness did not warrant optimistic views on CAVs. Lower interest and higher negative perceptions of CAVs were found among respondents who were older, female, and retired. The majority of respondents would still want to own private vehicles.

These findings suggest a greater need for understanding community concerns, further researching CAV impacts and best practices, and addressing community concerns through effective, locally relevant responses. Communities where ride-hailing and fleet-sharing can be a challenge may explore opportunities to manage the impact of private ownership, such as taxing based on usage or vehicle miles travelled. Public awareness and education should also cover aspects of CAVs that encourage greater safety and lower emissions. A framework for scenarios and an approach to policies and design guidelines that build on this primary research are presented in Chapters 4 and 5, respectively.

CHAPTER 4: SCENARIO FRAMEWORK

Findings from the research activities described in previous chapters—including the literature review, planner interviews, household survey, and stakeholder workshops—were used to refine the CAV scenario framework and develop a set of policies and design guidelines for proactive CAV planning in mid-sized regions. The primary output/deliverable for this culminating step is a detailed practitioner handbook, which guides users through the process of identifying scenarios, choosing action items, and, if desired, tailoring the scenario framework even more closely to the unique context of a given community. This handbook has been made available as a separate, standalone resource. For documentation purposes, we have also included a copy of the handbook in Appendix D of the present policy report. Additionally, we provide a brief, high-level summary of the scenario framework in the present chapter and of the policies and design guidelines in Chapter 5.

THE FRAMEWORK

As we develop our scenarios, we must think about the appropriate drivers and levers that relate to our goals (as an agency or department) and what are the important factors to be considered. The diagram (Figure 9) shows an abstraction of how the choice of levers and drivers create a set of scenarios that might be of our concern. The primary dimensions (x-axis, y-axis) construct the main point of concern and are easily visualized on an XY plane. However, this framework also allows for further complexities to be considered through additional dimensions (i.e., secondary dimensions). Secondary dimensions can either be levers or drivers and are considered necessary for the construction of the scenario framework. Each scenario can then be compared and assessed individually based on a set of impacts that, once again, are prioritized by different agencies. Based on our research, we have created a bucket list of drivers, impacts, and levers that can be chosen from Figure 9. These can vary from one application to another, depending on each entity's procedures and final goals. By selecting the appropriate dimensions, the scenarios are created accordingly, and impacts are evaluated.

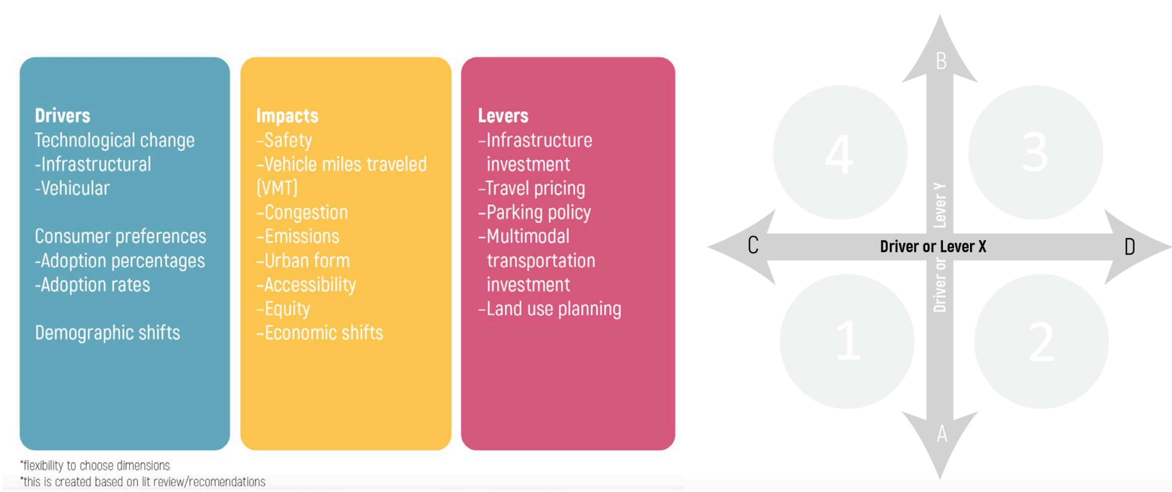


Figure 9. Drivers, levers, and impacts required for constructing the dimensions of the scenario framework.

Based on our surveys, discussion with transportation planners, technical leads, and decision-makers, we have developed a scenario framework that covers the most highlighted uncertainties. The dimensions we chose are Mode of Transportation and Type of Ownership. Based on the intersection of these two dimensions, four scenarios are generated. Please see Figure 10 to understand how we apply these dimensions and how the scenarios are generated accordingly.

Based on Figure 10, the first primary dimension (x-axis) underscores Mode of Transportation. This shows the extent of people using different modes of transportation. The second primary dimension (y-axis) we have chosen is Type of Ownership. This is important since it is expected that CAVs will take different forms of sharing and ownership such as ride-hailing and fleet-sharing. The third dimension is a secondary dimension (therefore not visible in the diagram) and highlights the extents of electric vehicle usage. This is also an influencing factor when considering emissions and pollution. Based on our literature review, surveys, discussion with transportation planners, technical leads, and decision-makers, we create a profile for each scenario describing the extent of each dimension. Please see Figure 10 and Figure 11 to understand how we apply these dimensions and how the scenarios are generated accordingly. We have omitted Scenario 4 from our analysis since we do not see this (shared-yet-single mode) as a plausible future.

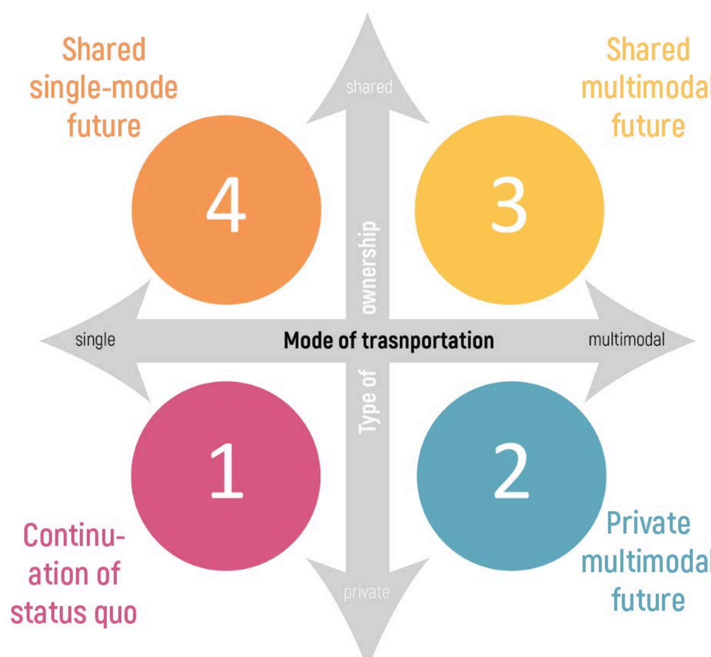


Figure 10. The scenario framework.

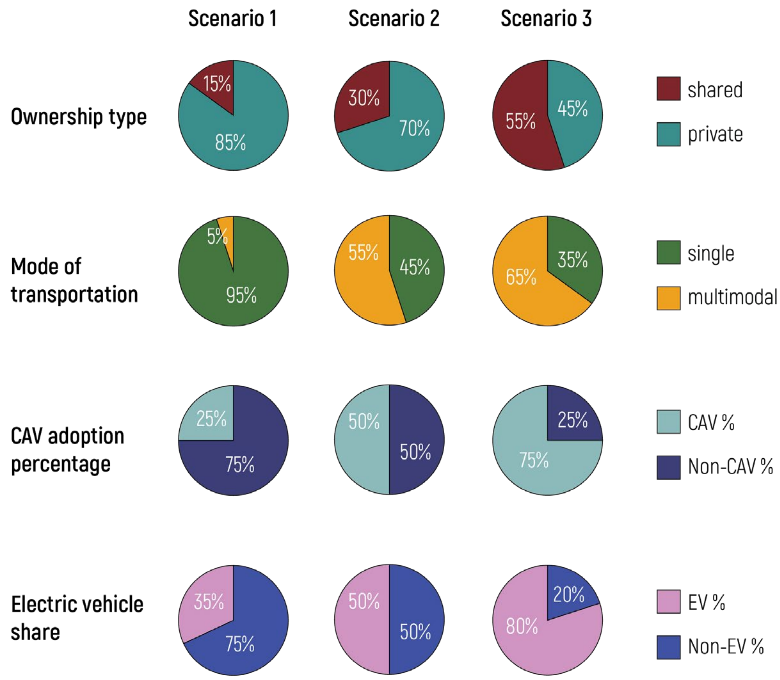


Figure 11. Summary of characteristics of each scenario.

THE SCENARIOS

We have named the four quadrants as follows. First, in the bottom-left quadrant in Figure 10, we have what we call a continuation of the status quo (scenario 1). The impacts and action items of scenario 1 are summarized in Figure 12 and Table 7, respectively. This scenario is based on the evolution of the current status and mobility behavior. The majority will own and use their private vehicle. This is especially true if CAVs' business models are made affordable. This scenario also imagines a transportation infrastructure that accommodates mostly private vehicles. This means that public transportation and private mobility do not complement each other. Likewise, the expectation is that much existing transit infrastructure is made less convenient due to the impact of CAVs. It is expected that the low-density model will continue to expand even if town centers might experience some higher density. Likewise, land use is expected to be less mixed and more segregated.

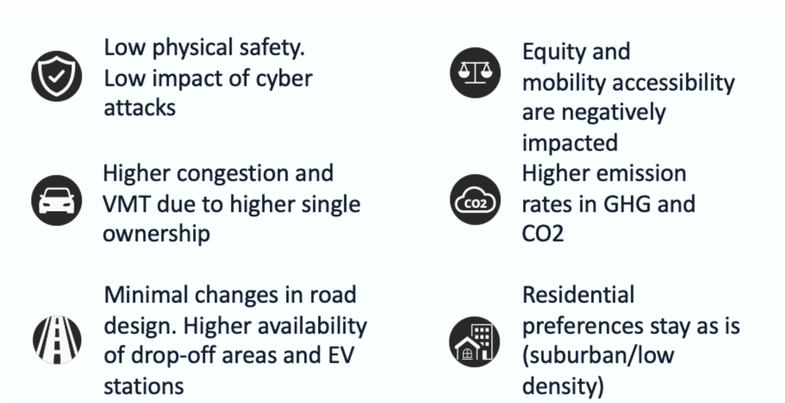


Figure 12. Scenario 1 impacts.

Table 7. Scenario 1 Action Items

Data & Digitization	Promote data sharing that preserves data privacy and security
	Establish centralized repositories to hold and provide structured access to mobility data
General	Prepare and educate staff about the CAV technology and its possible impacts
	Designate regulatory roles
Infrastructure	Deploy 5G infrastructure
	Designate roads for autonomous vehicles as they are ready
	Develop new models for pavement maintenance
Mobility & Traffic	Incentivize CAV business models that operate in a shared fleet (SAVs)
	Develop and enforce regulations of empty driving
	Manage and reduce congestion
	Provide equitable mobility
Planning	Update transportation and land use models to include CAVs
	Align CAV policy with local greenhouse-gas (GHG) reduction goals
	Reduce parking requirements or institute parking maxima
Street Design	Design separated bike lanes
	Introduce improvements in lighting, pedestrian crossing islands, and gateway treatments
	Prioritize right-of-way for pedestrians

The second scenario (bottom-right) in Figure 10, which is a private multimodal future, imagines a future that still maintains a high percentage of private ownership of vehicles (i.e., private autonomous vehicles). The impacts and action items of scenario 2 are summarized in Figure 13 and Table 8, respectively. However, the transportation infrastructure allows and encourages shifting between different modes since they are more accessible and affordable. These modes include shared CAVs, transit, walking, biking, and micromobility. Additionally, the expectation is that many of these private vehicles will be CAVs rather than traditional cars. This provides a higher chance for ultimately more efficient roads and less polluting emissions.

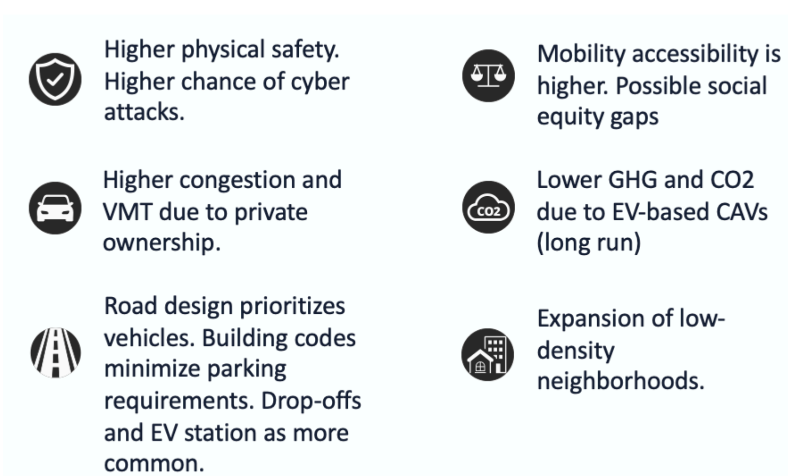


Figure 13. Scenario 2 impacts.

Table 8. Scenario 2 Action Items

Data & Digitization	Establish a standardized data report for collisions
	Establish centralized repositories to hold and provide structured access to mobility data
	Digitize existing transit infrastructure
General	Prepare and educate staff about the CAV technology and its possible impacts
	Designate regulatory roles
	Run CAV pilot program(s)
Infrastructure	Deploy 5G infrastructure
	Modify speed limits to low speeds
	Introduce smart intersections
	Add electric vehicle charging stations
	Designate roads for autonomous vehicles as they are ready
	Update traffic signs/markings; adjust signal locations and timing
Mobility & Traffic	Phase out local buses in favor of auto-jitneys and mobility-as-a-service
	Limit AV access in certain community, social space, and high pedestrian and cyclist densities
	Incentivize CAV business models that operate in a shared fleet (SAVs)
	Manage and reduce congestion
	Manage lanes through dedicated lanes for CAVs
	Introduce tolling and demand management
Planning	Plan for equity
	Densify low density areas
	Support public transit so it doesn't become obsolete
	Reduce parking requirements or institute parking maxima
Street Design	Rethink curb design and street space allocation
	Establish clear CAV (as well as transportation network company) drop-off and pick-up zones
	Introduce road diets

The third scenario, a shared multimodal future, imagines a region that has shifted from the dominant private ownership model. The impacts and action items of scenario 3 are summarized in Figure 14 and Table 9, respectively. This is boosted through shared CAVs being utilized and efficiently propagating among different neighborhoods. In this scenario, the infrastructure has also been updated to recognize different modalities such as walking, biking, transit, micromobility, and the automobile. Mobility-as-a-service is a key concept within this scenario. Most importantly it recognizes people as the center of the transportation system. Therefore, they are given the most space and many of the mobility codes prioritize the safe movement of pedestrians and cyclists. The distribution of land use and density percentages allows for higher proximity and equitable distributions.

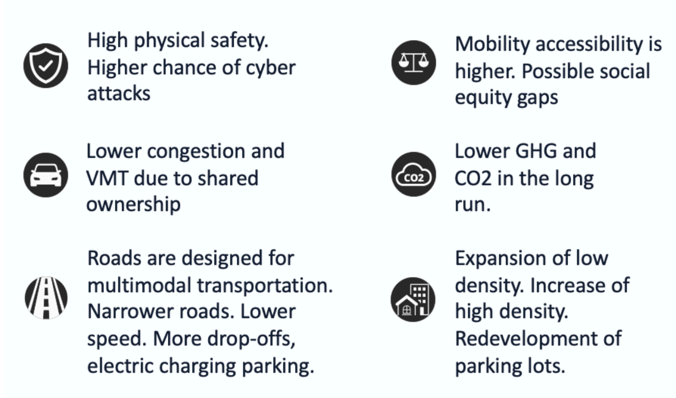


Figure 14. Scenario 3 impacts.

Table 9. Scenario 3 Action Items

Data & Digitization	Establish a standardized data report for collisions
	Require data reporting
	Promote data sharing that preserves data privacy and security
	Establish centralized repositories to hold and provide structured access to mobility data
	Digitize existing transit infrastructure
General	Prepare and educate staff about the CAV technology and its possible impacts
	Designate regulatory roles
	Run CAV pilot program(s)
Infrastructure	Deploy 5G infrastructure
	Modify speed limits to low speeds
	Introduce smart intersections
	Add electric vehicle charging stations
	Reduce lane width
Mobility & Traffic	Phase out local buses in favor of auto-jitneys and mobility-as-a-service
	Limit AV access in certain community, social space, and high pedestrian and cyclist densities
	Invest in autonomous rapid transit (ART) dedicated lanes
	Incentivize AV business models that operate in a shared fleet (SAVs)
	Develop and enforce regulations of empty driving
	Consider tailoring auto-jitneys to each neighborhood
	Introduce tolling and demand management
Planning	Provide equitable mobility
	Convert surface parking lots/garages to new development, public plazas, or green space
	Plan for vibrant social hubs
	Align CAV policy with local greenhouse-gas (GHG) reduction goals.
	Remove on-street parking in residential/commercial streets
Street Design	Rethink curb design and street space allocation
	Design and implement separated/protected bike lanes
	Introduce road diets
	Manage the curb for high people volumes, not cars

Finally, we have the fourth scenario in which transportation planners continue to focus primarily on the automobile—CAV-dominated planning—but the shared fleet idea takes off. We do not see this scenario as very likely, because it is hard to avoid owning your own car and foregoing door-to-door service if other modes are not robust, convenient, or safe.

	Scenario 1	Scenario 2	Scenario 3
Safety	low	high	high
VMT & congestion	high	high	low
Equity	low	low/high	low/high
Emissions	high	high	low
Density	low	low	low/high

Figure 15. Summary of impacts by each scenario.

Figure 15 provides qualitative but empirically grounded assessments (e.g., high, medium, low) of each scenario for each impact category. It shows how each scenario may perform on a set of impacts identified as important in the literature review and through the MPO interviews. The assessments are based on the literature review findings as well as the research team's expertise in transportation and land use planning. More information about our scenario framework, each of the scenarios, and how they can be employed in the planning process is presented in the handbook.

CHAPTER 5: ACTION ITEMS FRAMEWORK

As noted in Chapter 4, the primary deliverable for the scenario framework and policies and design guidelines is a practitioner handbook, available as a separate document and also provided in Appendix D of this policy report. Similar to the scenario framework (summarized in Chapter 5), detailed information about the policies and design guidelines (hereafter referred to primarily as "action items") is available in the handbook, but a high-level summary is provided in the sections that follow.

METHODS

The action items presented in the handbook were compiled from several sources. First, we documented practice-based strategies for CAV planning in the levers portion of the literature review process (Chapter 2). Second, we reviewed a variety of additional white papers, policy statements, and guidance documents related to CAV planning. These resources came from the following types of organizations:

- Associations of transportation agencies (e.g., National Association of City Transportation Officials, Association of Metropolitan Planning Organizations)
- Other professional associations and advocacy groups (e.g., American Planning Association, Association of Pedestrian and Bicycle Professionals, American Society of Landscape Architects, Congress for the New Urbanism)
- Transportation research centers (e.g., Pedestrian and Bicycle Information Center, university-based centers)
- Planning-related media sources (e.g., Planetizen, Urbanism Next)

We thoroughly reviewed these resources to identify the action items that were most relevant to the context of mid-sized regions, based on the findings of our previous research tasks. Finally, as described later in Chapter 6, we refined the list of action items following a set of stakeholder workshops, during which practitioners at varying levels of action (e.g., local, regional, state) provided feedback on draft inputs into the handbook document. This iterative process resulted in a total of 53 action items; the full list is available in the handbook, but in the following section, we describe the structure of the action items and how they can be effectively navigated.

NAVIGATION

An important objective of this project was to provide information that could be directly integrated into decision-making for MPOs and other transportation agencies. To accomplish this, and to allow for flexibility across a range of regions and contexts, we organized the action items in several different ways that facilitate easy navigation.

First, we organized the action items along the following major categories:

- Data and digitization
- Mobility and traffic
- Street design
- Infrastructure
- Planning
- General

Each action item falls into at least one category, and many are classified under multiple categories. This categorization is the primary organizing structure for the action items in the handbook, but we also allow for navigation along the following dimensions:

- Anticipated impact(s): safety, vehicle miles traveled, congestion, emissions, land use/urban form, equity/accessibility
- Anticipated costs: low, medium, high, uncertain, varying

In Tables 10, 11, and 12, we provide excerpts from the handbook to show how users can navigate the list of action items by category, impact(s), and costs, respectively. This structure allows practitioners to approach the list from different strategic angles; for instance, an agency interested in street design strategies can efficiently view those action items as a group, while an agency interested in reducing vehicle miles traveled can easily see which action items are most likely to advance that goal.

Table 10. Navigating Action Items by Category

		G	DD	MT	SD	I	P
		General	Data & Digitization	Mobility & Traffic	Street Design	Infrastructure	Planning
1	Establish a standardized data report for collisions						
2	Require data reporting						
3	Promote data sharing that preserves data privacy and security						
4	Establish centralized repositories to hold and provide structured access to mobility data						
5	Digitize existing transit infrastructure						
6	Prepare and educate staff about the CAV technology and its possible impacts						
7	Designate regulatory roles						
8	Run CAV pilot program(s)						
9	Plan for equity						

Table 11. Navigating Action Items by Primary (Blue) and Secondary (Gold) Impacts

		Safety	VMT	Congestion	Emissions	Urban form	Equity
DD-01	Establish a standardized data report for collisions	Gold		Blue			
DD-02	Require data reporting	Blue	Blue	Blue	Blue		Blue
DD-03	Promote data sharing that preserves data privacy and security	Gold	Blue	Blue	Blue		Blue
DD-04	Establish centralized repositories to hold and provide structured access to mobility data	Blue	Blue	Blue	Blue		Blue
DD-05	Digitize existing transit infrastructure		Blue	Blue	Blue		Gold
G-03	Prepare and educate staff about the CAV technology and its possible impacts						
G-04	Designate regulatory roles						
G-05/ MT-17	Run CAV pilot program(s)	Blue					
G-06	Plan for equity	Gold	Blue	Blue	Blue		Blue

Table 12. Navigating Action Items by Costs

		Low	Medium	High	Varying	Uncertain
1	Establish a standardized data report for collisions		X			
2	Require data reporting		X		X	
3	Promote data sharing that preserves data privacy and security		X		X	
4	Establish centralized repositories to hold and provide structured access to mobility data					X
5	Digitize existing transit infrastructure	X				
6	Prepare and educate staff about the CAV technology and its possible impacts		X			
7	Designate regulatory roles	X				
8	Run CAV pilot program(s)		X			
9	Plan for equity	X			X	

Finally, for users who are interested in strategies related to the four specific scenarios created during this research process, the handbook offers a list of recommended action items for each scenario. An example of this type of list for Scenario 3 (shared multimodal future) is provided in Table 13.

Table 13. Recommended Action Items for Scenario 3

Data & Digitization	Establish a standardized data report for collisions
	Require data reporting
	Promote data sharing that preserves data privacy and security.
	Establish centralized repositories to hold and provide structured access to mobility data.
	Digitize existing transit infrastructure
General	Prepare and educate staff about the CAV technology and its possible impacts
	Designate regulatory roles
	Run CAV pilot program(s)
Infrastructure	Deploy 5G infrastructure
	Modify speed limits to low speeds
	Introduce smart intersections
	Add electric vehicle charging stations
	Reduce lane width

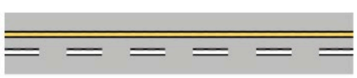
DETAILED INFORMATION

In addition to the summary navigation tables described above, the handbook also provides detailed information about each individual action item in a consistently formatted template/profile. The types of information presented in these profiles include:

- Category
- Description
- Stakeholders (implementing and/or involved)
- Scale (regional, local)
- Impact(s)
- Barriers to implementation
- Costs
- Time horizon
- Renderings and/or references, as applicable

The profiles thus serve as a detailed resource about each action item, providing critical information that handbook users can seek after they have navigated the full list and identified a set of candidate action items. An example of the detailed profile for a single action item is provided in the handbook excerpt in Table 14.

Table 14. Example of Detailed Profile for a Single Action Item

Attribute	Comments	Reference
Action Item	Update road markings	[25] [36]
Category	Street Design	
Code	SD-06	
Description	**General description:** - Road markings: Technologies need clear marking to function properly - Increase thickness of markings **Context-specific description:** - Start with updating the suburban streets and highways - Update marking for bike lanes	[25] [47]
Stakeholders	Public works, Municipality	
Scale	Regional	
Impact/Benefit	**Direct:** Safer reception of CAVs	
Barriers	Funds and financing Operational procedures	
Cost	Low investment allocated for revamping road markings/paintings ($)	
Time horizon	Short/long term, high CAV adoption	[25]
	Painted lane boundaries with good contrast     	[36]

CHAPTER 6: OUTREACH AND ENGAGEMENT

Once the scenario framework and the proposed approach to identify and organize policies and design guidelines were formulated, the research team's final engagement activity was to conduct a set of virtual scenario workshops with key stakeholders. The main objectives of the workshops were to validate and refine our frameworks and policy ideas. We also aimed to share our research with practitioners and experts in Illinois and to explore opportunities for future research. During the workshops, the research team presented the scenario framework and profiles and asked participants to (a) rate the importance of each impact category, (b) provide input on the desirability and likelihood of each scenario, (c) rank the scenarios based on their preferences, and (d) discuss the value and feasibility of the identified levers for CAV planning. We used results of the stakeholder scenario workshops to finalize the scenario analysis, updating the categorical performance assessment (high, medium, low) of each scenario and incorporating any necessary edits to reflect the context of mid-sized MPOs in Illinois. We also used the scenario workshop results to finalize our list of policy and design guidelines, a full list of which are included in the handbook.

STAKEHOLDER WORKSHOPS

Goal

The workshop offered an opportunity to summarize trends in connected and autonomous vehicle technologies and ongoing efforts around the nation to plan for them. We also expected this information to serve as baseline knowledge for participants to engage in the subsequent scenario and policy review activities. This was achieved through a presentation about our literature review findings along with the results and observations from our practitioner interviews and household surveys. This allowed us to highlight local attitudes toward travel in a CAV future, especially in mid-sized regions.

This background served our two main objectives. First, it validated the proposed scenario framework for mid-sized MPOs. We presented the three scenarios for CAV's future and asked the attendees which scenarios they (or their communities) may find most desirable and which they think is most likely. Their responses were compiled and shared, which facilitated an in-depth discussion.

Second, the stakeholders were asked to help review and refine the framework for policies and design guidelines (P&DG). They looked at the detailed template and categories of action items, as well as a number of specific examples under each category. They were asked to rate which action items (i.e., P&DG) they find most desirable versus which they believe is most likely/feasible. Stakeholders were also engaged through a facilitated discussion that highlighted some implementation opportunities and challenges. More details of our approach are discussed below.

Methods

Time and Date

We planned two half-day workshops (three-hours long) on different days of the week and different halves of the day. This allowed more flexibility for attendees to choose a time frame that was suitable for them. The two dates/times were as follows:

- Wednesday, 15 Sep 2021 | 1:00 p.m.–4:00 p.m.
- Thursday, 23 Sep 2021 | 9:00 a.m.–12:00 p.m.

Location

Both workshops were hosted virtually using Zoom.

Participants

Participants that joined our workshop include Illinois Department of Transportation representatives, both from planning and Tollway; Federal Highway Administration representatives; planners and other representatives from multiple mid-sized MPOs in Illinois; representatives of local governments, technology companies, and transit agencies; and other relevant stakeholders. A total of 45 invitations were sent. We had a turnout of 25 individuals across the two sessions. The number, size, and composition of each scenario workshop were managed in a way that ensures diversity in interests and geographic representation.

Sessions

During the scenario workshop sessions, we presented the updated scenario framework and our scenario profiles and asked participants to (a) rate the importance that they assign to each impact category, (b) provide qualitative input on the desirability and likelihood of each potential future outcome, (c) rank the scenarios based on their preferences, and (d) discuss the desirability and likelihood (feasibility) of the identified levers for CAV planning.

The sessions were organized as follows:

- **9:00 a.m. / 1:00 p.m.–9:30 a.m. / 1:30 p.m.** Welcome and Opening Presentation
- **9:30 a.m. / 1:30 p.m.–9:45 a.m. / 1:45 p.m.** Workshop Logistics
- **9:45 a.m. / 1:45 p.m.–10:30 a.m. / 2:30 p.m.** Activity I—Validation of Scenario Framework (breakout rooms)
- **10:30 a.m. / 2:30 p.m.–10:45 a.m. / 2:45 p.m.** Break
- **10:45 a.m. / 2:45 p.m.–11:15 a.m. / 3:15 p.m.** Activity II—Policies and Design Guidelines (breakout rooms)
- **11:15 a.m. / 3:15 p.m.–11:50 a.m. / 3:50 p.m.** Report back and discussion
- **11:50 a.m. / 3:50 p.m.–12:00 p.m. / 4:00 p.m.** Wrap up

Opening Presentation and Logistics

The research team summarized the current CAV planning landscape and shared findings from household surveys and practitioner interviews. The presentation also highlighted the following items:

- The scenario framework developed for CAVs in mid-sized regions
    - Three scenarios for mid-sized MPOs
- A framework for policies and design guidelines and how to navigate them using scenarios
    - Selected action items organized by category
- A sneak peek at the draft practitioner's handbook

Activity I—Scenario Framework

The research team presented the scenario framework, three CAV scenarios, and their expected impacts on a community. Participants were polled on likelihood and desirability of each and invited to comment on the framework and outcomes. Specific polls and discussion questions were as follows:

- Poll: Which scenarios are more likely in your community? Which would be more desirable?
- Discuss: What information would you add to the scenarios to improve their utility? What additional information would you like to know about CAVs and your community? How could this information advance your engagement and planning?

Inputs were collected by the research team through Google Forms and Jamboard.

- Survey Link: https://forms.gle/TZC8Me1txssFheuHA
- Jamboard Link: https://jamboard.google.com/d/1eppk6BRdK3erGZLtMLsxq2HqpED8ItPc2b7FQS2LvA4/edit?usp=sharing

Activity II—Assessment of Policies and Design Guidelines

Our framework for policies and design guidelines is closely coupled with the scenarios approach. Together they aim to offer practitioners guidance to navigate a wide range of uncertainties, planning contexts, and decision choices. As such, the goal for this activity was to first provide the attendees with a description of (1) our template for P&DG, (2) the categories of action items we are aiming to address, and (3) some examples of common CAV-related P&DG under each category. A related key goal was also to link this framework to the scenarios framework in ways that highlight how the policy choices can be intentional depending on the future a community expects to face or desires to pursue. An opening presentation by the research team covered these topics and offered the participants an opportunity to ask clarifying questions.

The presentation also clarified that the goal of this approach is not to cater to just the three scenarios, or to provide a long list of actions that the regions could pursue, but to develop a practical and nimble framework that allows regions to identify the policies and the design guidelines that are most suitable for their transformational stage, local preferences, and visions. The research team's presentation explained that some P&DG may work across a variety of scenarios, i.e., are "robust" regardless of the uncertainties, while others may be specific to a single scenario (Figure 16).

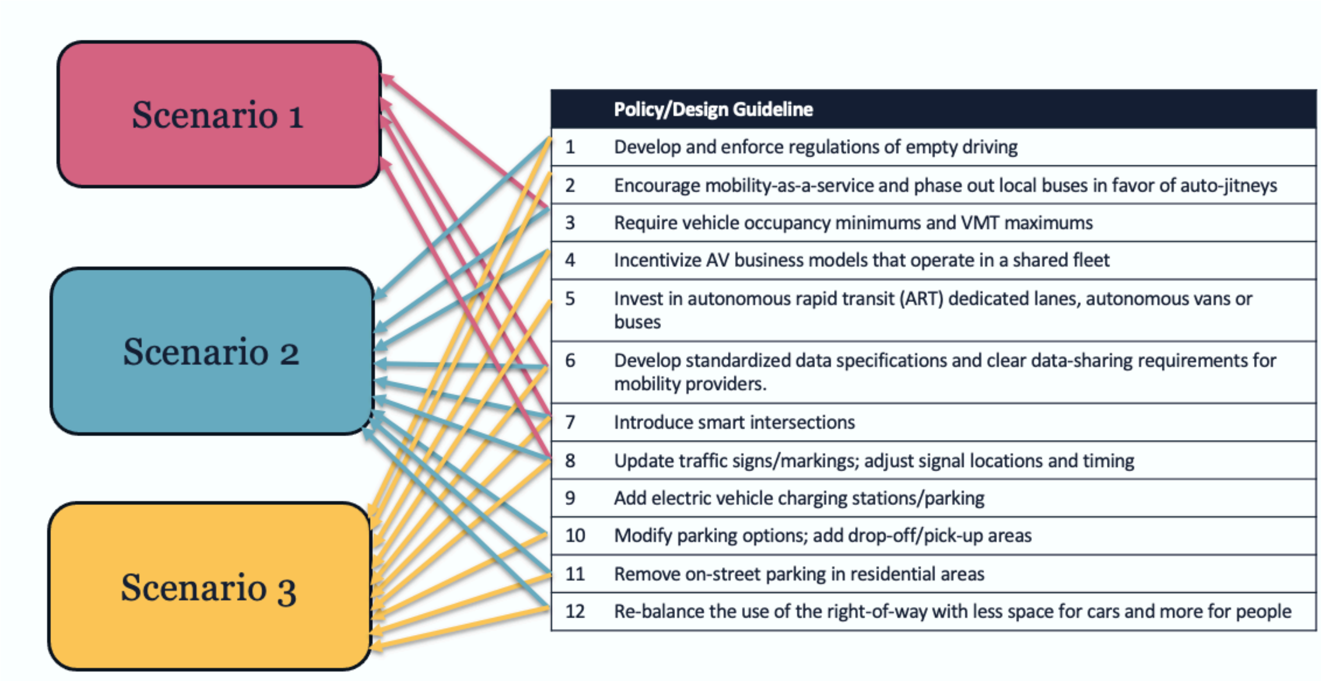


Figure 16. A snapshot of policies and design guidelines linked to each scenario.

The following are examples of questions to which the participants were invited to respond:

- Which P&DGs are most applicable to your community? Which are likely to be most preferred?

- How might the applicability of P&DGs vary by scenario, context, and planning agency? How would you prioritize P&DGs selection by scenario?

- How can we make the proposed P&DGs more useful? What are other important factors/attributes that we should consider for organizing the P&DG?

Similar to Activity I, participant responses were captured through Google Forms and Jamboard. The former collected participants' responses regarding likelihood and desirability of selected action item, and the latter invited their inputs regarding the overall framework, our categorization of the action items, and additional topics for the research team's consideration.

- Survey Link: https://forms.gle/aGenSmBk9VY53i9o9

- Jamboard Link: https://jamboard.google.com/d/18CBOwD9VQK8rTMcWC-l2-19xQlIRsZFZGB3ncGOM3rc/edit?usp=sharing

Observations and Results

Scenario Framework

The participants of the workshops confirmed that the proposed scenario approach is appropriate for planning for CAVs and addresses the uncertainties and decision choices faced by communities. They also agreed that the three scenarios selected by us capture the most impact factors and offer a good combination of future possibilities to consider when identifying planning responses, especially for mid-sized regions. There was no clear consensus on the most likely scenario. However, there seemed to be more consensus on the desirability of Scenario 3 (shared multimodal future), which had the highest votes in both workshop sessions. Cost and safety came across as the most important factors for steering the ultimate directions of the CAV future. Both aspects may play a role in the rollout of CAVs and the nature of their impacts, as well as influence the type of policies and guidelines that are adopted. Affordability and willingness to pay also came up as important factors to be considered in any of these scenarios.

Education and public awareness also came across as vital for encouraging cultural changes and shifting people's perspectives toward adopting a more sustainable future. This includes type of ownership, usage of different transportation modes, etc. A number of participants felt that, with adequate awareness and effort, achieving a shared multimodal future (Scenario 3) may be possible given the preferences of younger generations who are less interested in private ownership. Although, the continued preference for private ownerships, especially in mid-sized regions, may remain a challenge for advancing policies that promote shared ownership or greater equity.

Policies and Design Guidelines

The participants found the proposed format for organizing policies and design guidelines helpful in navigating the range of ideas currently being discussed in the CAV space. They also found the scenarios exercise as a path to identifying the best possible P&DG for a community highly useful and novel in the way it offers the communities an opportunity to be more intentional about their future.

The six categories of actions items and the selected P&DG vis-à-vis certain scenarios were also well received though, as discussed below, the participants had useful feedback about focusing the actions items and considering different economic and political dimensions to implementation. For example, many of the participants explained that enforcing regulations on residents/passengers such as taxing VMT, requiring minimum occupancies, and fining empty driving is mostly undesirable and likely will receive backlash from different stakeholders. On the other hand, focusing on shared mobility opportunities such as investing in autonomous rapid transit dedicated lanes and incentivizing shared AV business models were highly encouraged.

When it comes to design guidelines, most participants agreed that preparing the physical infrastructure for connected vehicles (regardless of their autonomous ability) is highly desirable as well as most likely. This includes introducing smart intersections, updating traffic signs and road markings, adding electric-charging stations/parking, and introducing more drop-off options. Participants also suggested that there must be a consensus on what is defined as "smart" and prioritize digitizing the infrastructure over any other intervention in the time being. However, any design guidelines related to reducing the authority of vehicles on the road were deemed less desirable as well the least likely since they jeopardize the current private ownership model. The guidelines include removing the on-street parking and rebalancing the street right-of-way to allow more space for people rather than vehicles.

Participants suggested further exploration of these guidelines such as associating them with the type of context/neighborhood and the type of existing infrastructure that would give residents different alternatives. The participants also have emphasized the role of the government in providing guidance and regulation at a national and state level. Otherwise, they noted that the implementation and adoption of these policies would be less efficient and will require a large amount of coordination between jurisdictions.

Key Takeaways

The reflections and the contributions of the workshop participants were vital in the research team's subsequent work on refining the scenarios and the action items framework that are detailed in the handbook. Based on the scenario workshops, we also expanded the list of resources to include references such as the American Association of State Highway and Transportation Officials. Below are a set of key takeaways from the workshops.

Public Awareness and Education

Awareness of CAV technologies will influence how CAVs roll out. This includes the rate and nature of adoption as well as the policies and design guidelines that a community may be willing to support. As a result, practitioners should focus on engaging residents in understanding the linkages between household and community choices and CAV futures, and how their involvement can play a role in steering the impacts of CAVs toward more desirable outcomes. Appropriate management of policies may also be important. For example, goals that detract from past practices, such as limited on-street parking, may require policies that allow easing into the proposed changes.

Vehicle Ownership

Given the primacy of private vehicles in mid-sized regions, transportation solutions that decrease congestion, VMT, and emissions must continue to consider high automobile ownership and its implications for travel demand and land use.

Equity

CAVs can advance equity but will require strong advocacy and vigilance policies that limit private ownership or favor micromobility over mass transit to ensure equitable mobility access to all groups.

Cost

Consideration of the cost of CAV deployment in various scenarios is important. Cost may include infrastructure, public education, adoption of policies/design guidelines, the cost of CAVs themselves, and overhead. Affordability and willingness to pay may impact the rollout and, as such, the cost of not preparing the infrastructure or the community for CAV technology should also be considered.

While the scope of this work does not allow detailed information on costs, scenarios can be helpful to compare the impact and cost of different action items and CAV futures.

Data and Digitization

Adequate protection for data privacy, quality, and use will become even more important with CAVs. State and federal agencies will need to continue to lead in this arena and provide communities with guidance regarding data collection, storage, tracking, and interoperability.

Public Acceptance and Context

Besides helping refine and validate our frameworks, the participants also highlighted the role of public acceptance in implementing CAV-related policies and in the future direction of a community. They underscored the value of making residents and planning/transportation staff aware of CAV technologies as well as their potential impact and advised that P&DG be sufficiently flexible to consider local contexts. Our detailed list of P&DG included in the handbook strongly respond to this feedback. For example, the scenario and action items framework suggest the appropriate scale of application (local/regional), the timing of the action (aspirational or responsive), and the nature of the action given the uncertainties (robust or contingent). We expect that these considerations will allow users to select and prioritize appropriate policies and design guidelines.

CHAPTER 7: CONCLUSION

As CAV technology continues to evolve, proactive planning for CAVs is becoming increasingly urgent and important. Much of the prevailing dialogue surrounding CAVs is about how they will operate in large urban centers, and while some of this conversation can be generalized to other settings, mid-sized regions would benefit greatly from their own guidance as they prepare for CAV rollout. This policy report and the accompanying practitioner handbook work toward this objective, providing information that mid-sized regions—particularly (but not exclusively) at the MPO level—can use to guide their CAV planning efforts at multiple time horizons.

Planning for CAVs is challenging and complex, due in large part to considerable uncertainty regarding their development, regulation, adoption, and impacts. Scenario planning is a valuable tool in the context of such uncertainty, and we have therefore applied a scenario planning lens throughout this research effort. Specifically, we consider how MPO planners and other stakeholders can make effective decisions in the face of uncertain external drivers of change (e.g., pace and extent of technology development, consumer preferences and adoption rates, regulatory environment); uncertain community impacts (e.g., vehicle miles traveled, congestion, emissions, land use, safety); and diverse internal levers available for planning and policy (e.g., regulation, travel pricing, multimodal investment, land use planning). Through this lens, we offer ways for planners to manage uncertainty as they prepare now for a rapidly approaching future.

Through multifaceted and engaged research methods—including a literature review, practitioner interviews, a household survey, and stakeholder workshops—we have developed a flexible scenario framework for mid-sized regions in Illinois and beyond to use for proactive CAV planning. This two-axis framework is defined by the intersection between key drivers and levers, allowing planners to consider how their own actions, in combination with external forces, can influence future community impacts related to CAV development. As presented in the handbook, the framework is based on the intersection between (a) degree of multimodal transportation investment (critical lever) and (b) private vs. shared model of CAV ownership/adoption (critical driver), resulting in four potential scenarios. The four scenarios are (1) continuation of status quo, (2) private multimodal future, (3) shared multimodal future, and (4) shared single-mode future. We provide detailed information on the characteristics and impacts of these four scenarios as well as provide guidance for users who wish to adapt and tailor the framework by changing its critical dimensions.

In the practitioner handbook, we also outline a set of concrete action items—including both high-level policies and specific design guidelines—that planners can use to guide their CAV efforts and associated impacts in line with community goals and objectives. These action items are organized into six major categories (with potential overlap): data and digitization, mobility and traffic, street design, infrastructure, planning, and general. We illustrate how these action items are linked to the four scenarios defined above, but we categorize them in a variety of other ways to allow for flexibility in strategy selection. Specifically, we note the type/category, scale, time horizon, stakeholder agencies, impacts, and anticipated costs of each action item, providing diverse dimensions upon which handbook users can base their decisions. For three of these dimensions—category, impacts, and costs—we provide tables for streamlined navigation by each factor. In this way, we present a diverse set of action items for practitioners to consider and guide them through the process of identifying which strategies are most appropriate for their context and goals.

The scenario framework and action items presented in the handbook (and summarized in this policy report) can be used to help planners and policy-makers respond proactively to CAVs, even in the face of considerable uncertainty. Our guidance is most closely tailored to the needs of mid-sized regions—particularly at the MPO level—but it is likely relevant to a broad range of settings, agencies, and community types. Moreover, given its flexibility, the scenario framework provides a tool that can be tailored to the context of any community, allowing them to consider how their unique needs, objectives, residential preferences, and planning trajectories may influence the nature of CAV rollout and adoption. Through this guided yet flexible approach, our work offers insight into how communities can achieve more sustainable, equitable, and otherwise desirable outcomes as the future of CAVs continues to unfold in uncertain ways.

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APPENDIX A: INTERVIEW INSTRUMENT

Opening (2 minutes): Thank you again for agreeing to this interview. As you know, we have prepared a set of questions about your views on CAVs, as well as any thoughts or experiences you may have regarding planning for CAVs. We will try to cover as many of our prepared questions as possible, though we are flexible and would be happy to listen to in-depth responses and additional comments, even if that means we don't get to all of the questions. We would encourage you to be as specific and open as possible – all findings and any quotations from these discussions will be used in an anonymized form only.

Background (3 minutes): *Let us start with a question about your role and background*.

1. Can you please describe your role within your agency? And, have you been involved in any project that addresses emerging technologies in transportation?

Self-driving cars (10 minutes): *Some of the greatest uncertainties of CAVs from a community's perspective are when they will happen, whether they will be private or shared, whether they will need more or less roads and parking, and how these shifts will affect our transportation and residential location choices, and ultimately, the nature of our communities. We might think of these things in two parts – big unknowns and their impacts. Let's take these things in sequence.*

1. What are some of the biggest unknowns when it comes to CAVs in your community?
2. What are the most significant impacts that these unknowns could have on your community? [For example, how might CAVs change vehicle miles traveled, parking demand, emissions? How would this affect economy, accessibility to jobs, land use, or social equity?]
3. Do you see any difference between impact of CAVs nationally or in large cities, versus how it might unfold in your community?

Planning for self-driving cars (25-30 minutes): *The following questions are about planning for CAVs.*

1. Have you or your organization worked on any projects that consider autonomous vehicles or their impacts on communities? Did it lead to any recommendations (or policies, design guidelines, etc.) for CAVs? If yes, please describe.
2. Irrespective of efforts by your organization, what do you think should be done by MPOs and related agencies to plan for CAVs? [Note to self: discuss respective roles of MPOs and other agencies as well as the coordination aspect].
3. Do you see any obstacles in your organization from pursuing such efforts?
4. What data, tools, and other support would be most helpful for MPOs in conducting the above activities effectively?

Lessons and Recommendations (10 minutes): *We have a few final, summary question to discuss*.

1. Taking everything we have talked about into consideration, how prepared do you think your region is for CAVs? (If you like, you can rate on a scale of 1 to 10).
2. Do you have suggestions about others we should interview? Can we use your name as a reference?
3. Would you like to add anything that we have not covered? Or ask us any questions?

APPENDIX B: SURVEY QUESTIONNAIRE

ILLINOIS

URBAN AND REGIONAL PLANNING
Temple Hoyne Buell Hall
611 E. Lorado Taft Dr.
Champaign, IL 61820

Dear Greater Peoria resident,

Greetings! You have been selected to participate in a survey about self-driving cars. This survey is part of a research project being conducted at the University of Illinois at Urbana-Champaign, in coordination with the Illinois Department of Transportation and the Illinois Center for Transportation. The goal of the overall project is to develop policies and design guidelines that will help regions in Illinois plan effectively for the arrival of self-driving cars.

To inform this process, we are conducting a survey of households in Greater Peoria, IL. The survey is divided into three main sections, in which we ask you about the following topics: (1) your current use of different forms of transportation, (2) your attitudes toward self-driving cars and how you might use them in the future, and (3) your basic personal and household characteristics. Your participation in this survey will help us to identify the major impacts of self-driving cars on communities in Illinois and the factors that planners, designers, and policy makers should keep in mind as they plan for the future.

The rest of this mailing packet includes a consent form for the study, a paper version of the survey, and a prepaid envelope for you to return your completed survey by U.S. Mail. If you would rather complete the survey online, you may visit the following web link or scan the QR code below using the camera on your cellphone for an electronic version of the survey:

https://go.illinois.edu/Self-driving-cars-survey

We are asking for **one adult household member** (age 18 or above) to complete the survey; if there are multiple adults living in your household, please have the adult who most recently had their birthday complete the survey. The survey should take about 15 minutes to complete.

We greatly appreciate your time and your help in preparing for a future of self-driving cars in Illinois. To show our appreciation, participants who complete the survey **by June 7** will have the opportunity to enter themselves into a random drawing for a chance to win one of fifteen $25 gift cards! If you have any questions or concerns, please feel free to contact Lindsay M. Braun at 217-300-7429 or lmbraun@illinois.edu.

Thank you for your time!

Lindsay M. Braun

Lindsay M. Braun, PhD
Assistant Professor
Department of Urban and Regional Planning

I ILLINOIS

URBAN AND REGIONAL PLANNING
Temple Hoyne Buell Hall
611 E. Lorado Taft Dr.
Champaign, IL 61820

IMPORTANT: Please read before proceeding

You are being asked to participate in a voluntary research study. The purpose of this study is to understand attitudes toward self-driving cars among Greater Peoria residents. The results of the survey will be used to help planners and policy makers prepare effectively for self-driving cars. Participating in this study will involve taking a 15-minute survey. We do not anticipate any risks related to this research beyond those you would encounter in day-to-day life. If you return your completed survey by June 7, you will be entered into a random drawing for a chance to win one of fifteen $25 gift cards.

Principal Investigator Name and Title: Lindsay M. Braun, PhD, Assistant Professor
Department and Institution: Department of Urban and Regional Planning, University of Illinois at Urbana-Champaign
Contact Information: lmbraun@illinois.edu; 217-300-7429

What is the survey about?
You will be asked to complete a 15-minute survey about your use of different types of transportation, your attitudes toward self-driving cars, and your personal characteristics. You may complete the survey either by filling out the attached form and returning it by U.S. Mail, or by visiting the following link to fill out an online version of the survey: *https://go.illinois.edu/Self-driving-cars-survey*. You will only be asked to participate in the survey once.

Will my study-related information be kept confidential?
Faculty, students, and staff who may see your information will maintain confidentiality to the extent of laws and university policies. Personal identifiers will not be published or presented.

Can I withdraw or be removed from the study?
Yes. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time. Your participation in this research is voluntary. Your decision whether or not to participate, or to withdraw after beginning participation, will not affect your current or future dealings with the University of Illinois at Urbana-Champaign.

Will data collected from me be used for any other research?
Your de-identified information could be used for future research without additional informed consent.

Who should I contact if I have questions?
If you have questions about this project, you may contact Lindsay M. Braun at 217-300-7429 or lmbraun@illinois.edu. If you have any questions about your rights as a participant in this study or any concerns or complaints, please contact the University of Illinois at Urbana-Champaign Office for the Protection of Research Subjects at 217-333-2670 or via email at irb@illinois.edu.

By returning the completed survey by mail or online, you indicate that you have read and understand the above consent form, you are at least 18 years old, and you indicate your willingness to voluntarily take part in this study. Please keep this consent form if you would like to have a copy for your records.

Section 1: General Travel Behavior
First, we would like to know some basic information about how you travel. As you answer these questions, please think about your typical behavior **during normal times** (not during a pandemic).

1. How often do you use the following forms of transportation? Think about all travel from place to place (work, shopping, visits, etc.).

	Never	Once a month or less	A few times a month	1-2 times a week	3-4 times a week	5+ times a week
a. Drive a car	☐	☐	☐	☐	☐	☐
b. Take Uber/Lyft	☐	☐	☐	☐	☐	☐
c. Get a ride from someone else	☐	☐	☐	☐	☐	☐
d. Take the bus	☐	☐	☐	☐	☐	☐
e. Walk*	☐	☐	☐	☐	☐	☐
f. Bicycle*	☐	☐	☐	☐	☐	☐

*Please do not include any walking/bicycling trips that are for exercise purposes only (such as walking/riding around the block or in the park).

2. Which of the following factors are **most important** to you when you decide which form(s) of transportation to use for your travel, in general? (*Please **select no more than three** options.*)

a. How much it costs	☐
b. How long it takes	☐
c. How far I have to travel	☐
d. How safe it is	☐
e. How convenient it is	☐
f. How healthy it is	☐
g. How much I will enjoy my travel	☐
h. How much I can interact with other people during travel	☐
i. Weather conditions	☐
j. Whether I have to carry things or transport other people	☐
k. Other (please specify) ______________________________	☐
l. Other (please specify) ______________________________	☐
m. Other (please specify) ______________________________	☐

3. During normal times (not during a pandemic), do you work or attend school outside of your home?

	Yes	No
If "Yes", go to question 4. *If "No", skip to question 7.*	☐	☐

4. How far do you live from work or school? (If you both work and attend school, or if you have more than one job, please answer this question and the following two questions about the place that you attend most often.) (*Select one.*)

a. Less than 5 miles	☐
b. Between 5-10 miles	☐
c. Between 10-20 miles	☐
d. More than 20 miles	☐
e. Don't know/not sure	☐

5. During normal times (not during a pandemic), which form(s) of transportation do you most often use to travel to work or school? (If you travel to work/school in different ways on different days, please answer this question for the way you travel most often. If you use more than one form of transportation for the same trip (e.g., drive to the bus stop and then take the bus to work) please *select all that apply for that trip*.)

f.	Drive a car	☐
g.	Take Uber/Lyft	☐
h.	Get a ride from someone else	☐
i.	Take the bus	☐
j.	Walk	☐
k.	Bicycle	☐

6. During normal times (not during a pandemic), about how long does it take you to get to work or school using the most common form(s) of transportation you selected above? *(Select one.)*

a.	Less than 10 minutes	☐
b.	Between 10-20 minutes	☐
c.	Between 20-30 minutes	☐
d.	More than 30 minutes	☐
e.	Don't know/not sure	☐

Section 2: Self-driving Cars

In this section, we would like to ask you about self-driving cars and how they might influence your travel behavior in the future. Self-driving cars will use advanced technology and therefore won't require a human to control or drive the vehicle. Using this advanced technology, self-driving cars will be able to communicate with other self-driving cars on the road, as well as with surrounding infrastructure and objects such as traffic lights, stop signs, parking spots, pedestrians, etc.

7. How would you rate your understanding of self-driving cars? *(Select one.)*

a.	I've never heard of them.	☐
b.	I've heard about them but I don't know much about what they do.	☐
c.	I have a general understanding of what they are and what they do.	☐
d.	I have extensive knowledge about them.	☐

8. Based on your understanding, when do you think self-driving cars will be widely available and used by the general public? *(Select one.)*

a.	In less than 10 years	☐
b.	In about 10-20 years	☐
c.	In about 20-30 years	☐
d.	In more than 30 years	☐
e.	Never	☐
f.	Don't know/not sure	☐

9. How likely would you be to use a self-driving car if they become available within the next 10 years? *(Select one.)*

a. Very unlikely	☐
b. Unlikely	☐
c. Likely	☐
d. Very likely	☐
e. Don't have enough knowledge to decide	☐

10. How much would you agree with the following statements about self-driving cars when compared to traditional cars that people drive today? *(Select one box for each row.)*

	Strongly disagree	Disagree	Agree	Strongly agree	Don't have enough knowledge to decide
a. Self-driving cars will be safer.	☐	☐	☐	☐	☐
b. Self-driving cars will help me get around faster.	☐	☐	☐	☐	☐
c. Self-driving cars will be more affordable in the long run.	☐	☐	☐	☐	☐
d. Self-driving cars will be safe from a hacking/privacy perspective.	☐	☐	☐	☐	☐
e. Self-driving cars will be better for the environment.	☐	☐	☐	☐	☐

11. Imagine that self-driving cars become widely available and are affordable for your household. These self-driving cars are sophisticated enough that you can do other tasks while driving (such as work, rest, be on your phone, etc.) and a license is not required for driving. In this scenario, how much do you agree with the following statements about how your behavior might change? *(Select one box for each row.)*

	Strongly disagree	Disagree	Agree	Strongly agree	Don't have enough knowledge to decide
a. I would travel by car more often.	☐	☐	☐	☐	☐
b. I would not mind longer hours in the car because I could use my time for other activities.	☐	☐	☐	☐	☐
c. I would choose to live farther from work.	☐	☐	☐	☐	☐
d. I would choose to live farther from other places that I go to on a regular basis.	☐	☐	☐	☐	☐
e. I think children should be able to go to school in a self-driving car without an adult in the car.	☐	☐	☐	☐	☐

12. As self-driving cars become widespread and commonly used, ridesharing companies such as Uber and Lyft may offer subscriptions to self-driving cars. Under this model, subscribers would have quick and easy on-demand access to self-driving cars for their trips, and could even choose to share rides with other people to split the costs of a trip. This might allow households to own fewer private cars or no cars at all. Assuming that this subscription service is about the same cost as owning and using your own private car, how much do you agree with the following statements about how your behavior might change? *(Select one box for each row.)*

	Strongly disagree	Disagree	Agree	Strongly agree	Don't have enough knowledge to decide
a. I would subscribe to this type of service.	☐	☐	☐	☐	☐
b. I would use this service as a way for my household to own fewer vehicles.	☐	☐	☐	☐	☐
c. I would use this service as a way for my household to own zero vehicles.	☐	☐	☐	☐	☐
d. I would share rides in self-driving cars with people I know.	☐	☐	☐	☐	☐
e. I would share rides in self-driving cars with people I do not know.	☐	☐	☐	☐	☐

13. Transportation has many impacts on our daily lives and on the communities where we live, work, and play. Some of these impacts are listed below. The importance of these types of issues will differ from person to person; for instance, some people might care very strongly about the environment while others might be more concerned with safety. We would like to know how important these issues are to you. Please rank the following issues on a scale from 1 (**most** important to you) to 7 (**least** important to you), being sure to use each number only once.

a. Air pollution	________
b. Fair access to transportation and job opportunities	________
c. Greenhouse gas emissions	________
d. Privacy (personal privacy and data privacy)	________
e. Public health	________
f. Traffic congestion	________
g. Traffic safety (crashes)	________

Section 3: General Information

Finally, we would like to know some general information about you and your household.

14. How comfortable are you with using technology (for example, using Google Maps, talking to Alexa, using cruise control and automatic parking in the car, etc.)? *(Select one.)*

a. I am very comfortable with new technologies and use them most of the time.	☐
b. I am somewhat comfortable with new technologies but don't depend on them all the time.	☐
c. I am not very comfortable with new technologies and use them only when I have to.	☐
d. I am not comfortable with new technologies and do not use them at all.	☐

15. What is your address or the nearest intersection to your home in the Peoria region? *(For example, "419 Fulton St." OR "Fulton St. and SW Madison Ave." Please include your ZIP code as well. No P.O. boxes, please.)*

____

____

16. Which of the following best describes the neighborhood where you live? *(Select one.)*

a. Urban	☐
b. Suburban	☐
c. Rural	☐

17. What is your current age in years? *(Please enter a whole number.)* ____________________________

18. Which of the following best describes your gender?

a. Female	☐
b. Male	☐
c. Non-binary/third gender	☐
d. Other (please self-describe) ____________________________	☐
e. Prefer not to answer	☐

19. Which of the following best describes your race/ethnicity? *(Select all that apply.)*

a. Asian	☐
b. Black or African American	☐
c. Hispanic or Latinx	☐
d. Native American	☐
e. Pacific Islander	☐
f. White	☐
g. Other (please specify) ____________________________	☐
h. Prefer not to answer	☐

20. What is the highest degree or level of schooling you have completed? *(Select one.)*

a. Less than high school diploma	☐
b. High school diploma or equivalent	☐
c. Some college	☐
d. Associates degree	☐
e. Bachelor's degree	☐
f. Master's degree	☐
g. Professional degree beyond bachelor's degree (for example: MD, DDS, DVM, JD)	☐
h. Doctoral degree	☐
i. Prefer not to answer	☐

21. What was your employment status in February **2020**? *(Select all that apply.)*

a.	Part-time employed	☐
b.	Full-time employed	☐
c.	Part-time student	☐
d.	Full-time student	☐
e.	Unemployed	☐
f.	Unable to work due to disability	☐
g.	Retired	☐
h.	Prefer not to answer	☐

22. How would you rate your overall health? *(Select one.)*

a.	Poor	☐
b.	Fair	☐
c.	Good	☐
d.	Very good	☐
e.	Excellent	☐
f.	Prefer not to answer	☐

23. Including yourself, how many people live in your household (adults and children)? *(Please enter a whole number.)* ______________________

24. What was your total household income before taxes during the past 12 months? *(Select one.)*

a.	Less than $10,000	☐
b.	$10,000 to $14,999	☐
c.	$15,000 to $24,999	☐
d.	$25,000 to $34,999	☐
e.	$35,000 to $49,999	☐
f.	$50,000 to $74,999	☐
g.	$75,000 to $99,999	☐
h.	$100,000 to $149,999	☐
i.	$150,000 to $199,999	☐
j.	$200,000 or more	☐
k.	Prefer not to answer	☐

25. If you would like to be entered into a drawing for a chance to win a $25 gift card, please provide your mailing address in the space to the right. You will be contacted by mail in June if you've won. *(If you choose to enter the drawing, the address you provide to the right will **not** be linked to your survey answers in any way.)*

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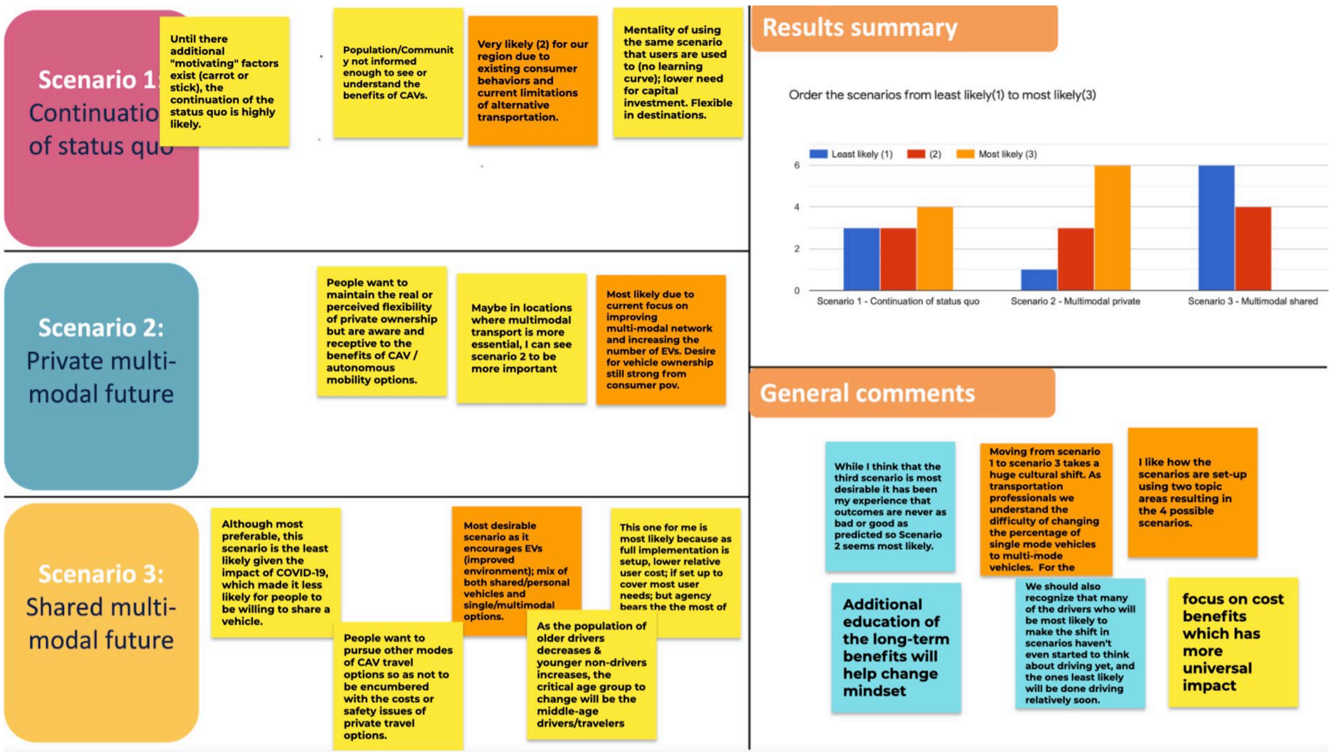
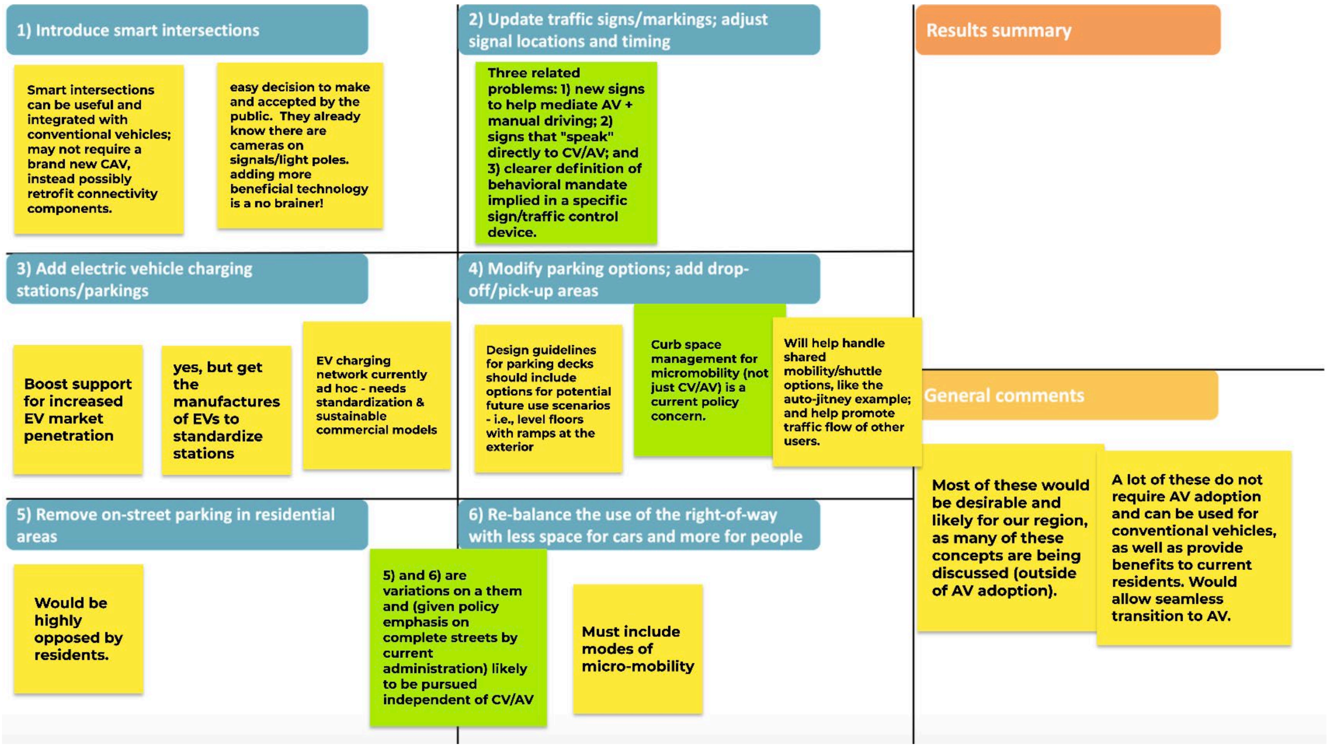
APPENDIX C: WORKSHOP PARTICIPANT RESULTS

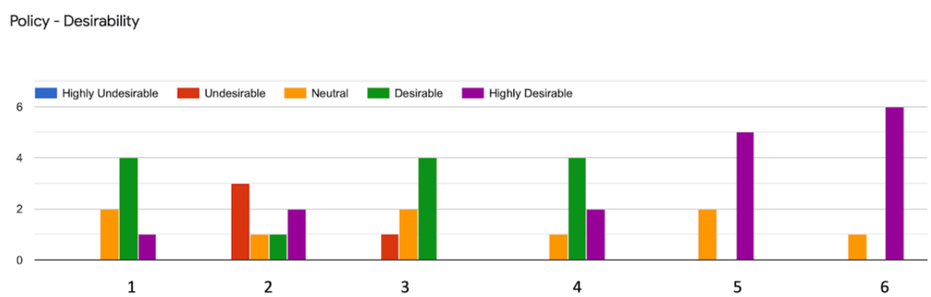
SESSION 1

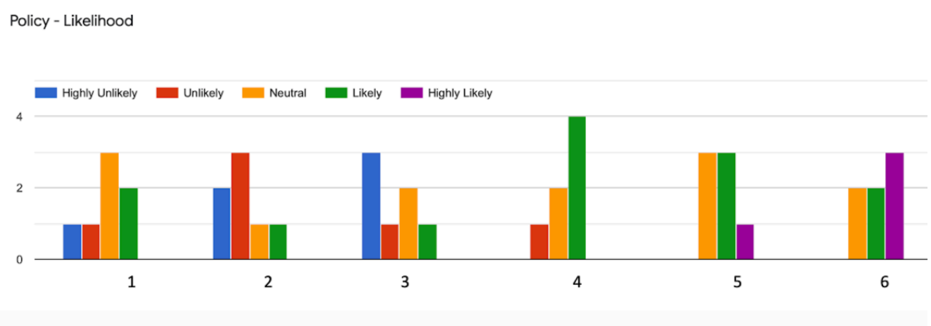



From the perspective of your community/agency
What are the primary drivers?
Demographics (age/income)
Acceptance
Safe, Cost Effective and Reliable Accessibility of infrastructure to support CAV, EV or other modes of "new" transportation
Cost
Accessibility & Availability
Reliability
Knowledge of understanding (availability of education materials/resources)
Infrastructure
Multimodal Options
Perception
Urban/Rural
Safety
What are the key impacts?
Safety
Cost
Reasonable difference in cost investment (whether private or multimodal)
Congestion and flow
VMT
Usage/Ridership density
Cost to Public
Sustainability/Environmental
Land use
equity
Financial sustainability
Trust / Least Amount of Risk
1) De
drivin
egulations of e
This one would be critical in controlling congestion and challenges with pick-up and drop off.
Too invasive of personal desires, habits, circumstances or needs
Perhaps more useful to establish clear precedent when the vehicle fails to adhere to accepted driving standards (with perhaps different expectations if there is a passenger or not).
Enforcement will be difficult for cash strapped cities
2) Phase out local buses in favor of auto-jitneys and mobility-as-a-service
Promotes lower occupancy vehicles. Seems to phase out current fixed route services.
the market is likely to do this - larger policy question if redefining the "boundary" between public and private, and grappling with the well known issues of public/private partnerships.
Would the auto-jitneys travel at a closer speed with personal or other vehicles; may reduce issues associated with bus traveling speeds (slower travel and more effort to stop and go)
Results summary
3) Require vehicle occupancy minimums and VMT maximums
Should be split two separate policies. Desirable to have VMT maximums but less desirable to have occupancy min.
Probably too hard to enforce. Consider the fate of VMT taxation.
too difficult to enforce
4) Incentivize AV business models that operate in a shared fleet
Important in reaching broader stakeholder reach.
easier corporate/fleet owner decision to make
Probably won't work, as consumer acceptance is the key, not directly incentive to invest.
General comments
Can you elaborate more on how these 12 policies/design guidelines were selected why limit to 12?
5) Invest in autonomous rapid transit (ART) dedicated lanes, autonomous vans or b
Dedicated lanes would provide means to guide changes in infrastructure design, e.g., pavement design, and associated maintenance and rehab
Probably likely, but heavily dependent on (rather risky) pilot testing.
Pilot implementation required
Very desirable and feasible. These types of services are already increasing in popularity.
6) Develop standardized data specifications and clear data-sharing requirements
Incorporating robust data handling and security will help in improving public trust.
absolutely necessary! and, should be the same for municipality, state and feds...good luck!
Standardization will be difficult at the local level
sine qua non of realizing public benefit from machines that are not immediate attached to a human will.



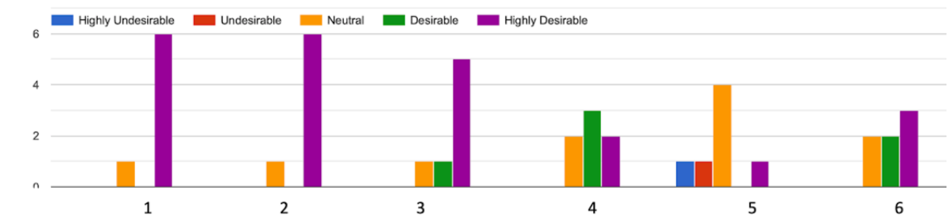
1	Develop and enforce regulations of empty driving
2	Encourage mobility-as-a-service and phase out local buses in favor of auto-jitneys
3	Require vehicle occupancy minimums and VMT maximums
4	Incentivize AV business models that operate in a shared fleet
5	Invest in autonomous rapid transit (ART) dedicated lanes, autonomous vans or buses
6	Develop standardized data specifications and clear data-sharing requirements for mobility providers.



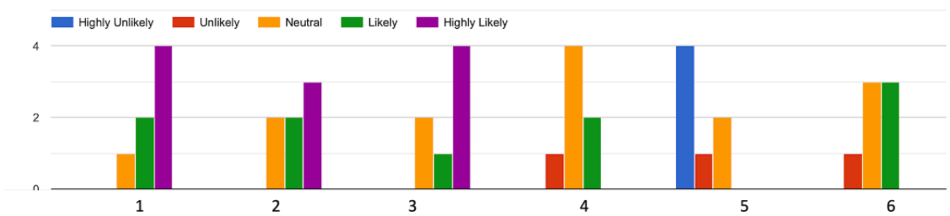


1	Introduce smart intersections
2	Update traffic signs/markings; adjust signal locations and timing
3	Add electric vehicle charging stations/parking
4	Modify parking options; add drop-off/pick-up areas
5	Remove on-street parking in residential areas
6	Re-balance the use of the right-of-way with less space for cars and more for people

Design Guidelines: Desirability



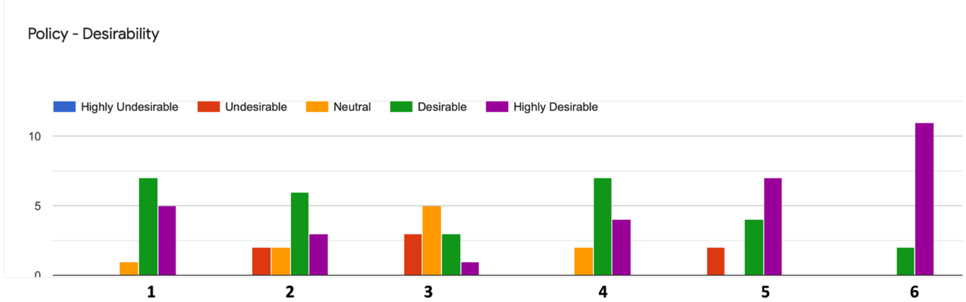
Design Guidelines - Likelihood

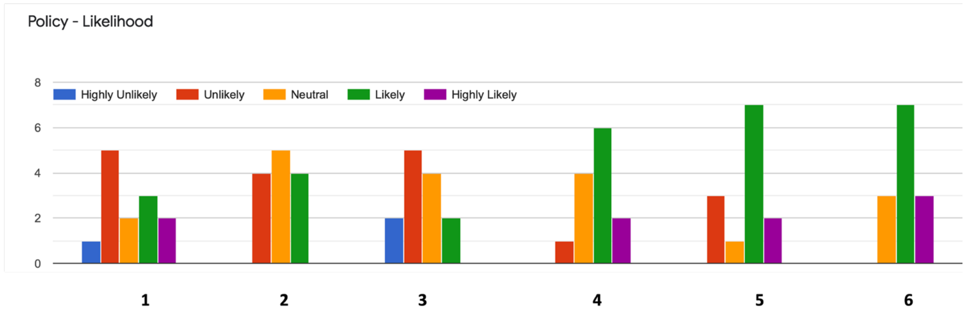


SESSION 2


1) Develop and enforce regulations of empty driving
Finding the right balance between sticks and carrots will be important. I wouldn't 'open' with this one, but would focus on nudges, social norming, incentives and indirect consequences for not
this is an ongoing issue of resource utilization, temporary holding areas like the ones they have at airports will have to be developed
Develop the regulations but ease into the enforcement.
2) Phase out local buses in favor of auto-jitneys and mobility-as-a-service
This would be a retreat from our current transit policy, which is to treat mobility as a right, not a commodity
Will need to think about how this will impact those who are transit-dependent. How can this type of policy be implemented in a way that is equitable and doesn't leave some communities behind?
Potentially a very good option. Questions here on 'creatures of habit' and routine... 'Just-in-time' / on-demand mobility could prove much more complex to pull off initially and/or have unintended
Needs further study for feasibility, public acceptance and costs.
Not to bring up Jarrett Walker too much, but this increases the geometry (congestion) issue solved by urban mass transportation.
3) Require vehicle oc
Consumption / VMT taxes could be part of the solution, but would likely have a disproportionate burden on lower income populations that live farther from employment, etc.
Hard to enforce
Long term objectives influenced by CAV developments and capabilities.
pay to play, Singapore's fees are on a user-based system. i.e. you have a number of choices available to you so access is democratized, if you choose the private version, you pay more. e.g. higher/private use
4) Incentivize AV business models that operate in a shared fleet
Could proliferate if concerns over ease-of-use/multiple apps/providers are not addressed early.
Very logical and doable since corporations can more easily make these decisions and fund this transportation initiative.
General comments
For both 1 and 6, development of regulations and specifications, I think many municipalities would look for Federal guidance and regulations to be developed as a base.
<<< Agree with this!
Whatever happens in the CAV realm for implementation, the public must be part of the planning and investment process for anything to succeed.
ART must be planned with the scale of the community in mind
There are been so many developments in the transportation sector over the last decade that actual built infrastructure could be cautious to fully embrace (invest in) one piece.
Shouldn't this be more about right sizing for the need? Demand driven by leveraging technology to understand the specific need at the specific time?
May prove the best and highest use of CAV for communities...
Great investment in the long run for the community
This investment should happen sooner that later.
6) Develop standardized data specification
An obvious choice and need for development and funding to create a more "universal" CAV environment from community to community.
As we are experiencing with the roll-out of electric vehicle infrastructure, consistency will be important.
This is vital - as the volume of data generated by an interconnected transportation system expands, there must be standards to maintain (or create) interoperability.
Local agencies in our area are focused on interoperability of the hardware right now, but having consistency wrt data formats and availability will be equally important.
Could gain efficiency and safety benefits here.
Critically Important.
Interoperable data requirements.
1) Introduce smart intersections
Let's have a consensus on defining a smart intersection, plus robust data on outcomes from the early adopters.
This is THE MOST IMPORTANT thing a small municipality can do right now. Wire all of your lights with fiber. And create digital duplicates of your infrastructure.
prioritize pedestrians & other minor road users, scooters, etc. crosses between #1 & #2 which is why it's on the boundary
This is already happening. One of the ongoing struggles will be how to make sure the jurisdictions with less access to funding are able to move forward with these types of projects.
traffic signs/markings; adjust
ations and timing
The NEW ROLE that municipalities will play is in managing mobility in the digital universe, just as it does in the physical universe today.
Less important. DIGITAIZING this signage is most critical
Results summary
3) Add electric vehicle charging stations/parkings
Adding charging capacity seems to be increasing without much intervention.
Jurisdictions will need to be mindful of how to deploy electric charging equitably - i.e. to service MF housing areas, rural areas, etc. Also, need to ensure the ongoing viability of the electric grid to support these facilities.
we see silly issues like people with ICE cars blocking these spots, needs to be addressed
arking options; add drop-
areas
This can have a powerful effect on implementation.
General comments
5) Remove on-street parking in residential areas
We have an enormous amount of pavement currently dedicated for people to store their personal property (cars) that could be used otherwise.
The validity of this is dependent upon the nature of the residential area - in other words, only where residents have alternatives, such as driveways.
creates wider streets for multimodal access & new use cases straddles #5 & #6
6) Re-balance the use of the right-of-way with less space for cars and more for people
Will depend on the pace of implementation.

1	Develop and enforce regulations of empty driving
2	Encourage mobility-as-a-service and phase out local buses in favor of auto-jitneys
3	Require vehicle occupancy minimums and VMT maximums
4	Incentivize AV business models that operate in a shared fleet
5	Invest in autonomous rapid transit (ART) dedicated lanes, autonomous vans or buses
6	Develop standardized data specifications and clear data-sharing requirements for mobility providers.





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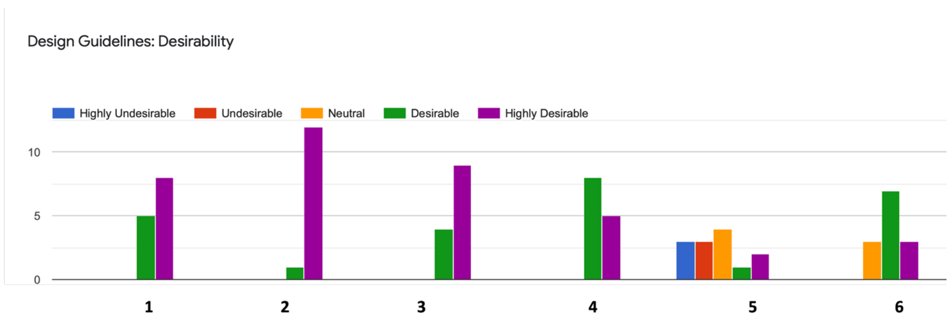

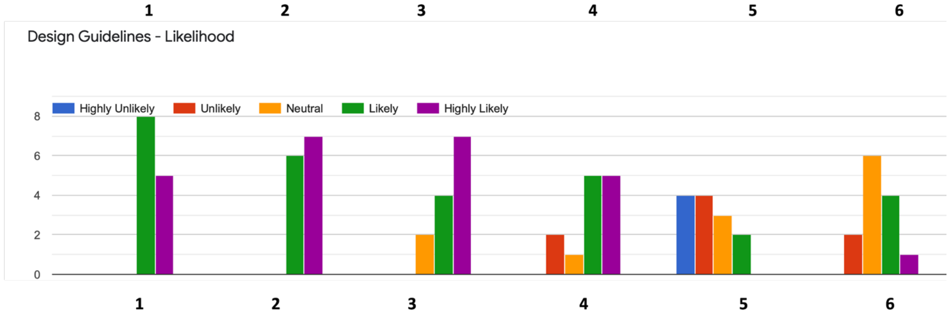

APPENDIX D: PLANNING FOR CONNECTED AND AUTONOMOUS VEHICLES IN MID-SIZED REGIONS: PRACTITIONER'S HANDBOOK

Planning for Connected and Autonomous Vehicles in Mid-sized Regions: Practitioner's Handbook

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EXECUTIVE SUMMARY

This handbook is intended for planners in mid-sized regions of Illinois as they prepare their communities for a future with connected and autonomous vehicles (CAVs). The document offers a range of CAV-related policies and design guidelines, a set of plausible or likely CAV scenarios, and a framework to select the most applicable policies and design guidelines depending on a community's desired future outcomes. The handbook is informed by the latest literature on CAV technologies and the ways some "CAV-forward" communities are responding, as well as primary research conducted by a University of Illinois team with residents and practitioners in Illinois, and with experts on CAV-related planning concerns. The handbook is organized as follows:

The introduction section provides an overview of the handbook. It discusses various connected and autonomous vehicle technologies, and why we need communities to consider their potential impacts and plan for them. The introduction also highlights the value of scenario planning – a tool for managing uncertainties – as a useful framework to think about the paths that CAV technologies and their impacts on communities may take, and the decisions that planners may have to make in order to influence these relationships and create more desirable outcomes for the community. This is followed by a short description of key factors and trends in technology development and adoption (drivers), mechanisms that planners and policy makers may employ to intervene in or prepare for CAV futures (levers), and community-level outcomes of different plausible CAV futures (impacts). This section also includes a summary of ongoing CAV-related planning efforts in some US regions. Finally, the introduction provides some directions for how to navigate this handbook.

The section on scenario planning starts with a description of the topic and its recent applications in urban planning, and explains why scenario planning is a useful tool to plan for CAVs. It goes on to describe how the scenarios are constructed for the purpose of this handbook. In brief, it identifies the three main drivers that according to our research will influence the rates of CAV adoption and usage: 1) advancement in infrastructure and vehicular technologies; 2) acceptance and willingness of residents to use CAVs; and 3) State endorsement and effective planning by related stake- holders. It also identifies a shortlist of frequently studied impacts, such as safety (cyber and physical), travel (congestion and mileage), and the economy (property value and job market), and the most commonly studied policy levers, such as traffic management strategies, incentives for shared transportation; pursuing complementary land use and urban design policies. From this list of factors, the key dimensions for constructing scenarios are selected and their main would be impacts are identified. The constructed scenarios are as follows: (1) continuation of the status quo, (2) private multi-modal future, and (3) shared multi-modal future. For each scenario, a set of recommended action items are identified.

The next section lists the policies and design guidelines – key actions and decisions that planners and communities may consider to prepare for or to respond to different CAV-scenarios. The policies and design guidelines are categorized into six sets of action items: (1) General, (2) Data and Digitization, (3) Mobility and Traffic, (4) Street Design, (5) Infrastructure and (6) Planning. Specific action items, such as "redesign the residential road" or "limit CAV access in areas of high pedestrian and cyclist activity", are included under 'street design' and 'infrastructure' categories respectively. Moreover, details of each action item are organized in a format that allows the user to consider each carefully and to assess its feasibility in specific region or city. The format includes detailed description of each action item, key stakeholders to engage, the right scale of implementation, potential barriers, cost, and time horizon. Furthermore, an organization matrix is included to distilled information to facilitate comparison across action items.

The final section focuses on taking action and includes detailed guidance for the user on how to select from the available list of policies and design guidelines. The guidance includes making choices based on selected impacts and expected costs, among other consideration. The section also provides guidance for communities to create their own scenarios, and identify the decisions necessary to reach the best outcomes under these.

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INTRODUCTION

Purpose

Connected and autonomous vehicles (CAVs) promise to dramatically alter future mobility landscapes and will have profound social, economic, and environmental impacts. Many studies estimate that CAVs will be available within the coming decade. However, the nature and impacts of these technologies are still highly uncertain, making it a challenge for transportation agencies and other organizations to determine the scope of their efforts and to strategically plan for this rapidly evolving mode of transportation. Proactive planning in the midst of this uncertainty is difficult, but is critical for maximizing the benefits of CAVs while also minimizing their potential negative impacts. Regional and local transportation planners, in particular, will play an important role in influencing the nature and impacts of CAV technology rollout.

Image Source: Adobe Stock

Researchers at the University of Illinois at Urbana-Champaign worked with the Illinois Department of Transportation to develop policies and design guidelines to help mid-sized regions in Illinois prepare for an effective CAV future. Our efforts included understanding the state of research and practice surrounding planning for CAVs broadly; and developing a work plan to ground this knowledge locally through practitioner interviews, and household surveys. The complementary interviews and surveys were intended to help us better understand local preparedness for CAVs as well as community perceptions and attitudes surrounding self-driving cars. These lessons informed the scenarios presented in this handbook and the selected list of policies and design guidelines that mid-sized regions may pursue to prepare for CAVs. The guidance presented here to navigate the long list of available decision choices has been developed through engagement with practitioners and experts in the field, and hopes to serve practitioners in various situations be more intentional about the future that they and their communities aspire to achieve.

Preparing Mid-sized Regions for CAVs

Within the scope of our research, Connected and Autonomous Vehicle or CAV is any vehicle with autonomy or connection abilities. According to National Highway Traffic Safety Administration (NHTSA) there are five stages of automation (figure in the following page), and today we are going through the 3rd (conditional automation) and 4th stages (high automation). This includes features such as adaptive cruise control, traffic assist, self-parking, and lane keeping assist (NHTSA, 2019). According to the same resources, fully autonomous car without any driver assistance may be widely available by 2025.

Despite their transformative potential, effective planning for CAVs remains a challenge both due to the novelty of these technologies and uncertainties surrounding their impact on communities. Some communities in the US are currently testing CAVs on public roads or developing engineering and technology standards. However, most planning and transportation agencies as well as private sector companies are uncertain of the pace of technological change and adoption of CAVs, as well as the extent of their impact on driving demand, safety, roadway design, jobs, and the broader urban form. Furthermore, these uncertainties may vary by type of travel (freight vs. passenger), geography (highways vs. local), and socioeconomic context (low-income or elderly riders). As a result, regulations and policies that can promote desirable outcomes remain undefined or unclear.

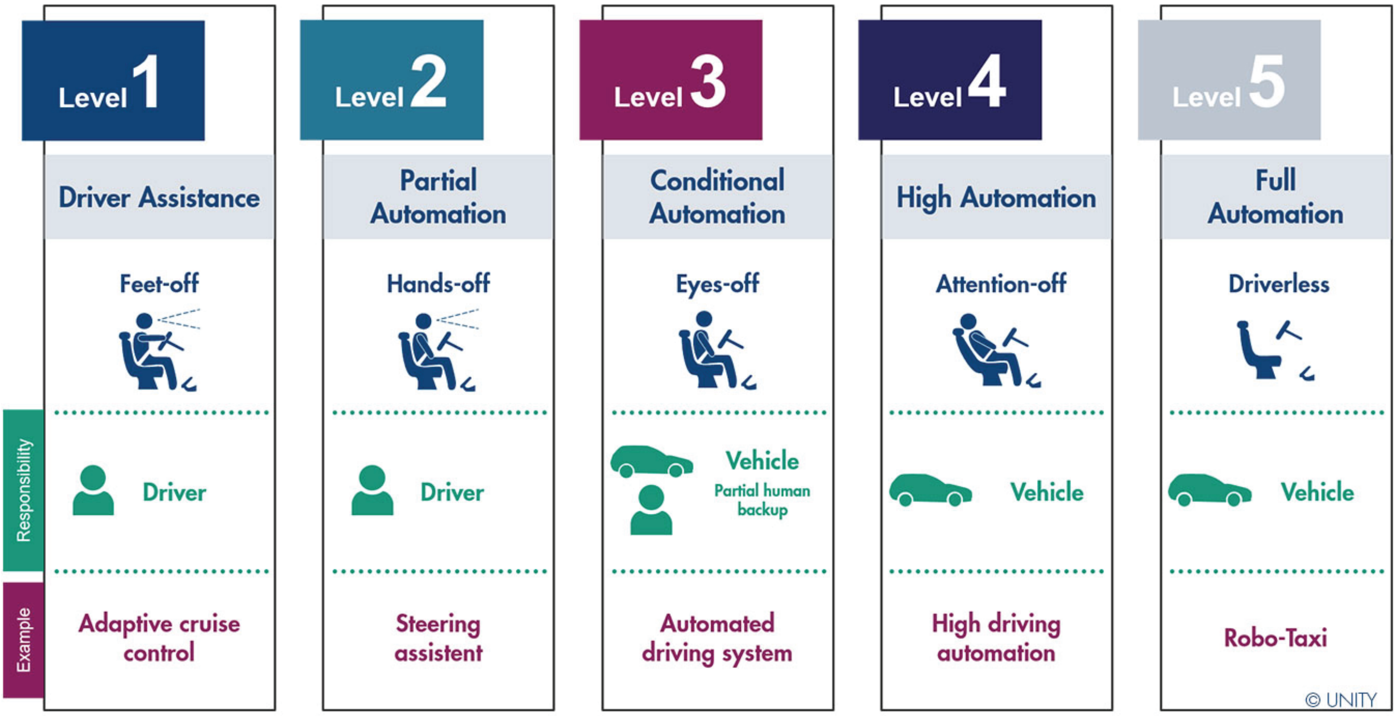


Image Source: Gaupp, F., & Wibbing, P. (2019, July)

Communities need to anticipate how the trajectories of possible changes vis-à-vis CAVs could affect them and devise plans that can help achieve favorable outcomes not just in terms of mobility and urban form, but also the broader economy, environment, and society.

While a number of resources exist for scenario analysis in transportation planning, little guidance exists in the area of CAVs, particularly for mid-sized MPOs. The Federal Highway Administration (FHWA) maintains a robust resource for basic techniques and noteworthy practices in scenario planning. The Association of Metropolitan Planning Organizations maintains a resource page on CAVs directed at MPOs and State DOTs, as does the FHWA. Yet, none of these resources adequately guide transportation planners to systematically navigate the various uncertainties associated with CAVs, nor do these sufficiently assist in formulating policy and design guidelines that can help communities reach favorable outcomes. This is further challenged due to the greater focus of available information on large urban regions at the expense of small and midsize regions. This handbook aims to address this gap.

Scenario Planning

Scenario planning is a suitable approach for MPOs to identify policies and design guidelines to plan for CAVs. Scenario planning can help examine the various uncertainties and organize them in a structured format that will help in identifying important external drivers of change, such as new technologies and extent of adoption, as well as the uncertainties due to varying rates of technological change and adoption (Guerra 2016). It can help planners organize complex information, engage stakeholders, analyze possible impacts of uncertainties, and make choices that can help communities reach a favorable future. Finally, scenario planning can help identify possible short- medium-, and long-term impacts, and offers a path to track and adjust policies based on their performance.

Scenario planning is frequently used to examine the potential impacts of different CAV scenarios on transportation and environmental outcomes. This is often conducted through simulation and modeling tools (i.e., Land use and Transportation models) where CAVs are incorporated into the existing infrastructure and network and their various impacts are assessed accordingly (Rodier et al. 2018). This includes examining impact such as VMT, congestion, accessibility, and emissions (Cohen and Cavoli 2019). Scenario planning along with modeling techniques are used to identifying critical uncertainties, probe plausibility for future applications, while also drawing from previous empirical analyses (Lyons 2016). The assessment of scenarios plays an important role in deconstructing uncertainties as well as policymaking, especially for emerging and unstable technologies such as CAVs. Therefore, it is necessary that the assumptions and limitations appropriated during scenario planning are made explicit and accessible when developing policies and guidelines (Curtis et al. 2020).

Research Methods

The scenario framework and action items presented in this handbook were developed through multiple research methods, including a literature review, planner interviews, a household survey, and stakeholder workshops. These methods and their findings are documented in detail in the policy report accompanying this handbook; a brief summary is provided below.

First, we conducted an extensive review of the academic and policy literature surrounding CAV planning and development. Adopting a scenario planning lens for this effort, we reviewed studies that addressed the major external drivers of CAV planning (e.g., pace and extent of technology development, consumer preferences, anticipated adoption rates, federal and state guidance/legislation); the policy levers that transportation planners can use to guide CAV outcomes (e.g., travel pricing, land use planning, multimodal transportation investments, street design); and the most critical impacts that CAVs are likely to have on communities in the future (e.g., vehicle miles traveled, congestion, emissions, land use and development, safety). The output of this process was a preliminary scenario framework, which outlined the most important drivers, levers, and impacts for CAV planning and the critical uncertainties associated with each.

Next, we refined this preliminary scenario framework through practitioner interviews and a household survey. During phone and Zoom interviews with fifteen MPO and municipal planners across the six regions, we asked participants to describe their agencies' CAV planning efforts (if any) and then discuss the CAV-related issues that their community views as most critical. We then distributed a mail-based survey to 5800 households in the Peoria region and received 733 responses. The survey asked participants to rate their understanding of CAVs; their perceptions of CAVs and potential community impacts; their willingness to adopt CAVs in varying formats; and their expectations of how their travel behaviors and residential location decisions might shift in a CAV future. We used the interview and survey results to refine the preliminary scenario framework and increase its relevance to the mid-sized MPO context.

Finally, we facilitated a series of stakeholder workshops to obtain feedback on the revised scenario framework, as well as on a preliminary list of policies and design guidelines derived from the "levers" portion of the literature review and a scan of additional practice-based CAV guidance. A total of twenty five individuals participated in the workshops, representing local, regional, and state transportation agencies in Illinois and beyond. Participants were asked to rate individual scenarios and policy/design guidelines according to both their likelihood and their desirability. These ratings, along with the group discussion surrounding them, were used to finalize the scenario framework, individual scenarios, and policies and design guidelines presented in the remainder of this handbook.

CAVs in Recent Long-Range Plans

Long-range transportation plan (LRTP) is a long-range strategy and capital improvement program with 20 to 30-year horizons. The plan is aimed at guiding the effective investment of public funds in improving regional mobility and transportation facilities. The plan is usually prepared by Metropolitan Planning Organizations (MPOs) to address their vision and plans for transportation in their respective metropolis and updated every 4 or 5 years to reflect occurring changes (Miami Valley RPC, 2016). Based on an assessment of LRTPs in terms of their readiness to CAVs conducted by Guerra (2016), the majority of cities five years ago were not planning for or envisioning a future with CAVs yet. Today, based on our LRTP assessment, the status has changed and many regions, regardless of their population size, have indeed started discussing CAVs in their planning for emerging technology.

Drivers of CAVs

The main source of varying reactions towards planning for CAVs is the uncertainty and timeline of this technology. MPOs have expressed how difficult it is to make concrete decisions and act given the high uncertainties and varying opinions about the drivers and possible impacts of autonomous vehicles. For example, according to Merced County (2018), "[the MPO will] continue to monitor this technology because the schedule for its adoption and implementation, and its implications remain highly uncertain." In general, we have concluded that MPOs are most uncertain about three aspects of CAVs: 1) pace of technological advancement, 2) degree and pace of adoption (consumer acceptance), 3) and potential impacts of CAVs on traffic (e.g. VMT, congestion)

Infrastructure's technology that is yet to be further developed and deployed includes 5G technology, Internet of Things (IoT), data storage, centralization of database, data integration, Big Data, drones (UAVs), Online platforms, information sharing, live streaming of signal/intersection data. Additionally, upgrades to the telecommunications technology, fiber, and Intelligent Transportation Systems (Miami-Dade MPO, 2016; Miami-Dade MPO Memorandum, 2016). Building an infrastructure that reinforces communication abilities between vehicles and the city's physical system enables an efficient deployment of connected and autonomous cars. Based on the assessment of many LRTPs, most cities are not there yet in terms of preparedness (KPMG 2019). (NYMTC 2017) however has started an initiative of testing connectivity between vehicle and infrastructure by supporting 10,000 vehicles including city buses. The initiative investigates the efficiency of live data sharing from and to the infrastructure/vehicles (traffic data, intersection status, etc.) Arlington Texas has also started updating their traffic signals and data communication infrastructure (North Central Texas Council of Governments 2018b).

One of the most important drivers for CAV proliferation (after assuring the technology is safe) is consumers accepting this technology (North Central Texas Council of Governments 2018a). People are still hesitant about autonomous vehicles. Palm Beach, Florida has shown in their transportation plan that approximately 40% of their respondents are willing to ride a fully autonomous vehicle (Palm Beach Transportation Planning Agency 2019), while other resources have shown that acceptance rates are on the increase (Missouri DOT 2018). Acceptance rates vary based on demographics, prior experience with autonomous technology, and trust. Several locations such as Georgia DOT are aware of this, which encouraged some of the agencies to increase efforts in marketing and educating their residents about CAVs. Considering any possible demographic shifts, perspectives and desires for using CAVs highly affects acceptability rates. According to Nashua's MPO, with their current high population of drivers it is expected that as the driving population ages, the need for CAVs will increase (Nashua Region MPO 2019).

Impacts of CAVs

Safety

Passenger safety is the one of the most certain impacts of CAV technology. They are promised to reduce human error close to 80% (Delaware Valley MPO 2017), resulting in minimum crashes and less fatal accidents. According to a research conducted by The Jackson Area MPO, cyclists and pedestrians feel safer walking or biking along with CAVs as they are more attentive and cautious than human drivers (Jackson MPO 2018). However, virtual safety (cybersecurity) is highly jeopardized and prone to more cyber-attacks (Fredericksburg MPO 2018).

Congestion and travel:
Connected and autonomous vehicles according to literature will have higher efficiency as they can plan trips and communicate with other vehicles and the infrastructure. Most studies point out that although CAVs might resolve the problem of congestion and increase equitable mobility, it will lead to higher Vehicle Miles Traveled (VMT). As a result, experts recommend that extended research should be conducted on potential policies and regulation of controlling VMT increase (Hunter et al. 2018).

Emissions:
If CAVs are to be based on electric charging rather than fuel/gasoline, this results in less vehicle and GHG emissions as well as air pollution (Miami-Dade MPO, n.d.; Fredericksburg MPO 2018). However, these conclusions are not definite anymore, given that VMT rates are to increase with CAV penetration, and the difficulty of having freight/trucks that are electricity based (due to battery size).

Urban form and parking:
Parking space is assumed to reduce since there is no need to accommodate human activity (open/close doors). It is predicted that decrease in parking spaces reaches up to 80% if CAVs are shared 100% (Nygarrd and Will, 2018). The reduced lane widths and elimination of side parking provides more open spaces and encourages human scale redevelopment (North Central Texas Council of Governments, 2018). Based on these changes, building design is also affected due to less parking requirements and inclusion of more drop-off areas (North Central Texas Council of Governments, 2018).

Levers (Action Items)

Given that LRTPs are comprehensive documents at a regional scale, levers are often discussed at a very high or abstract level, which may make it very difficult to translate into actionable policies or regulations. The most proactive levers discussed in many MPO plans are those related to pilots or testing programs. This 'lever' in fact is an action towards understanding the implications of CAVs rather than endorsing/combating possible impacts and driving factors. In some cases, more detailed levers were found in other documents and studies, white papers, and agency reports. These documents often include some guidance for preparing the physical and virtual (data) infrastructure of the city. Additionally, some MPOs encouraged collaborations and working with different stakeholders in order to better plan for CAVs.

Infrastructure investment
In addition to technology, physical infrastructure itself is influential for CAV deployment such as road markings, road surfaces, road signs, electric charging stations. LRTPs so often talk about the need for investing in the existing infrastructure and updating roads and traffic lights to be smart and well connected to receive and transmit data.

Travel pricing
Pricing strategies are suggested as a form of controlling endless roaming of CAVs as they might cause congestion and inefficient traffic flows (Chicago Metropolitan Agency for Planning 2019; Seattle MPO, n.d.). There hasn't been any optimal strategies or methods proposed yet. Some travel pricing method suggested using VMT taxation, cordons and variable tolls (DFML, 2017).

Parking policies
Reduction of parking is one of the certain impacts that most literature agree upon. Therefore, it is the most common "aspect" studied with actionable items to be deployed. Many agree on reducing minimum parking requirements (Horizon, 2018), getting rid of side parking

(APA, 2019), shift parking garages to the peripheries and reduce size of parking (Shaver, 2019). The city of Chandler, AZ has already deployed a regulation by reducing parking requirement by 40%.

Multimodal transportation investment
Uncertainty can be tackled by designing transportation programs that have access to all modes (flexible and adaptable in the future). Investing in the public transportation infrastructure and facilitating the connection between different modes of transportation encourages the use of shared CAVs/SAVs and minimizes private vehicle ownership (Side Walk Labs, 2018; DFML, 2017).

Land use planning and housing policies
Urban form and land use implication are very uncertain, as a result that levers are vague as well. However, recommended regulations try to regulate sprawl by using geofencing techniques (Missouri's Transportation, 2018) and rethinking Euclidean zoning (APA, 2019). There is also a focus on urban design aspects such as developing livable streets, reduce lane widths, and up zoning.

Navigating the Document

Our handbook identifies key uncertainties, discuss how MPO choices may accommodate or influence those uncertainties, and recommend policy and design guidelines for common situations. This handbook can be considered a starting point for MPOs interested in conducting their own detailed scenario planning activity, either specifically for CAVs or for broader transportation and regional planning. We expect this handbook to also be a resource for similarly sized MPOs around the Midwest. This is because little such guidance currently exists from FHWA and other leading agencies, and because CAVs are expected to impact mid-sized cities and regions differently than larger regions due to their less dense urban form and more automobile-oriented transportation infrastructure.

This handbook is meant to assist practitioners in navigation the uncertain future of CAVs. We do so by giving an overview of CAVs and their impacts. We also introduce a scenario framework that simplifies some of the possible futures and their expected outcomes that will impact these regions. The handbook also provides a comprehensive set of recommendations, policies, and design guidelines that facilitate the navigation of the possible scenarios. The handbook also provides inputs and guidelines for practitioners interested in imagining the future of their regions.

The first section provides an introduction to autonomous vehicles, what different MPOs are doing, and the various impacts of this technology on our regions. The second section then introduces the concept of scenario planning within the context of CAVs. In this section we talk about different elements such as drivers, levers and impacts of CAVs. All of these are necessary of imagining and understanding the possible CAV futures. An important part of this section is explaining the various scenarios (3 futures) and a detailed profile of each scenario. The third section discusses the list of action items that can be selected and adopted by the various stakeholders. Each action item is described in detail, including information on costs, benefits, timelines, scale of adoption. The final section provides a guideline for navigating and filtering the different action items based on your agency's interests and deliverables. Similarly it guides you through creating your own scenarios.

SCENARIO PLANNING

What is Scenario Planning?

Scenario Planning

Scenario planning is a tool for decision making under uncertainty and it is commonly employed by many metropolitan planning organizations (MPOs) in developing long-range transportation plans (LRTPs) (Zegras, 2004). Since Portland's Land Use, Transportation and Air Quality plan, many metropolitan areas have used scenario planning in exploring alternative futures and in identifying a course of action (Chakraborty, 2011). In Illinois, the Chicago Metropolitan Agency for Planning (CMAP) relied on scenario planning in their Go to 2040 and On to 2050 plans (CMAP 2019). In Indiana, the Indianapolis MPO has initiated 2050 Scenario Planning as a way to visualize the possible future(s) of the land use and transportation in Central Indiana (Indiana MPO 2020). This initiative assisted regional planners in assessing the different conditions and their possible outcomes, which could then be used in their long-range transportation plans. MVRPC in their updated LRTP have used scenario planning to assess the impacts of CAVs on mobility metrics such as congestion rates, VMTs, and empty trip percentages. This has assisted them in identifying the desired CAV adoption rates by 2050 (Miami Valley RPC 2021).

Why is Scenario Planning important?

Scenario planning is a suitable approach for MPOs to identify policies and design guidelines to plan for CAVs. Scenario planning can help examine the various uncertainties and organize them in a structured format that will help in identifying important external drivers of change, such as new technologies and extent of adoption, as well as the uncertainties due to varying rates of technological change and adoption (Guerra 2016). It can help planners organize complex information, engage stakeholders, analyze possible impacts of uncertainties, and make choices that can help communities reach a favorable future. Finally, scenario planning can help identify possible short-medium-, and long-term impacts, and offers a path to track and adjust policies based on their performance.

Scenario planning can be used to examine the potential impacts of different CAV scenarios on transportation and environmental outcomes. This can be conducted through simulation and modeling tools (i.e., Land use and Transportation models) where CAVs are incorporated into the existing infrastructure and network and their various impacts are assessed accordingly (Rodier et al. 2018). This includes examining impact such as VMT, congestion, accessibility, and emissions (Cohen and Cavoli 2019). Scenario planning along with modeling techniques can also be employed to identify critical uncertainties, probe plausibility for future applications, while also drawing from previous empirical analyses (Lyons 2016). The assessment of scenarios plays an important role in deconstructing uncertainties as well as policymaking, especially for emerging and unstable technologies such as CAVs. Therefore, it is necessary that the assumptions and limitations appropriated during scenario planning are made explicit and accessible when developing policies and guidelines (Curtis et al. 2020).

This handbook articulates a set of plausible CAV scenarios for mid-sized regions. It also offers a curated list of policies and design guidelines which, locally-contextualized in appropriate subsets, can offer practitioners in these communities important tools to plan for and respond to CAVs, and to achieve desirable outcomes for their communities. Finally, the handbook includes guidance on how to navigate the provided scenarios and policies, as well as for communities to design their own scenario planning process.

Drivers, Levers, and Impacts

Scenarios are the outcome of organizing important considerations along two primary axes: (1) external forces which are exogenous to MPO planners (**i.e. drivers**) and (2) actions over which transportation agencies may have some influence (**i.e. levers**). The different scenarios then can be compared and evaluated based on a set of metrics that are of interest to planners (**i.e. impacts**).

Drivers

Drivers are the key external factors that planning agencies are not in control of, which will eventually have an effect on the development and adoption of CAVs in communities. According to existing studies, three main drivers will influence rates of CAV adoption: 1) advancement in infrastructure and vehicular technologies; 2) acceptance and willingness of residents to use CAVs; and 3) State endorsement and effective planning by related stakeholders. This includes investments and development conducted by the private sector in which forwards CAV proliferation rates.

Impacts

We define impacts as changes -tangible and non-tangible- that communities experience due to the introduction and usage of CAVs. Among the most frequently studied are impacts on safety (cyber and physical), travel (congestion and mileage), and the economy (property value and job market). The environment (emissions), urban form (land use, sprawl and density), and the nature of accessibility and equity are also considered.

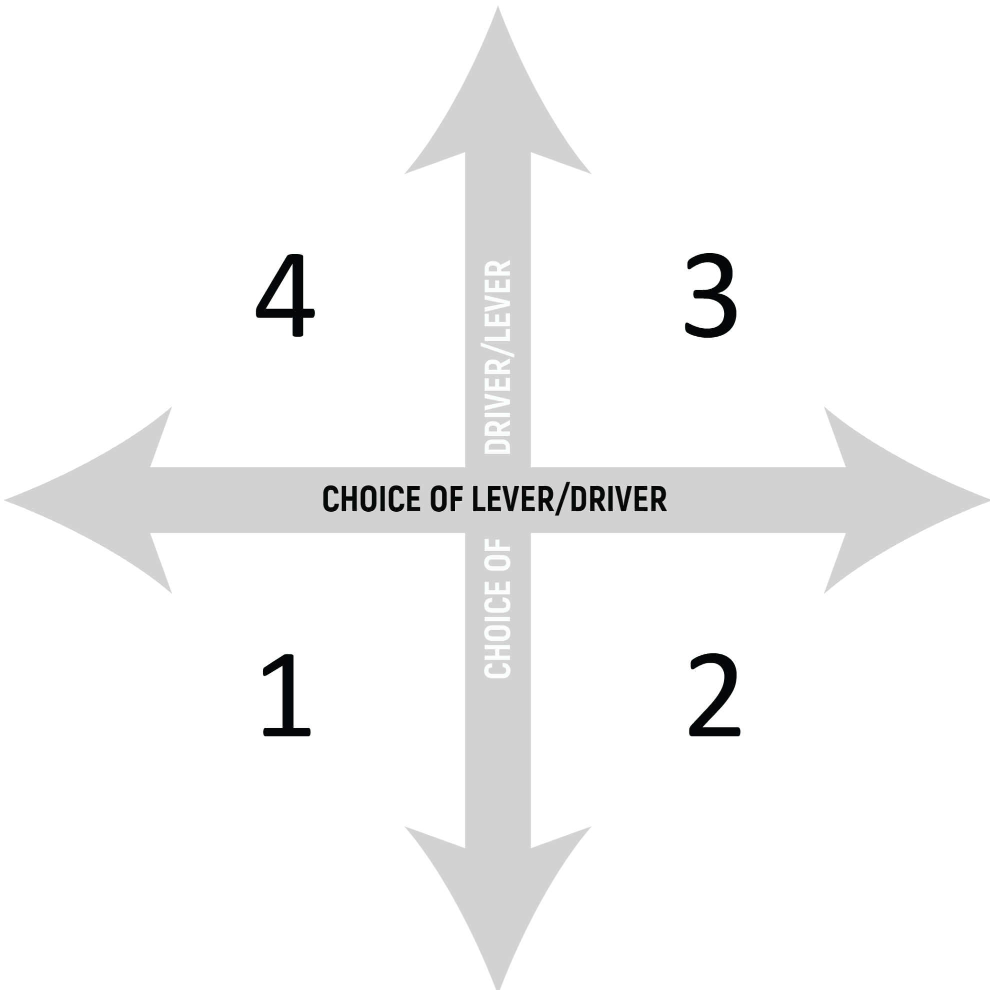
Levers

Levers are any actions that entities may adopt in order to manage the impact of CAVs in a community under different futures. Levers can be adopted by planning agencies, transportation departments, and other involved stakeholders. The actions most commonly cited in the CAV literature are: introducing traffic management strategies; enhancing physical and digital infrastructure; providing incentives for shared transportation; pursuing proactive land use policies; and developing adjusted urban design guidelines (e.g., reduced parking requirements).

General Framework

Framework

As we develop our scenarios, we have to think about the appropriate drivers and levers that relate to our goals (as an agency or department) and what are the important factors to be considered. The figure below shows an abstraction of how the choice of levers and drivers create a set of scenarios that might be of concern. The **primary dimensions** (x-axis, y-axis) construct the main point of concern and are easily visualized on an xy plane. However, this framework also allows for further complexities to be considered through additional dimensions (i.e. **secondary dimensions**). Secondary dimensions can either be levers or drivers and are considered necessary for the construction of the scenario framework. Each of these scenarios can then be compared and assessed individually based on a set of impacts that, once again, are prioritized by the different agencies.



Dimensions

Based on our research detailed in FHWA-ICT-22-012, we have created lists of important drivers, impacts, and levers that can be summarized in the figure below. A subset of drivers and levers can be packaged to create a scenario, which could then be assessed on a set of impacts. The selected 'package' of drivers/levers/impacts may vary from one application to another depending on an agency's or a community's need.

Drivers

Technological change
- -Infrastructural
- -Vehicular

Consumer preferences
- -Adoption percentages/rates
- -Type of ownership
- -Electric vehicle share

Demographic shifts

Impacts

-Safety
-Vehicle miles traveled (VMT)
-Congestion
-Emissions
-Urban form
-Accessibility
-Equity
-Economic shifts

Levers

-Infrastructure investment
-Travel pricing
-Parking policy
-Multimodal transportation investment
-Land use planning

Scenario Framework

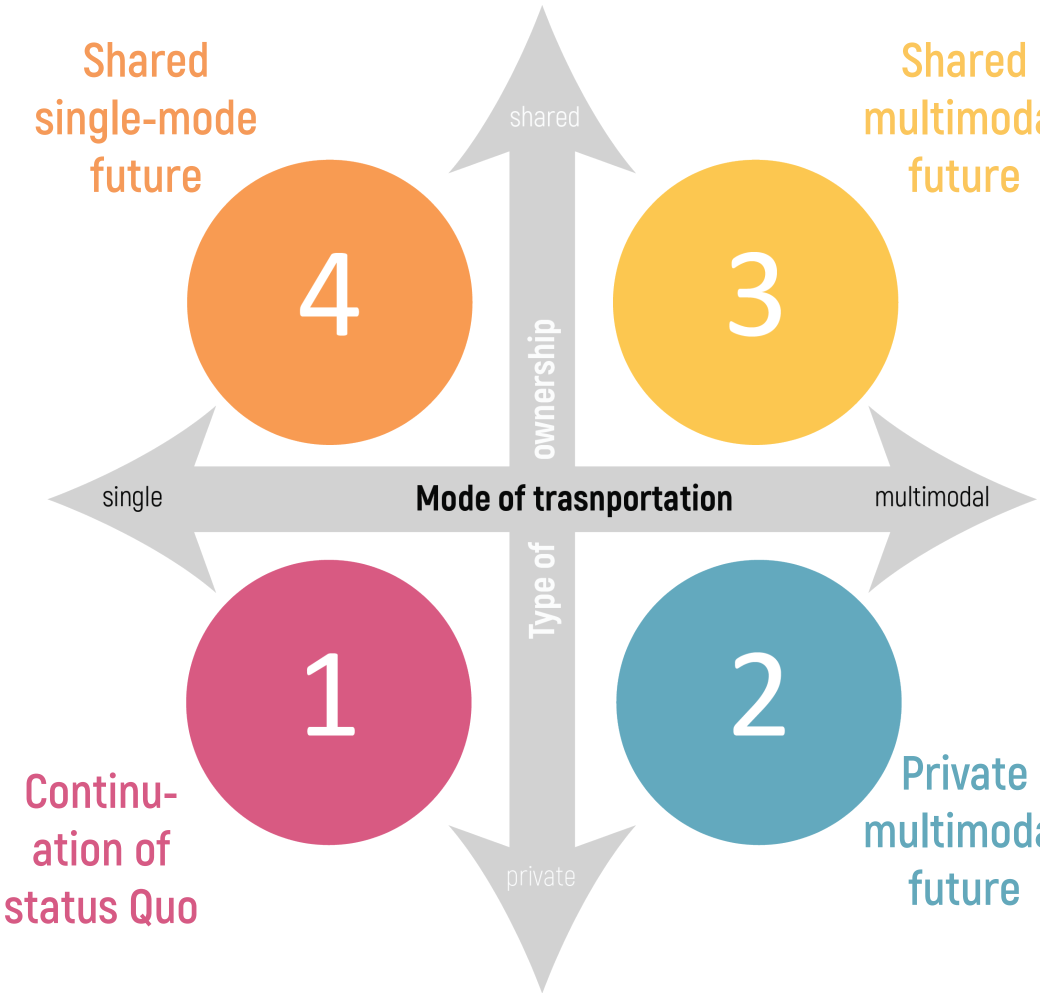
Dimensions

In this section, we highlight a select set of scenarios that aim to capture the most important uncertainties for planners and policymakers in mid-sized regions. These scenarios are constructed around a subset of drivers, levers and impacts which are identified through extensive research, which included household surveys in the Greater Peoria region and interviews with transportation planners, technical leads, and decision makers throughout the State of Illinois.

The two drivers deemed most important for our scenario creation purposes, i.e. the primary dimensions, are (1) Mode of Transportation and (2) Type of Ownership. Mode of Transportation captures the extent to which individuals may using single or multiple modes of transportation. This looks at whether residents mostly depend on one mode (i.e. their own vehicle) or several modes (i.e. walk and use the bus) to reach work/school. Type of Ownership is important because the form of CAV ownership – shared vs. individually owned – remains highly uncertain, and is expected to be one of the important factors defining future ridership demands and travel patterns. Type of ownership measures the percentage of population owning a private vehicle versus residents who are signed up for shared forms of transportation including public transportation, Uber/Lyft, taxis and coaches.

Four scenarios are created using based on these drivers. These are Shared Single Mode, Shared Multi-Modal, Private Multi-Modal, and Continuation of Status Quo. The figure in the next page explains how each quadrant represents a scenario.

Our scenarios also consider two additional factors, not included in the axial diagram, electric vehicle usage and CAV adoption percentage. The electric vehicle share aims to capture conversion of vehicle fleet from primarily gasoline-powered to electricity powered, and is expected to be an important factor in greenhouse gas emissions and air pollution. This metric estimates the percentage of vehicles that are electric-based rather than gasoline/diesel based. These include non-private vehicles such as buses, taxis, TNCs (e.g. Uber/Lyft), and paratransit. CAV adoption percentage aims to capture the percentage of vehicles that are highly autonomous (SAE levels 4 & 5). This includes non-private vehicles such as buses, taxis, TNCs (e.g. Uber/Lyft), and paratransit.

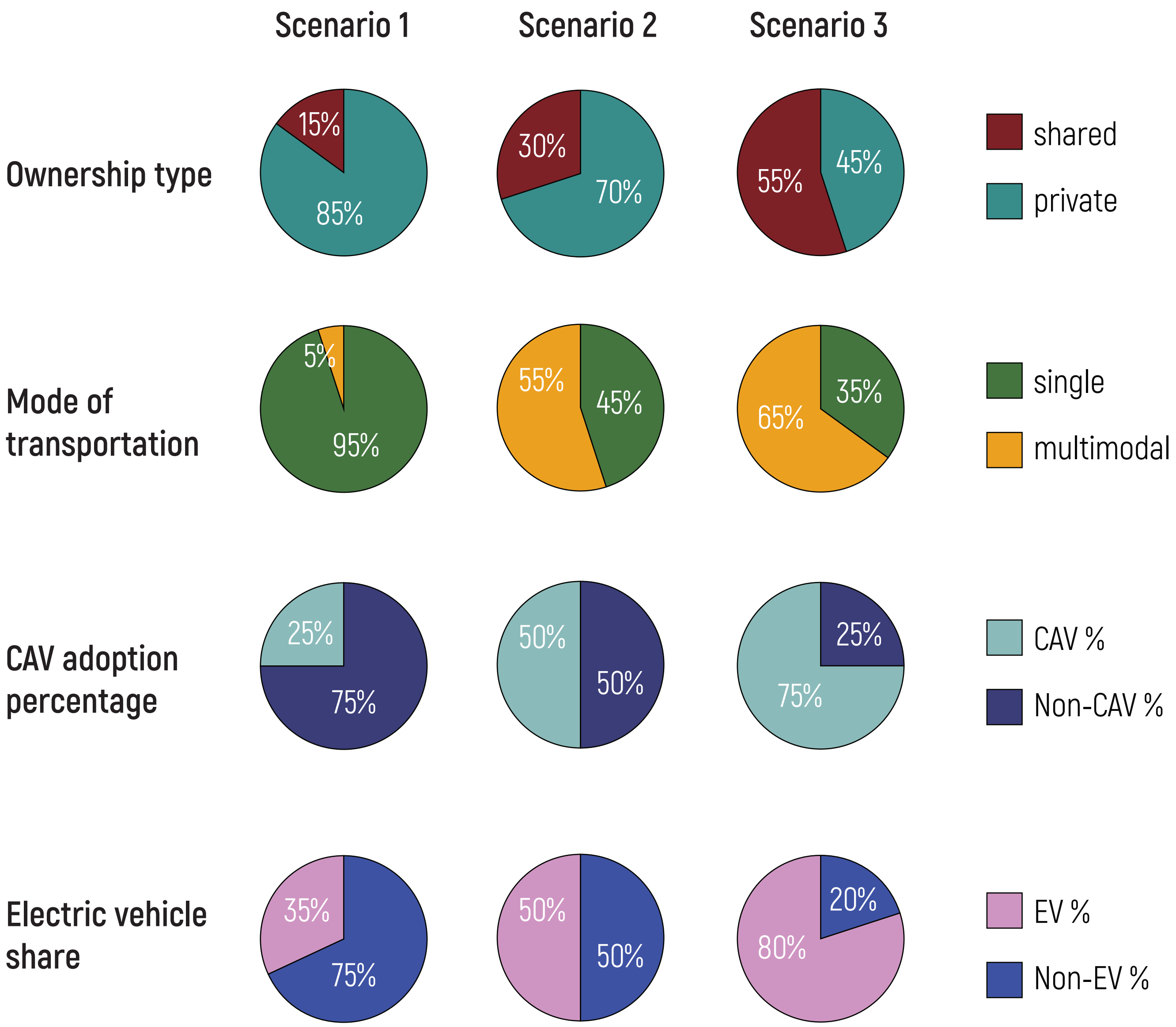


Shared
single-mode
future
shared
Shared
multimodal
future
4
ownership
3
single
Mode of trasnportation
multimodal
Type of
1
2
Private
multimodal
future
Continu-
ation of
status Quo
private

Scenarios

Scenarios

Based on our literature review, surveys, discussion with transportation planners, technical leads, and decision makers, we create a profile for each scenario describing the extent of each dimension. Please see the figure below to understand how we apply these dimensions and how the scenarios are generated accordingly. We have omitted Scenario 4 – shared yet single mode – from our analysis since we do not see this as a plausible future outcome.



Impacts

In the following section we talk about each scenario in detail, including how the different drivers, levers, and impacts influence each other. We then visualize and describe the various expected impacts of each scenario. These impacts are categorized under six groups described below: Emissions, Congestion & Vehicle Miles Traveled (VMT), Road design, Accessibility & Equity, Safety, and Land use & Density. Finally, based on these projected impacts, we recommend a list of action items that can facilitate achieving a desirable scenario, or, if achieving a desirable scenario as defined this handbook were not the goal, at least a set of desirable impact outcomes under each scenario.

Emissions

This evaluates the possible increase/decrease in greenhouse gases (GHG) as well as other polluting agents (i.e. carbon)

Congestion & Vehicle Miles Traveled (VMT)

These are common metrics used for evaluating traffic and mileage conditions. Congestion measures the efficiency of the introduced system whereas VMT measures the increase/decrease in miles traveled by non-active transportation modes

Road design

This concerned with documenting changes in right-of-way (ROW), drop-offs/pick-ups, lane widths, change of lane assignments such as high-occupancy lanes and bike lanes.

Safety

This evaluates the extent at which CAVs would impact physical safety (i.e. crashes) and virtual safety (cyber-security).

Land use & Density

This evaluates the different expectations with regards to changes in land uses, redevelopments, population density changes, etc.

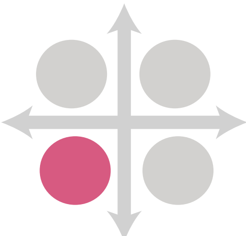
Accessibility & Equity

This evaluates the equity gaps created or exacerbated by CAVs.

Scenario 1: Continuation of Status Quo

Image Source: Adobe Stock

Scenario 1: Continuation of Status Quo



This scenario is based on the evolution of the current status and mobility behavior. The majority of households will be owning and using their private vehicle. This is especially true if CAVs business model are made affordable.

This scenario also imagines a transportation infrastructure that continues to serve private ownership. This means that public transportation and private mobility do not complement each other sufficiently. Likewise, the expectation is that many of the existing transit infrastructure is made less convenient due to the impact of CAVs.

In this scenario, the low-density built form will continue to expand even if the town-centers might experience some higher density. Likewise, land use is expected to be less mixed and more segregated.

Ownership type: Mostly private
The majority will use their private vehicles to move around and reach destinations with 85% continuing to privately own automobiles.

Mode of transportation: Mostly single
The majority of residents will opt for using vehicles whether in the form of CAVs or traditional cars to reach their destinations.

CAV adoption: Low
In this scenario it is expected that residents will adopt CAVs at a very slow pace. End state is low adoption percentage (25%).

EV share: Low
The expected EV share will not exceed 25% as they are not affordable yet and the infrastructure is not EV-friendly.

Image Source: Shutterstock

There is minimal reduction in physical safety and car accidents, since many vehicles are still non-CAVs (75%). Vehicles that are connected to the digital system might face cyber-attacks.

Congestion rates are expected to be high since vehicle ownership is expected to increase. Likewise vehicle miles traveled (VMTs) are projected to increase as residents are willing to travel more often.

Road design and street widths are expected to maintain the existing structure and form as the number of vehicles using the roads is to increase. Drop-off areas and electric charging stations will become available to serve CAVs and EVs.

Expected high equity gaps as lower-income residents will not have access to their own vehicles and poor alternatives for mobility.

Emissions such as GHG and CO2 will increase as VMTs and congestions increase. Additionally, since the EV share is expected to be low (25%), reductions in emissions due to electric charging will be relatively low.

Living preferences are expected to stay the same. Residents preferring to live close to their workplace or downtown will not change their location. Likewise applies to residents living far from their daily destinations.

Scenario 1: List of recommended action items

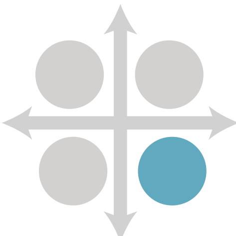
Data & Digitization	Promote data sharing that preserves data privacy and security
	Establish centralized repositories to hold and provide structured access to mobility data
General	Prepare and educate staff about the CAV technology and its possible impacts
	Designate regulatory roles
Infrastructure	Deploy 5G infrastructure
	Designate roads for autonomous vehicles as they are ready
	Develop new models for pavement maintenance
Mobility & Traffic	Incentivize CAV business models that operate in a shared fleet (SAVs)
	Develop and enforce regulations of empty driving
	Manage and reduce congestion
	Provide equitable mobility
Planning	Update transportation and land use models to include CAVs
	Align CAV policy with local greenhouse-gas (GHG) reduction goals
	Reduce parking requirements or institute parking maxima
Street Design	Design separated bike lanes
	Introduce improvements in lighting, pedestrian crossing islands, and gateway treatments
	Prioritize right-of-way for pedestrians

A detailed description for each action item and how they are selected can be found in the third chapter titled Action Items: Policies and Design Guidelines.

Scenario 2: Private Multimodal Future

Image Source: Adobe Stock

Scenario 2: Private Multimodal Future



The Private Multimodal scenario imagines a future that still maintains a high percentage of private ownership of vehicles (i.e., private autonomous vehicles). However, the transportation infrastructure allows and encourages shifting between different modes since they are more accessible and affordable. These modes include shared CAVs, transit, walking, biking, and micromobility.

Additionally, the expectation is that many of these private vehicles will be CAVs rather than traditional cars. This provides a higher chance for ultimately more efficient roads and less polluting emissions.

Ownership type: Mostly private
The majority will use their private vehicles to move around and reach destinations with 70% owning these vehicles.

Mode of transportation: Mostly multimodal
Although most vehicles will be private, there are many opportunities for using different modes since the existing infrastructure allows for that (55%).

CAV adoption: Medium
In this scenario it is expected that residents will adopt CAVs at a faster pace. End state is medium adoption percentage (50%)

EV share: Medium
The expected EV share will align with CAV adoption and electric-based vehicles become more affordable. Likewise, there are many charging stations and incentives encouraging the usage/ownership of EVs.


Image Source: Shutterstock

It is expected that physical safety will be higher due to the higher adoption of CAVs. However, due to higher connectivity, it is also anticipated that there is a higher chance of cyber-attacks.

Mobility accessibility is higher. Possible social equity gaps.

Higher congestion and VMT due to private ownership.

Lower GHG and CO2 due to EV-based CAVs (long run)

Road design prioritizes vehicles. Building codes minimize parking requirements. Drop-offs and EV station as more common.

Expansion of low-density neighborhoods.

Scenario 2: List of recommended action items

Data & Digitization	Establish a standardized data report for collisions
	Establish centralized repositories to hold and provide structured access to mobility data
	Digitize existing transit infrastructure
General	Prepare and educate staff about the CAV technology and its possible impacts
	Designate regulatory roles
	Run CAV pilot program(s)
Infrastructure	Deploy 5G infrastructure
	Modify speed limits to low speeds
	Introduce smart intersections
	Add electric vehicle charging stations
	Designate roads for autonomous vehicles as they are ready
	Update traffic signs/markings; adjust signal locations and timing
Mobility & Traffic	Phase out local buses in favor of auto-jitneys and mobility-as-a-service
	Limit CAV access in certain community, social space, and high pedestrian and cyclist densities
	Incentivize CAV business models that operate in a shared fleet (SAVs)
	Manage and reduce congestion
	Manage lanes through dedicated lanes for CAVs
	Introduce tolling and demand management
Planning	Plan for equity
	Densify low density areas
	Support public transit so it doesn't become obsolete
	Reduce parking requirements or institute parking maxima
Street Design	Rethink curb design and street space allocation
	Establish clear CAV (as well as transportation network company) drop-off and pick-up zones
	Introduce road diets

A detailed description for each action item and how they are selected can be found in the third chapter titled Action Items: Policies and Design Guidelines.

Scenario 3: Shared Multimodal Future

Image Source: Shutterstock

Scenario 3: Shared Multimodal Future

Shared Multimodal scenario imagines a region that has shifted from the dominant private ownership model. This is boosted through shared CAVs being utilized and efficiently propagating amongst the different neighborhoods.

In this scenario the infrastructure has been updated to recognize the different modalities such as walking, biking, transit, micromobility, and the automobile. Most importantly it recognizes people as the center of the transportation system. Therefore, they are given most space and many of the mobility codes prioritize the safe movement of pedestrians and cyclists.

The distribution of land use and density percentages allows for higher proximity and equitable distributions.

Ownership type: Mostly shared
The majority will use their shared vehicles to move around and reach destinations. Given the medium size of these regions is less than 45% owning private vehicles.

Mode of transportation: Mostly multi-modal
The majority of residents (65%) use a combination of modes to reach their desired destination. This includes active and non-active modes.

CAV adoption: High
In this scenario it is expected that residents will adopt CAVs at a very faster pace. End state is high adoption percentage (75%)

EV share: High
The expected EV share (75%) is high since CAVs are expected to be EV-based.

Image Source: Shutterstock

High physical safety.
Higher chance of cyber-attacks

Mobility accessibility is higher. Possible social equity gaps

Lower congestion and VMT due to shared ownership

Lower GHG and CO2 in the long run.

Roads are designed for multimodal transportation. Narrower roads. Lower speed. More drop-offs, electric charging parking.

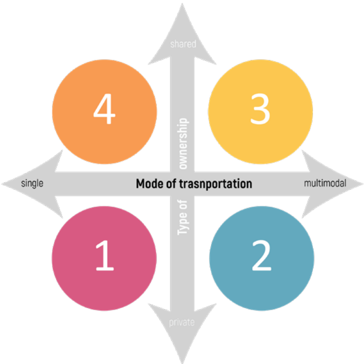
Expansion of low density. Increase of high density. Redevelopment of parking lots.

Scenario 3: List of recommended action items

Data & Digitization	Establish a standardized data report for collisions
	Require data reporting
	Promote data sharing that preserves data privacy and security
	Establish centralized repositories to hold and provide structured access to mobility data
	Digitize existing transit infrastructure
General	Prepare and educate staff about the CAV technology and its possible impacts
	Designate regulatory roles
	Run CAV pilot program(s)
Infrastructure	Deploy 5G infrastructure
	Modify speed limits to low speeds
	Introduce smart intersections
	Add electric vehicle charging stations
	Reduce lane width
Mobility & Traffic	Phase out local buses in favor of auto-jitneys and mobility-as-a-service
	Limit CAV access in certain community, social space, and high pedestrian and cyclist densities
	Invest in autonomous rapid transit (ART) dedicated lanes
	Incentivize CAV business models that operate in a shared fleet (SAVs)
	Develop and enforce regulations of empty driving
	Consider tailoring auto-jitneys to each neighborhood
	Introduce tolling and demand management
Planning	Provide equitable mobility
	Convert surface parking lots/garages to new development, public plazas, or green space
	Plan for vibrant social hubs
	Align CAV policy with local greenhouse-gas (GHG) reduction goals
	Remove on-street parking in residential/commercial streets
Street Design	Rethink curb design and street space allocation
	Design separated bike lanes
	Introduce road diets
	Manage the curb for high people volumes, not cars

A detailed description for each action item and how they are selected can be found in the third chapter titled Action Items: Policies and Design Guidelines.

Summary



This section identifies four possible future scenarios using the drivers and levers identified as the most important from planning and policy standpoint. First, is a continuation of the status quo–of largely automobile-oriented planning and an ownership model in which most CAVs are privately owned and operated. There is not much room for or consideration of other modes, and there's not much of a shared fleet to speak of. Second, the "private multimodal future," is a scenario in which transportation planners do a good job of accommodating other modes of travel–there's not just an exclusive focus on CAVs–but the shared fleet concept hasn't taken off. There's still a predominance of private vehicle ownership. Third is a future in which transportation planning is multimodal–all modes are accommodated and CAVs are well integrated with other modes–and in which most of the vehicle fleet is shared. We have a subscription model in which people can hire cars to take them where they need to go on an as-needed, on-demand basis, rather than having to own their own vehicles that travel lots of empty miles. Mobility-as-a-service is a key concept within this scenario. And, finally, we have the quadrant in which transportation planners continue to focus primarily on the automobile–we have CAV-dominated planning–but the shared fleet idea takes off. This scenario is not seen as likely, because it is hard to avoid owning your own car and foregoing door-to-door service if other modes are not robust, convenient, or safe. As such, in this section, the first three of these scenarios are discussed in detail along with their possible impacts and actions that communities may take to prepare for them, or in response to them.

	Scenario 1	Scenario 2	Scenario 3
	Low	High	High
	High	High	Low
	Low	Low/High	Low/High
	High	High	Low
	Low	Low	Low/High

ACTION ITEMS: POLICIES AND DESIGN GUIDELINES

Organization of Policies and Design Guidelines

Findings from the research activities described in previous chapters—including the literature review, planner interviews, household survey, and stakeholder workshops—were used to refine the CAV scenario framework, and compile and organize a set of policies and design guidelines (hereafter referred to primarily as "action items") for proactive CAV planning in mid-sized regions.

In this section we provide a list of action items with additional descriptive guidance to help connect them to specific scenarios or decision situations. These action items represent both policies and design guidelines and can be adopted based on their various characteristics/attributes. A total of fifty-three entries were included from various sources, including government documents, recommendations for national organizations, and academic research, and organized in a format that allows users to navigate them effectively. These action items are organized into six categories based on their scope and field of application: General, Data & Digitization, Mobility & Traffic, Street Design, Infrastructure, and Planning. These categories were chosen to facilitate navigation and prioritization processes that will be adopted by the different entities and agencies.

General

Data/Digitization

Mobility & Traffic

Street Design

Infrastructure

Planning

Action Items

The action items in this section are presented in a format that allows the user to understand the details of each policy or design guideline, and to assess their feasibility in their region or city. The organization matrix aims to facilitate comparing actions item either by their costs and benefits, scale of intervention, stakeholders, and time horizon. The following table provides a description of the template and definitions of terms that we used for organizing the action items. The action items in the following pages are organized into one of the six categories.

Attribute	Comments	Reference
Action Item	Policy/Design Guideline statement	
Category	The scope of the suggested policy/design guideline. Once policy/design guideline can cover more than one category. The list of categories are as follows: • Mobility & Traffic (MT) • Street Design (SD) • Infrastructure (I) • General (G) • Planning (P) • Data and Digitization (DD)	
Code	The formal coding/numbering we assign for each of the action items. This facilitates the navigation process. It is also used as a reference system. • AA-XX • AA: Category abbreviation (MT, SD, I, G, P, DD) • XX: Number of policy/design guideline (01, 02, 03, ...)	
Description	**General description:** A clear description of the Policy/Design Guideline statement and the different forms of applying it. **Context-specific description (optional):** A contextual description of the policy especially related and projected in midsize regions. This section describes any context-based applications or deployment of the policy/design guideline.	
Stakeholders	The agencies and entities who should be engaged in considering/ implementing this policy/design guideline.	

Scale	The appropriate spatial extent for deploying of the policy/design guideline. We limit the scale to either Regional or Local to allow users to identify the responsible stakeholders and the extent of deployment. · Regional: Policy/Design guideline is recommended to be applied at a regional level. This allows for coordination between the different cities/towns to reap more benefits (more effective) of the policy/design guideline. · Local: Policy/Design guideline doesn't require wider geographical adoption/implementation and is sufficient at the local level.	
Impact/Benefit	The possible positive impacts of implementing this policy/design guideline. This includes impacts on emissions, VMT, congestion, safety, urban form, mobility and equity.	
Barriers	The possible barriers or hurdles faced when implementing the policy/design guideline. This includes obstacles related to technology, operations, public acceptance, and financing.	
Cost	The expected financial costs/burdens imposed in the implementation of these policies/design guidelines. The different sources and venues for the financial burdens. We categorize by the expected level of investment (e.g., personnel, budget, stakeholders) · Low investment ($) · Medium Investment ($$) · High investment ($$$) · Uncertain · Varies	
Time horizon	The recommended timeline suggested for starting to plan/apply a specific policy/design guideline. Alongside, we state the required level of CAV adoption to proceed with planning and applying the action item. Timeline for starting P/DG adoption: · Short term · Medium term · Long term Percentage of CAV adoption required for P/DG adoption: · Low adoption: Does not require CAV adoption. · Medium adoption: Require some percentage of CAV adoption. · High adoption: Require highest CAV adoption percentages.	
Example/ visualization	A case study or visualization, where applicable, showcasing the implementation of the policy/design guideline. It is recommended to view the source of this case study or visualization to learn more about the details.	

General

General action items relate to generic recommendations to planning for CAVs. They are not necessarily specific to a category and fall under overall preparations for a better CAV future.

Attribute	Comments	Reference
Action Item	Align CAV policy with local greenhouse-gas (GHG) reduction goals	[3]
Category	Planning/General	
Code	P-01/G-01	
Description	General Description: - Strategic deployment of CAVs can help communities meet GHG-reduction goals through their Climate Action Plans. CAV policies should encourage shared and electric CAVs and incentivize lower vehicle miles traveled (VMT).	[3]
Stakeholders	State Departments of Transportation, Mass transit agencies, Municipality, Metropolitan Planning Organizations, Environmental Protection Agency	
Scale	Regional	
Impact/Benefit	Direct: Lower GHG emissions, achieve environmental sustainability goals. Indirect: Lower VMT, congestion, and infrastructure costs	
Barriers	Dependent on CAV adoption rates and ownership model (shared vs. private)	
Cost	Stricter fuel economy standards (varies) Advancing electric-based charging infrastructure ($$)	[13]
Time horizon	Long term, high CAV adoption -CAVs will require time to significantly impact GHG emission reductions -Requires high electric-based vehicles	[13]
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Reposition transportation-related revenues	[4] [19]
Category	Planning/General	
Code	P-02/G-02	
Description	General description: - Communities rely on revenues from gasoline taxes to fund road maintenance, transportation infrastructure, and transit subsidies. Additionally, significant sources of municipal revenue include parking fees, parking tickets, and moving violation fines. CAVs may speed up revenue decline in multiple ways. CAV may self monitor parking and driving behavior and reduce fines. If CAV fleets are heavily comprised of electric vehicles, gas tax revenues may also decline, potentially leading to budget shortfalls in communities that reply on such revenues. Communities can look to make up for lost funds through transportation charges, such as per-mile fees, and new land use/property taxes on, for example, parking lots converted to higher-value uses. - Communities should: 1. Understand their revenues structures and the policy levers. 2. Identify existing curb demand and areas for flexible curb space. 3. Ensure all loading zone signage is specific, visible, and managed. 4. Confirm current tax code does not incentivize parking lots. 5. Determine appropriate areas for eliminating parking minimums.	[4] [19]
Stakeholders	State Departments of Transportation, mass transit agencies, metropolitan planning organizations, local parking authority, and municipal public works	
Scale	Regional	
Impact/Benefit	Direct: Alternative revenues and resources; More job opportunities from new developments Indirect: Reduced congestion	
Barriers	Context-based	
Cost	The cost of this policy is based on how an entity decides to reposition it revenues (varies)	
Time horizon	Medium term, medium/Hhigh CAV adoption	
Example/ visualization	-Calgary, Alberta showed that if the city could consume a quarter less land through a denser growth pattern, it could save $11 billion in capital costs alone. -Washington and Oregon are experimenting with vehicle miles traveled (VMT) fees.	[19]

Attribute	Comments	Reference
Action Item	Prepare and educate staff about the CAV technology and its possible impacts	[22]
Category	General	
Code	G-03	
Description	**General description:** - Build partnerships with trasnportation insitutions, technology providers, stakeholders concerned with CAVs, and educational institutions - Identify needs for expanding staff skills sets or restructuring program areas - When possible, provide facilitate participation in regional, state, or national dialogues - Ensure staff are aware of how vehicle connectivity and automation technology impacts their program areas - Incorporate workforce readiness, education, and training programs into mobility and equity innovation zone (any shared-mobility projects that free people from the expensive necessity of owning a car) **Context-specific description:** - Promote collaboration among practitioners from different departments and agencies to assess the role CAVs in their respective regions.	[22] [23]
Stakeholders	Municipality, especially planning and public works departments, regional planning agency, State Department of Transportation, mass transit agencies	
Scale	Local	
Impact/Benefit	**Direct:** Readiness for CAVs and better reception **Indirect:** Spread of knowledge	
Barriers	Work culture and overemphasis on status quo Lack of resources and expertise Funding Uncertainty related to the technology and its evolution	
Cost	Hiring experts Allocating time for teaching and learning ($-$$)	
Time horizon	Short term, low/high CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Designate regulatory roles	[3]
Category	General	
Code	G-04	
Description	**General description:** - In some cases, state policy explicitly preempts local governments from regulating or banning CAV technology in their jurisdictions. In order to avoid confusion over preemption (especially when there are overlapping authorities), federal and state authorities should designate which agencies or commissions are responsible for regulating and overseeing CAVs. - Engage with all stakeholders to develop for adoption legislative policies for CAVs related to certification, licensing, training, and tort liability. - Develop design guidance standards with partners - Create model state enabling legislation - Create a standards entity composed of cross-sector partners **Context-specific description:** - Since midsize regions are smaller in size, scope of the regulatory roles most probably will have a higher overlap between agencies and individuals. This means that cross-agency coordination is necessary for the clarification of these roles and tasks.	[3] [4] [19]
Stakeholders	Municipality, especially planning and public works departments, regional planning agency, State Department of Transportation, mass transit agencies, parking authority	
Scale	Regional	
Impact/Benefit	**Direct:** Better reception of CAVs	
Barriers	Outlining the regulatory roles and tasks clearly Designating the suitable experts to each role	
Cost	Various	
Time horizon	Short term, low CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Run CAV pilot program(s)	[28]
Category	General / Mobility & traffic	
Code	G-05/MT-17	
Description	**General description:** - Define the pilot's goals and outcomes at the beginning of the process and make sure every pilot activity is designed to achieve them. - Study what happened and put those findings into a final evaluation report. - Foster relationships and build trust. - Create a policy framework (i.e., regulations, contracts, agreements) for each pilot project that advances the public good and is easy to understand.	[28]
Stakeholders	Municipality, especially planning and public works departments, regional planning agency, State Department of Transportation, mass transit agencies	
Scale	Regional	
Impact/Benefit	**Direct:** Informed planning for CAVs Higher safety	
Barriers	Budget, identification of pilot objectives, location of pilot program, liabilities, stakeholder coordination	
Cost	$$	
Time horizon	Medium term, low CAV adoption	
Example/ visualization	Autonomous Vehicle Pilots Across America	[29]

Attribute	Comments	Reference
Action Item	Plan for equity	[31]
Category	General	
Code	G-06	
Description	**General description:** - Autonomous vehicles must operate primarily in the form of FAVES to the maximum extent possible, to promote sustainable and equitable outcomes. - Single-occupancy autonomous vehicles owned either by individuals or companies must be strongly disincentivized to reduce air pollution, greenhouse gas emissions, and vehicle miles traveled. Examples include progressive, equitable road pricing or similar fees on single- occupancy autonomous vehicles. - FAVES and all other forms of autonomous vehicles should increase affordable, accessible, efficient, safe, and reliable mobility for all people, while supporting and enhancing walking, biking, and public transit. - FAVES and all other forms of autonomous vehicles must provide fair labor practices, retraining programs, and a Just Transition for workers displaced by self-driving technology. - Support equitable investment, policy, and engagement strategies. - Require meaningful community-based engagement with an emphasis on marginalized and underserved communities. - Support CAV technology investment that advances community-driven needs and increase access to desirable mobility options. - Promote best practice approaches for public-private data sharing, analysis and use to ensure equitable deployments of CAVs and shared mobility within communities. - Support CAV technology investments that augment existing public transportation service and access, including first mile last mile connections. - Leverage these technologies to foster future talent while developing the current workforce. - Understand how CAV will impact a mixed-fleet environment. - Address how CAV technologies may not be affordable for all users.	[4] [19]
Stakeholders	DoT, MPO, Municipality, parking authority, MTD, Public works	
Scale	Regional	
Impact/Benefit	**Direct:** Informed planning for CAVs, higher equity **Indirect:** Low emissions, higher safety, lower congestion, lower VMTs, possible changes in land use, street network structure, and road designs	
Barriers		
Cost	Varying based on strategies adopted (%)	
Time horizon	Short term, low CAV adoption	

Data & Digitization

Data and digitization action items relate to any policies and design guidelines that pertain to issues of data, data organization and sharing, data privacy, data security, and digital infrastructure.

Attribute	Comments	Reference
Action Item	Establish a standardized data report for collisions	[1]
Category	Data & Digitization	
Code	DD-01	
Description	General description: - Establishment of a standardized data report to be submitted through a third-party platform with detailed information on disengagements and collisions, and the locational data before and after the incident. Crash data and conflict avoidance or disengagement incidents around bicyclists and pedestrians in particular may be important measures of automated driving systems (ADS) performance. Formulate robust data collection and reporting processes • Enhance and Update Data Management Policies • Build Up In-House Data Capacity • Control the Means of Communication • Coordinate for Privacy	[1]
Stakeholders	Department of information technology & telecommunications, pedestrian and cycling groups, police department, regional planning agencies, municipality	[24]
Scale	Regional	[16]
Impact/Benefit	Direct: Safety; reduced incidence of collisions Indirect: Reduce congestion	
Barriers	Privacy and data sharing restrictions may limit the benefit and usability of such data.	
Cost	Overhead of personnel and additional resources to be used/adopted for accomplishing this policy ($$)	[2]
Time horizon	Short term, low CAV adoption	

Attribute	Comments	Reference
Action Item	Require data reporting	
Category	Data & Digitization	
Code	DD-02	
Description	General description: - Data reporting requires agencies to share and save data related to CAVs in a common repository. Data should be stored in a secure repository that is accessible to researchers and public officials, but also includes robust user-privacy protections. Support data sharing and explore opportunities for using vehicle connectivity and automation as an additional data source - Inform and share information regarding the current status of vehicle connectivity and automation deployment - Draft a Standard Operating Agreement (SOA) that dictates a data sharing policy between AV fleet operators and regional municipalities 1. Determine data needs and wants. 2. Draft data-sharing policy. 3. Begin implementing with existing mobility providers. 4. Evaluate the value of information sharing and refine guidelines as needed.	[3] [4] [23] [27]
Stakeholders	Any organization with data related to CAVs	
Scale	Regional	
Impact/ Benefit	Direct: Better reception of CAVs Clear data-reporting requirements will help ensure compliance with CAV policies and will help inform future planning and policymaking efforts related to CAVs. Provide a better chance for measuring and analyzing equitable distributions Indirect: Reduce congestion, emissions, VMT. Chance of less cyber security/privacy for users, yet facilitate better physical safety.	[3]
Barriers	Storage and interoperability of the data Management and update of the data/repository Access and security of the data Engagement and willingness of stakeholders to participate data sharing/reporting	
Cost	Resources for repository management and maintenance ($$/%)	
Time horizon	Short term, low CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Promote data sharing that preserves data privacy and security	[32]
Category	Data & Digitization	
Code	DD-03	
Description	**General description:** - Protect personal information and proprietary data and promote secure, vehicle-to-infrastructure (V2I) enabling information sharing. - Advance a connected vehicle ecosystem that enables reliable, consistent, and secure V2I data exchanges to support cooperative automated transportation and CAV. **Recommendations:** - Preserve data privacy and data security - Promote sharing of data from CAV and shared mobility platforms between public and private sectors - Enable IOOs to leverage innovative ways to store, analyze, manage, secure, retain and discard CAV data. - Develop national frameworks and best practice approaches to manage government and industry data and enact general data protection regulations; privacy-by-design, data reporting, data sharing, open source and other, related data standard needs. - Promote Security-by-Design—Need to protect the security of the transportation system and the physical and digital infrastructure, to prevent cyber attacks. - Support technology interoperability across vendors, industry, jurisdictions, and regions. - Address data governance roles and definitions for local governments, states, and the Federal government, including federal guidance for state or privately-owned datasets, and defined data stewards for CAV data. - Identify data stewards for CAV data and gain a clearer understanding of data ownership.	[32]
Stakeholders	Any orgnization with data related to CAVs	
Scale	Regional	
Impact/Benefit	**Direct:** Better reception of CAVs Clear data-reporting requirements will help ensure compliance with CAV policies and will help inform future planning and policymaking efforts related to CAVs. Provide a better chance for measuring and analyzing equitable distributions **Indirect:** Reduce congestion, emissions, VMT. Chance of less cyber security/privacy for users, yet facilitate better physical safety.	
Barriers	Privacy and data sharing restrictions may limit the benefit and usability of such data.	
Cost	Resources for repository management and maintenance ($$/%)	
Time horizon	Short term, low CAV adoption	

Attribute	Comments	Reference
Action Item	Establish centralized repositories to hold and provide structured access to mobility data	[14]
Category	Data and digitization	
Code	DD-04	
Description	**General description:** - Centralized repositories will provide stakeholders access to data from multiple regions, which is often key to identifying patterns and unlocking insights. Individual entities should make sure that their data is easily connected to centralized repositiries. - Partnering with a trusted third party—e.g., a university or national laboratory—for repository management can help ensure that transparency laws such as the Freedom of Information Act do not result in accidental exposure of personally identifiable information contained in uploaded data.	[14]
Stakeholders	Department of information technology & telecommunications, state department of Transportation, mass transit agencies, parking authority, transportation network companies, third party (i.e., university labs), regional planning agencies, municipality	
Scale	Regional	
Impact/Benefit	**Direct:** Access and analyze the transforming travel behavior Provide a better chance for measuring and analyzing equitable distributions **Indirect:** Reduce congestion, emissions, VMT. Chance of less cyber security/privacy for users, yet facilitate better physical safety.	
Barriers	Data privacy and sharing	
Cost	Cost of data sharing and third party management	
Time horizon	Short term, low CAV adoption	
Example/ visualization	An excellent example of a centralized transportation-data repository is the Secure Data Commons (SDC). The SDC enables data providers to voluntarily add data and specify which data users (e.g., researchers, city planners, etc.) may access it. Providers can also specify whether data may be exported for offline analysis or not.	[14]

Attribute	Comments	Reference
Action Item	Digitize existing transit infrastructure	
Category	Data & Digitization	
Code	DD-05	
Description	**General description:** - Ensure fleet vehicles and station infrastructure is wired for technology - Streamline payment and transfers	[16]
Stakeholders	State department of Transportation, mass transit agencies	
Scale	Regional	
Impact/Benefit	**Direct:** Better reception of CAVs Improved efficiency of transit Provide a better chance for measuring and analyzing equitable distributions **Indirect:** Reduce congestion, emissions, VMT Higher accessibility Possible changes in location of land uses, road/street widths and forms	
Barriers	Financing Streamlining of processes	
Cost	Varying based on technology adopted and level of digitization (various)	
Time horizon	Short term, low CAV adoption	

Mobility & Traffic

Mobility and traffic action items relate to any policies and design guidelines that pertain to issues of mobility, transportation and the movement of vehicles.

Attribute	Comments	Reference
Action Item	Limit CAV access in certain community, social space, and high pedestrian and cyclist densities	[5]
Category	Mobility and Traffic	
Code	MT-01	
Description	**General description:** - Implement access limitations to create auto-free zones. These might include time-of-day pricing schemes or other options. - Limit the maneuvering of CAVs in highly dense areas of active transportation (residential areas and school zones) to assure the safety of non-passengers. - In the absence of voluntary industry action and/or statewide or federal regulation or guidance to ensure safe and consistent behaviors, there may be opportunities for local policy regulations to restrict (e.g., at night, on shared streets, in pedestrian districts, school zones, etc.) where and when automated driving systems (ADS) can operate in order to protect pedestrians and bicyclists. - NACTO, have called for restrictions on vehicles with less than Level 4 ADS to operate on any roadways where pedestrians and bicyclists are allowed.	[5] [1]
Stakeholders	Municipality, regional planning agency, mass transit agencies	
Scale	Local	
Impact/Benefit	**Direct:** Assure higher safety of the pedestrians and cyclists Encourage active-transportation developments Higher accessibility for peds and cyclists Reduced congestion and VMT Reduced emissions **Indirect:** Impact land use and density of buildings	
Barriers	Managing the maneuvering of shared CAVs and CAV buses/auto-jitneys in such areas Political opposition	
Cost	Consideration of pricing policies ($)	
Time horizon	Medium/long term, medium CAV adoption	

Attribute	Comments	Reference
Action Item	Invest in autonomous rapid transit (ART) dedicated lanes	[6]
Category	Mobility & Traffic	
Code	MT-02	
Description	**General description:** - Investing in autonomous rapid transit (ART), like bus rapid transit (BRT) but with more nimble vehicles. Only two dashed lines are needed for automated lane guidance using cameras. - Combining characteristics of battery-powered buses and typical wheel-rail systems. Allow BRT operators to link multiple buses together seamlessly, adapting to demand and adding capacity as needed. **Context-specific description:** - In mid-sized regions this must be compared to the utility of smaller auto-jitneys	[6] [7]
Stakeholders	Mass transit agencies, regional planning agency, municipality	
Scale	Regional	
Impact/Benefit	**Direct:** Higher accessibility: If ART have dedicated lanes, autonomous vans or buses could be 30 percent faster than BRT and cost 80 percent less because there would be no drivers Mobility efficiency: ART shares the same benefits of a metro system yet with significantly lower capital costs and faster speed to market. Reduced VMT/congestions **Indirect:** Improved safety is another potential benefit of autonomous rapid transit. Reduced emissions Changes in road network and land uses	[8] [9] [7]
Barriers	Charging stations for electric ARTs	
Cost	It is feasible to modifying regular diesel buses for ART ART's virtual tracks are based on dedicated bus lanes, meaning it does not require costly and time-consuming infrastructure development as for a rail system Autonomous buses may also not need drivers, reducing operating costs. Autonomous buses could also operate in a narrower lane than conventional BRT vehicles. ($)	[8]
Time horizon	Medium term, medium CAV adoption	
Example/ visualization	In 2018, the Taiwanese government started to test the autonomous rapid transit (ART) concept through proof-of-service trials. Thousands of people experienced a 9-meter autonomous bus on a fixed bus route in Taichung, the second largest city in Taiwan, with a speed of up to 30 km/h.	[8]

Attribute	Comments	Reference
Action Item	Incentivize CAV business models that operate in a shared fleet (SAVs)	[10]
Category	Mobility & Traffic	
Code	MT-03	
Description	General description: - Advance policies that encourage shared mobility strategies - Support public transit by providing first and last mile connections to major transit lines via shared, autonomous vehicles, and by providing cost-effective, on-demand transit in lieu of low-performing fixed routes. This allows for refocusing planning on the principle of mobility as a service - Emphasis should be placed on creating model state enabling legislation to authorize localities to control public infrastructure for public benefits and fully implement sustainable land use policies that fully exploit the opportunities presented by the shared mobility model of CAV adoption. - SAV integration: increasing the otential for shared CAVs and need for standards for such operations - Explore oppurtunities to collaborate with private sector where shared CAVs is highlighted - Highlight the different ways to prioritize shared CAVs in development projects and road maintenance Context-specific description: - SAV integration is based on the expected scenario and the consumer prefernces of each region. Therefore it is necessary to survey the current use and preference of residents towards owning and sharing vehicles/ rides.	[10] [25] [30]
Stakeholders	Department of Information Technology, Pedestrian/cycling groups, Police department, Municipality, regional planning agency, State Department of Transportation, mass transit agencies, Association of Pedestrian and Bicycle Professionals	
Scale	Regional	
Impact/Benefit	Direct: Will help reduce the number of single-occupancy vehicles on the road (VMT & congestion). Reduction in transportation-related emissions Indirect: Change in road network and design to facilitate sharing vehicles	[11]
Barriers	Public acceptance and market penetration Developing a working model that is efficient and profitable for CAV providers	
Cost	Various Uncertain	
Time horizon	Short/medium term, medium/high CAV adoption	[25]

Attribute	Comments	Reference
Action Item	Make multi-modal transportation seamless	[12]
Category	Mobility & Traffic	
Code	MT-04	
Description	**General description:** - People taking transit usually have to walk a longer distance to, from, and between transit services. Autonomous vehicles have the potential to fill this gap by eliminating the walk between the parking space and final destination. Making connections between transit and other modes seamless is thus essential to making transit work both today and in the future. - Providing seamless connections between suburban mobility options is essential for reducing private car ownership, as most suburban residents expect completely seamless travel between their origin and destination. - Potential solutions for breaking down first/last mile barriers include: • Multimodal trip planners that let people plan trips across multiple modes based on the options that work best for them • Mobility hubs that aggregate mobility options in a single location to enable seamless transfers • Integrated fare products that let people pay for their entire trip on multiple modes at once • Redesign bus networks for improved travel time and reliability	[12] [16]
Stakeholders	Regional planning agency, State Department of Transportation, mass transit agencies	
Scale	Regional	
Impact/Benefit	**Direct:** Access to improved transportation for disadvantaged groups Less private vehicle ownership Less VMT and less environmental impacts Higher safety **Indirect:** Less congestion Changes in land use, transit stations, and road design	[12]
Barriers	Coordination between stakeholders Clear definition of 'seamless' Budget and funding	
Cost	Cost of connecting the mobility network and strengthening the mobility as a service (%)	[8]
Time horizon	Short/medium term, low CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Develop and enforce regulations of empty driving	[15]
Category	Mobility & Traffic	
Code	MT-05	
Description	**General description:** - Shared CAV use could increase VMT, therefore, consider regulations related to empty driving and sustainability - Explore VMT-based taxation - Work with other agencies to unify around a vehicle occupancy monitoring and pricing policy whereby there would be an inverse cost related to occupancy such that higher costs would be incurred for zero occupant vehicles	[15]
Stakeholders	Police, municipality, especially planning and public works departments, regional planning agency, State Department of Transportation, mass transit agencies, Association of Pedestrian and Bicycle Professionals	
Scale	Regional	
Impact/Benefit	**Direct:** Reduce VMTs and congestion rates **Indirect:** Reduce emissions Changes in urban form	
Barriers	Politically controversial, opposition of residents/transportation network companies (TNCs), finding optimal pricing model	
Cost	This depends on what type regulations are implemented and what type of technology is deployed (various)	
Time horizon	Medium term, high CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Foster mobility-as-a-service (MaaS)	[4] [16]
Category	Mobility & Traffic	
Code	MT-06	
Description	General description: - Mobility as a Service (MaaS) is a nascent concept that would combine trip planning, booking, and payment within a single platform. The likeliest implementation, although not the only possible one, would be through a smartphone application. - Step 1: Build or foster data-sharing and interoperability requirements - Step 2: Improve coordination of existing public transportation services - Step 3: Ensure MaaS aligns with regional Mobility Goals - Focus on open data specifications & interoperability	[4] [16]
Stakeholders	Third party, Transportation Network Companies, municipality, regional planning agency, State Department of Transportation, mass transit agencies	
Scale	Local + Regional	
Impact/Benefit	Direct: Higher CAV adoption; reduced VMT MaaS promises to make planning and completing multimodal journeys simple, fast, reliable, and convenient. These systems will make multimodal transportation so user-friendly that travelers may be persuaded to make less use of private vehicles and more use of alternative transportation modes. This encourages wider adoption and use of SAVs. Reduced emissions Indirect: Changes in urban form and road design Reduced congestion	
Barriers	The unexpected adoption percentages Participation of different transportation vendors Network availability	
Cost	Cost of online platform and maintenance (low cost ($)/various)	
Time horizon	Short term, medium CAV adoption	
Example/ visualization	MAAS CASE STUDY: WHIM · Early multi-modal transportation app · Offers one-app trip payments, real-time trip planning · Launched by MaaS Global in Helsinki, December 2017 · 70,000 registered users by 2019 (10,000 use regularly) · Promoted as "one app for all your transport needs" · Pay-as-you-go and subscription models available · Expanding to Antwerp, Belgium, Birmingham (UK), Miami, Vancouver, and Chicago	[16]

Attribute	Comments	Reference
Action Item	Manage and reduce congestion	[4]
Category	Mobility & Traffic	
Code	MT-07	
Description	**General description:** - Congestions pricing: One avenue for congestion pricing, involves the potential to incentivize shared rides. - Distance-based fees, which assess tolls based on how far a vehicle travels, could also be used to incentivize short trips - Route-based fees can be used to price discriminate, offering lower fees for CAVs that travel less-congested routes - Adopt a variation on the Canadian federal government's carbon tax model: everyone pays the carbon tax on the energy products they use, but enjoys a credit on their income tax. 1. Profile existing traffic patterns and congestion. 2. Learn from existing programs and establish objectives. 3. Define your guiding principles. 4. Develop a congestion pricing strategy and communications plan. 5. Improve transit uptake and performance. 6. Design a pilot, learn and scale.	[4]
Stakeholders	Municipality, especially planning and public works departments, regional planning agency, State Department of Transportation, mass transit agencies	
Scale	Regional	
Impact/Benefit	**Direct:** Less traffic congestion via toll pricing that encourages ridesharing Increased traffic-flow control via deployment of congestion pricing New revenue stream via CAV access fees with easy tracking Reduced emissions and VMTs Higher oppurtunities for safety **Indirect:** Better public transportation as multi-modal trips become more enticing Changed urban form and road network	[4]
Barriers	Backlash from TNCs, Preparation of data collection and integration	
Cost	Tolling CAVs will potentially be less expensive and easier to assess and enforce because CAVs have real-time, highly-accurate continuous location monitoring. Cities will not need to pay for observational infrastructure such as cameras to collect tolls. Instead, they can use a software-based query to identify all instances of CAVs entering the city center and simply invoice the CAV operators.	[4]
Time horizon	Medium term, low CAV adoption	
Example/ visualization	Washington D.C. - Implemented in late 2017, the high- way's tolls cost an average of $12.59 for a two-way trip but can sometimes increase to well over $40.	[4]

Attribute	Comments	Reference
Action Item	Assign curb-space dynamically and flexibly	[17]
Category	Mobility and traffic	
Code	MT-08	
Description	**General description:** - Dynamically and flexibly assign curb-space, so different types of users can use the same curb at different times, varying by time of day, week, and year - Charge fees to allocate scarce space, adjusted based on demand Collect data on curb usage to inform demand projections and future allocations.	[17]
Stakeholders	Municipality, especially planning and public works departments, regional planning agency, State Department of Transportation, mass transit agencies	
Scale	Regional	
Impact/Benefit	**Direct:** Efficient mobility Less congestion Well-utilized streets for longer periods of the day Provide walkable and safer options Urban form at microscale will be have more street/ROW space requirements Higher safety measures **Indirect:** Reduced VMT	
Barriers	Mapping and defining the criteria for 'space' assignment, 'times' of assignment and 'prioritization'. How to develop the framework/criteria Modelling the benefits and costs Scales of deployment	
Cost	Preparing the infrastructure to implement this policy and data collection	
Time horizon	Long term, medium CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Consider tailoring auto-jitneys to each neighborhood	[20]
Category	Mobility & Traffic	
Code	MT-09	
Description	**General description:** - Auto-jitneys would run mostly in areas bounded by main streets (aka “arterials” and “collectors”). If someone lives between social hubs, the local auto-jitney might take him or her to the two nearest social hubs, not just the nearest one. Human beings like the familiar, so colors, tone, any advertising, language (e.g. Spanish, Chinese), and so on could be peculiar to each neighborhood. **Context-specific description (optional):** - Since midsize regions are more dispersed, auto-jitneys might cover larger areas and used for transportation between one suburb and another. Auto-jitneys could also be introduced in university towns since students/staff/faculty move from one building/area to another.	[20]
Stakeholders	Municipality, Transportation Network Companies, Paratransit	
Scale	Local	
Impact/Benefit	**Direct:** Encourage shared mobility Ensure higher safety for pedestrians Reduced congestion, VMT, and emissions **Indirect:** Equity gaps since disadvantage groups might not be living in proximity to social hubs or other amenities Higher access to effecient shared mobility	
Barriers	Political opposition, funding	
Cost	Cost for vehicles and their maintenance ($$/$$$) Plan of deployment and distribution ($$)	
Time horizon	Medium term, medium CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Prioritize right-of-way for pedestrians	[1]
Category	Street Design/Mobility & Traffic	
Code	SD-02/MT-10	
Description	General description: - Automobiles, regardless of the level of automation, should give right- of-way to pedestrians at legal crosswalks as current laws require.	[1]
Stakeholders	Municipality, Transportation Network Companies, regional planning agency, State Department of Transportation, mass transit agencies, Paratransit companies	
Scale	Regional	
Impact/Benefit	Direct: High physical safety Less crashes/accidents Higher access to mobility for active transporters Reduced VMT Indirect: Reduced emissions Reduced congestion Improved multimodal street design	
Barriers	Opposition from technology developers and private sector	
Cost	Require technology developers to prioritize this in CAV devel-opment (uncertain)	
Time horizon	Short term, low CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Phase out local buses in favor of auto-jitneys and mobility-as-a-service	[20]
Category	Infrastructure/Mobility & Traffic	
Code	I-02/MT-11	
Description	**General description:** - Auto-jitneys are 8–12-seater cars that can be used for 'public transportation' instead of buses. They are faster, more efficient, and safer. However, trains and buses can run only between social hubs. Consider providing skip-stop service where demand justifies it. Some auto-buses might go straight downtown, for instance, bypassing neighborhood social hubs on the way. **Context-specific description:** - Auto-jitneys can replace both the bus system and 'hoppers' in mid-sized regions.	
Stakeholders	Municipality, especially planning and public works departments, regional planning agency, mass transit agencies	
Scale	Local	
Impact/Benefit	**Direct:** More efficient transportation Improved accessibility Reduced emissions Potentially increased congestion/VMT **Indirect:** Chnages in road design, street network and allocation of land uses	
Barriers	Financing	
Cost	Cost of apps, vehicles, maintenance ($$$)	
Time horizon	Medium term, low CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Manage lanes through dedicated lanes for CAVs	[25]
Category	Traffic & Mobility	
Code	MT-12	
Description	**General description:** - Dedicating portions of existing infrastructure to exclusively CAV operation, such as dedicated CAV lanes, enabling higher capacity and throughput - Segregating CAV infrastructure from all non-CAV vehicular traffic, maximizing throughput but potentially worsening connections by other modes like walking. **Context-specific description:** - Applies only to highways and multi-lane roads	[17]
Stakeholders	Municipality, especially planning and public works departments, regional planning agency, mass transit agencies, State department of Transportation	
Scale	Local + Regional	
Impact/Benefit	**Direct:** Higher capacity and throughput (less congestion) Higher adoption of CAVs Higher safety Reduced congestion/VMT **Indirect:** Less emissions	
Barriers	Political opposition Financing Highly dependent on CAV adoption	
Cost	Infrastructure update (various)	
Time horizon	Medium term, medium/high CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Introduce tolling and demand management	[5]
Category	Mobility & Traffic	
Code	MT-13	
Description	General description: - Tolling and demand management: Exploring various methodologies to ensure travelers for the marginal cost of their trip - Start developing pricing plans & policies to reduce congestion 1. price the place 2. price the curb 3. price the trip - Ensure pricing revenue is dedicated to improving transit, walking, and biking - Prioritize equity when pricing mobility - Develop a coalition of support - Use a data-driven approach to implement and evaluate any pricing scenario	[5] [16]
Stakeholders	Tolls department/division, State department of Transportation	
Scale	Regional	
Impact/Benefit	Direct: Reduce congestion Reduced emissions/VMT Impact on equity and access to roads Indirect: Change in road networks and land use	
Barriers	Political opposition Unequitable distribution of costs	
Cost	Conducting planning and feasibility studies Deployment of physical and digital infrastructure (various/uncertain)	
Time horizon	Medium term, medium CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Introduce geofencing (geographical restriction) to SAVs, CAVs, or empty CAVs for better management of their impacts	[17]
Category	Mobility & Traffic	
Code	MT-14	
Description	**General description:** - Cities can apply GPS technology to create versatile geographic boundaries for particular areas and particular uses. - Constraining SAV fleet service within a carefully chosen geofence may provide some congestion mitigation - Some cities have already experimented with "geofences" to alter locations for TNC pickups and drop-offs. - Future rules could be dynamic and change based on demand and time of day, with information disseminated through TNC apps or CAV control systems. **Context-specific description:** - Geofencing can be dynamic based on levels of congestion and time of the day. For example, school areas can introduce a no-vehicle entrance during peak hours. Likewise, downtown areas can only allow shared vehicles during peak hours.	[17] [26]
Stakeholders	Municipality, mass transit agencies, various agencies, third party	
Scale	Local	
Impact/Benefit	**Direct:** Manage congestion and VMTs **Indirect:** Less emissions Change in land use distribution and commercial hubs, transit networks, drop-off/pick-up locations Improved safety	
Barriers	Optimal allocation of geofenced areas Political opposition	
Cost	The cost of technlogy deployment, locations prioritzed(uncertain)	
Time horizon	Medium term, high CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Support public transit so it doesn't become obsolete	[16][30]
Category	Mobility & traffic/Infrastructure	
Code	MT-15	
Description	**General description:** - Support public transit by providing first and last mile connections to major transit lines via shared, autonomous vehicles, and by providing cost-effective, on-demand transit in lieu of low-performing fixed routes. - Integrate CAVs with reliable, affordable, comfortable, convenient, and safe transit systems, because access to such systems predicts higher quality of life and improved mental health. **Context-specific description:** - This doesn't necessarily apply to regions with non-extensive public transport system as auto-jitneys and automated hoppers can be used instead	[5] [16]
Stakeholders	Mass transit agencies, Municipality, regional planning agency	
Scale	Regional	
Impact/Benefit	**Direct:** Improved mobility Higher accessibility Reduced congestion Reduced emissions/VMT **Indirect:** Change in land use distribution and commercial hubs, transit networks, drop-off/pick-up locations	
Barriers	Political opposition Unequitable distribution of costs	
Cost	various	
Time horizon	Medium term, low CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Provide equitable mobility	[16]
Category	Mobility & Traffic/Planning	
Code	MT-16/P-03	
Description	**General description:** - Improve mobility for all, contributing to a more equitable transportation system, where benefits reach all demographics, and any negative effects are not unjustly concentrated. **Context-specific description:** - Since mid-sized regions have less-efficient transit, areas/users that are dependent on any mode other than private vehicle should be given priority	[16]
Stakeholders	Regional planning agency, mass transit agencies	
Scale	Regional	
Impact/Benefit	**Direct:** Higher accessibility and equity **Indirect:** Reduced congestion Reduced emissions Higher safety Reduced VMT Changes in urban form, land use distributions, and density	
Barriers	Identifying equity communities	
Cost	Varying based on type of investments and strategies adopted (%)	
Time horizon	Short term, low CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Run CAV pilot program(s)	[28]
Category	General / Mobility & traffic	
Code	G-05/MT-17	
Description	**General description:** - Define the pilot goals and outcomes at the beginning of the process and make sure every pilot activity is designed to achieve them. - Study what happened and put those findings into a final evaluation report. - Foster relationships and build trust. - Create a policy framework (i.e., regulations, contracts, agreements) for each pilot project that advances the public good and is easy to understand.	[28]
Stakeholders	Municipality, especially planning and public works departments, regional planning agency, mass transit agencies, State department of transportation	
Scale	Regional	
Impact/Benefit	**Direct:** Informed planning for CAVs Higher safety	
Barriers	Budget, identification of pilot objectives, location of pilot program, liabilities, stakeholder coordination	
Cost	Cost of collaborating with companies and needed experts $$	
Time horizon	Medium term, low CAV adoption	
Example/ visualization	Autonomous Vehicle Pilots Across America	[29]

Street Design

Street design action items relate to updated road designs, new requirements for the street right-of-way, and new design considerations for CAVs.

Attribute	Comments	Reference
Action Item	Rethink curb design and street space allocation	[16]
Category	Street Design	
Code	SD-01	
Description	General description: - Several pressures–including traffic congestion, increased demand for curb use, and the proliferation of delivery vehicles and TNCs–are making city planners rethink the use of the curb. - As CAVs require less space, automobile lanes can be removed or narrowed in favor of buses, bicycles, and wider sidewalks, or even vibrant public spaces such as parklets and patios. - Parallel parking spots can be used as pick-up/drop-off zones. - The IEEE estimates that lanes can support 3.7 times as many autonomous vehicles per lane. - Step 1: Map the curb - Step 2: Establish a prioritization framework - Step 3: Pilot alternative curb uses and pick/up/drop-off zones - Step 4: Establish a curb use and street allocation master plan	[16] [51]
Stakeholders	Municipality, especially planning and public works departments, regional planning agency, State department of transportation	
Scale	Local+Regional (guidance)	
Impact/Benefit	Direct: Safer roads, lower congestion from drop-off and pick-up, increased efficiency of ride-hailing (reduced VMT) Indirect: Reduced emissions Changes in road design	
Barriers	Requires coordination and approval from many stakeholders	
Cost	Varies based on adopted strategies (various)	
Time horizon	Short term, low CAV adoption	
Example/ visualization	-National Association of City Transportation Officials introduced a program, SharedStreets, to foster mapping of curbs. -Washington D.C. - turning 45 parking spaces into a pick-up/drop-off zone -Texas - updated its Complete Streets initiative, a transportation policy and design approach to creating safe and convenient transportation and access for all visitors and residents across a myriad of travel options. This initiatve highights CAV considerations such as lane width and separation of lanes -Seattle, Washington - Commercial streets are prioritizing freight delivery and passenger pick-up/drop-off over private car parking. Other uses are dedicated transit and bike lanes.	[16] [18] [51]

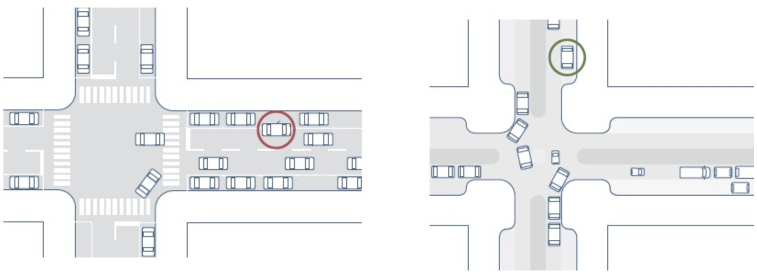
Attribute	Comments	Reference
Action Item	Prioritize right-of-way for pedestrians	[1]
Category	Street Design/Mobility & Traffic	
Code	SD-02/MT-10	
Description	General description: - Automobiles, regardless of the level of automation, should give right-of-way to pedestrians at legal crosswalks as current laws require.	[1]
Stakeholders	Municipality, TNC (private sector), paratransit, transportation department, MPO, pedestrian and bicycle advocacy groups	
Scale	Regional	
Impact/Benefit	Direct: High physical safety Less crashes/accidents Higher access to mobility for active transporters Reduced VMT Indirect: Reduced emissions Reduced congestion Improved multimodal street design	
Barriers	Opposition from technology developers and private sector	
Cost	Require technology developers to prioritize this in CAV devel-opment (uncertain)	
Time horizon	Short term, low CAV adoption	
Example/ visualization	N/A	

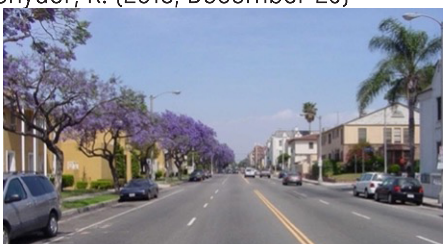
Attribute	Comments	Reference
Action Item	Design and implement separated/protected bike lanes	[1]
Category	Street Design	
Code	SD-03	
Description	General description: - Cities and counties could separate CAVs and bicycle and pedestrian traffic through the use of existing separated/protected lanes, creation of additional such lanes, and effective management of curb space. Streets should give ultimate priority to pedestrians, bicyclists and transit riders. Context-specific description: - Separated bike lanes may be first introduced in urban centers, dense areas, and campus towns where there is a higher use of bicycles.	[33] [16]
Stakeholders	MPO, municipality, public works, transportation department, pedestrian and bicycle advocacy groups	
Scale	Local	
Impact/Benefit	Direct: Improved safety for cyclists More robust multimodal environment Allows for more controlled testing of CAVs on local streets while keeping cyclists and pedestrians clearly separated from them Reduced congestion as vehicles don't have to lower speed for cyclists Indirect: Lower emissions New road design	[33]
Barriers	Financers: Financing extra space for bike lanes Developers: Requiring bike parking in new developments	
Cost	Redesigning the ROW to include separated/protected bike lanes for cyclists ($$) Retrofitting existing roads and pedestrian pathways to include separated/protected bike lanes for cyclists ($$)	
Time horizon	Short/medium term, low CAV adoption	
Example/ visualization	Image from the Blueprint for Autonomous Urbanism, Courtesy of NACTO (National Association of City Transportation Officials 	[16]

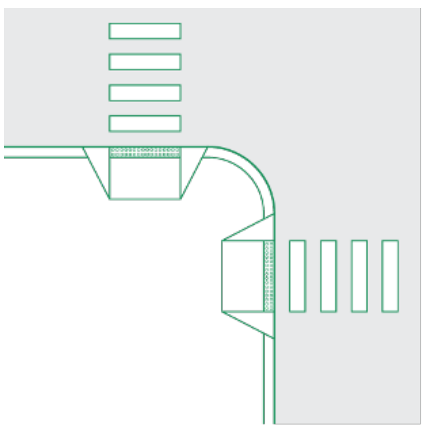
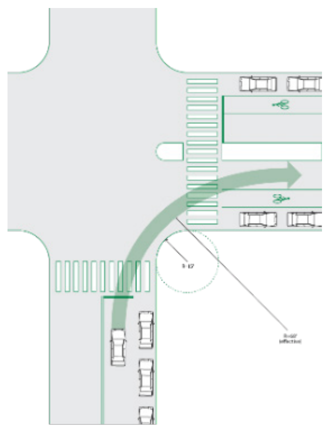
Attribute	Comments	Reference
Action Item	Create temporary or flexible dedicated lanes for cycling with movable barriers or time restrictions on lane use	[33]
Category	Street Design	
Code	SD-04	
Description	General description: - On local streets, it may be more practical to employ tactical urbanism by creating temporary or flexible lanes through movable barriers. Or another approach would be to restrict lane use during peak travel periods.	[33]
Stakeholders	MPO, municipality, transportation department, public works, pedestrian and bicycle advocacy groups	
Scale	Local	
Impact/Benefit	Direct: Improved safety for cyclists. More robust multimodal environment Less congestion New road design Indirect: Less VMT due to more active trasnporters	
Barriers	N/A	
Cost	Uses low-investment equipment such as free-standing delineators Requires only retrofitting existing roads/streets to allow for dynamic designation of lane use (i.e. cycling) ($)	[35]
Time horizon	Short term, low CAV adoption	
Example/ visualization	Shutterstock 	[35]

Attribute	Comments	Reference
Action Item	Introduce improvements in lighting, pedestrian crossing islands, and gateway treatments	[1]
Category	Street Design	
Code	SD-05	
Description	General description: - Signage development: Update signage and signage standards to ensure vehicles can read and respond appropriately - Implement frequent pedestrian islands and stopping points - Implement diverters and mini-roundabouts Context-specific description: - Rural signage and rural road design: Urban areas are likely to be more affected first, but rural changes would also be necessary in the long term	[25] [16]
Stakeholders	Public works, municipality, MPO, transportation department, pedestrian and bicycle advocacy groups	
Scale	Regional	
Impact/Benefit	Direct: Safer reception of CAVs Indirect: Reduced congestion, VMT, emissions Higher mobility accessebility New road design	
Barriers	Funds and financing	
Cost	Low investment required for revamping road markings/paintings, signage and some gateways ($)	
Time horizon	Short/long term, medium CAV adoption	[25]
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Update road markings	[25] [36]
Category	Street Design	
Code	SD-06	
Description	**General description:** - Road markings: Technologies need clear marking to function properly - Increase thickness of markings **Context-specific description:** - Start with updating suburban streets and highways - Update marking for bike lanes	[25] [47]
Stakeholders	Public works, municipality	
Scale	Regional	
Impact/Benefit	**Direct:** Safer reception of CAVs	
Barriers	Funds and financing Operational procedures	
Cost	Low investment required for revamping road markings/paintings ($)	
Time horizon	Short/long term, high CAV adoption	[25]
Example/ visualization	Painted lane boundaries with good contrast Shutterstock 	[36]

Attribute	Comments	Reference
Action Item	Establish clear CAV (as well as TNC) drop-off and pick-up zones	[5] [16]
Category	Street Design/Infrastructure	
Code	SD-07/I-07	
Description	General description: - Add drop-off/pick-up areas around hot spots - To drop off passengers, vehicles on major streets will first turn right. - Turning off of the main street to stop reduces congestion on main corridors and allows more space along the curb to be dedicated to other uses. Where bicycle traffic is heaviest, right-turn pick-ups and drop-offs may be less ideal. Context-specific description: - Drop-off areas are part of flex zones where they are used for drop-off/pick-up, loading/unloading, transit stops, vendors, parklets and rideshares - Drop-off/pick-up locations are located at every other block, making it convenient for people to move things from their vehicle to their homes and reduce distance required to travel to individual stops.	[5] [16] [44]
Stakeholders	Regional planning agencies, municipality, public works, transportation network companies	
Scale	Regional	
Impact/Benefit	Direct: Safer and better reception of CAVs and SAVs Reduced VMT New road design Indirect: Reduced congestion as there will be less cars on the road and effective allocation of drop-off and pick-up locations	
Barriers	Opposition from developers	
Cost	Retrofitting existing roads Including requirements as part of building codes ($$)	
Time horizon	Short/medium term, medium CAV adoption	
Example/ visualization	Image from the Blueprint for Autonomous Urbanism, Courtesy of NACTO (National Association of City Transportation Officials 	[16]

Attribute	Comments	Reference
Action Item	Introduce road diets	[37]
Category	Street Design	
Code	SD-08	
Description	**General description:** -Since CAVs can safely space themselves much closer together than human-driven vehicles, and can even "connect" and form platoons, they won't likely need the same number of lanes that human-driven vehicles do. Therefore, cities should reduce the number of travel lanes for vehicles and use the freed-up space for other purposes **Context-specific description:** -In mid-sized regions, one-way roads with several lanes can make use of this guideline first to allow for other purposes such as active transportation and plazas. -In low-density regions, and on residential streets with low traffic volumes especially, bi-directional travel is a practical solution. This enables cars to travel in either direction as needed.	[37] [39]
Stakeholders	Regional planning agencies, municipality, state department of transportation, public works, consultants, pedestrian and bicycle advocacy groups	
Scale	Local	
Impact/Benefit	**Direct:** Attractive opportunities for travelers to forego private automobile ownership in favor of Mransportation as a Service (MaaS)reduced congestion/ VMT, higher safety **Indirect:** More space for other travel modes; higher access to mobility Reduced emissions	[37]
Barriers	Political opposition, financing updates/changes	
Cost	Remodeling and calculating traffic loads Repurposing extra space for other uses ($$/$$$)	
Time horizon	Medium/Long term, medium CAV adoption	
Example/ visualization	Snyder, R. (2018, December 25)  	[37]

Attribute	Comments	Reference
Action Item	Introduce tight corner radii	[16]
Category	Street Design	
Code	SD-09	
Description	General description: -This strategy can be achieved by selecting the smallest possible design vehicle, accommodating trucks and buses on separate routes, and restricting right turns on red.	[16]
Stakeholders	Public works, municipality, CAV manufacturers, regional planning agencies, state department of transportation	
Scale	Regional	
Impact/Benefit	Direct: Higher safety for pedstrians Indirect: Better reception of CAVs Better use of space to accommodate other travel modes. Expands the pedestrian area, allowing for better pedestrian ramp alignment.	[41]
Barriers	Opposition from developers	
Cost	Cost of redesigning and refitting current corner radii	
Time horizon	Long term, medium CAV adoption	
Example/ visualization	Image from the Blueprint for Autonomous Urbanism, Courtesy of NACTO (National Association of City Transportation Officials  	[41] [42]

Attribute	Comments	Reference
Action Item	Reduce parking requirements or institute parking maxima	[17]
Category	Planning/Street Design	
Code	P-06/SD-10	
Description	General description: - Some cities are already reducing parking requirements for new construction (i.e. reducing the so-called "parking minimums"), while others like San Francis- co have even begun to institute "parking maximums" for new construction. Some new parking garages are being built so that they could later be converted to other uses, such as office or residential space. - The first goal is to provide the city with more flexibility to reduce min- imum parking requirements as the demand for parking is expected to change. - Develop flexible parking policies	[44] [17] [30]
Stakeholders	Municipality, regional planning agencies, planning and zoning commission, public works, transportation department	
Scale	Regional	
Impact/Benefit	Direct: Reduced VMT Better use of developable space Potential for denser development Indirect: Reduced congestion Reduced emissions Reduce parking burdens	
Barriers	Coordination with the different agencies	
Cost	Minimal since this would be an amendment through a memorandum($)	
Time horizon	Short/medium term, low CAV adoption	
Example/ visualization	City of Chandler: Ride Sharing and Autonomous Vehicles Zoning Code Amendment This zoning amendment aims to prepare the City of Chandler, Arizona for changes in land use as a result of changes in transportation behavior resulting from an increase in ride sharing and autonomous vehicles. 1-The first goal is to provide the city with more flexibility to reduce minimum parking requirements as the demand for parking is expected to change. 2-The second goal of the zoning amendment is to encourage developments to install passenger loading zones.	[34] [45]

Attribute	Comments	Reference
Action Item	Remove on-street parking in residential/commercial streets	[17]
Category	Planning/Street Design	
Code	P-07/SD-11	
Description	General description: - On-street parking lanes can be removed when they are not required anymore (due to curb management strategies and pick-up/drop-off). This should happen in phases. For example, keeping only one lane, then moving to the opposite lane. - Example of a transitional, mixed-vehicle type design: 1. On-street parking reduced by 50 percent from current conditions 2. One 20-foot-wide, two-lane, two-way traffic way for CAVs and other vehicles 3. One or two four- to 12-foot-wide pedestrian sidewalks 4. Reclaimed space used for creative purposes: parklets, stormwater, plant- ers, bike parking, etc. - Example of a long-term, no-conventional-vehicle design: 1. On-street parking reduced by 80 percent from current conditions 2. One eight-foot-wide, flex-direction traffic way for CAVs 3. One or two four- to six-foot-wide pedestrian sidewalks 4. Reclaimed space given back to adjacent parcels for extended yards, home additions, or auxiliary housing units	[17] [44] [46]
Stakeholders	Municipality, regional planning agencies, planning and zoning commission, public works	
Scale	Regional	
Impact/Benefit	Direct: Containment of unutilized space Encourage denser development Reduced VMT Indirect: Reduced congestion/emissions Provide more space for pedestrains and CAVs	
Barriers	Backlash due to limited parking options	
Cost	Minimal cost since this would be an amendment through a memorandum ($)	
Time horizon	Medium/long term, high CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Redevelop non-utilized space such as front yards and garages	[20]
Category	Planning/Street Design	
Code	P-09/SD-12	
Description	General description: - Consider capturing the space in front yards and garages for additions or even new construction. Just as drivers have a "shy distance" of a few feet from jersey barriers, residents have a shy distance from wide, noxious streets. If the streets are placid, then front yards become buildable space. Context-specific description: - With reduced private ownership of vehicles, a substantial share of housing stock may be transformed, with garages converted to other uses such as studios, rented short-term lodging, or granny flats. In theory, driveways may no longer be needed either. These could be turned into greened front yards, spaces for children to play, and/or spaces for residents to walk and meet their neighbors.	[20] [46]
Stakeholders	Municipality, developers	
Scale	Local	
Impact/Benefit	Direct: Increased density Increased property values Uncertain impact on physical safety since developments/additions are closer to the street Potential impacts on equity Indirect: Reduced congestion	
Barriers	Political opposition Requires approval and change in building codes/zoning ordinances	
Cost	($$)	
Time horizon	Long term, medium CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Manage the curb for high volumes of people, not cars	[22]
Category	Street Design	
Code	SD-13	
Description	General description: - Streets should by principle prioritize people over vehicles especially in social hubs. This includes space allocated for active transportation, safety measures considered for pedestrians and cyclists, and open spaces. Additinally chosing the frequency and location of drop-off/pick-up locations impacts how people/pedestrians use these roads.	[20]
Stakeholders	Regional planning agencies, municipality, public works, paratransit agency, transportation department	
Scale	Regional	
Impact/Benefit	Direct: Improved physical safety Improved accessibility for pedestrians and cyclists Reduced VMTs New road design Indirect: Potential for increased congestion Higher accessebility for pedestrians	
Barriers	Political opposition especially in highly occupied streets	
Cost	($$)	
Time horizon	Short term, low CAV adoption	
Example/ visualization	N/A	

Infrastructure

Infrastructure action items relate to any policies and design guidelines that pertain to issues of infrastructure such as telecommunications, traffic intersections, and signage.

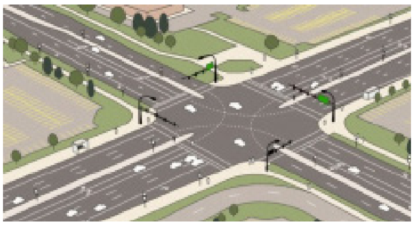
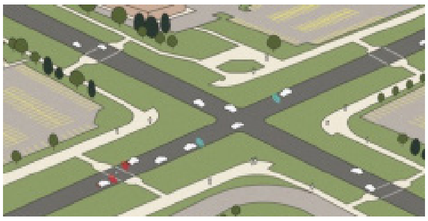
Attribute	Comments	Reference
Action Item	Deploy 5G infrastructure	[21]
Category	Infrastructure	
Code	I-01	
Description	General description: - As part of the CAV future, carsharing ecosystems will need robust, high-speed, and widely available 5G networks to support the data deluge that will arise from mobile apps and connected vehicles all communicating in real time, at scale. Context-specific description: - Deployment in mid-sized regions should first start with urban centers and social hubs where more users are expected.	
Stakeholders	Municipality, public works, private sector (CAV manufacturers)	
Scale	Regional	
Impact/Benefit	Direct: -Better reception of CAVs; having a 5G network assures better communication between CAVs and the infrastructure, which facilitates a smoother reception of CAVs as well as assuring they are being used to thier best/safest potential. -Potential cybersecurity threats Indirect: Better management of traffic (i.e. lower congestion and VMTs) Potential equity gaps (allocation of infrastructure and 5g deserts)	
Barriers	Financing and prioritization of deployment locations	
Cost	Cost of planning, prioritizing areas, hiring the experts/third-party, and deployment ($$/$$$)	
Time horizon	Medium term, low adoption	
Example/ visualization	N/A	

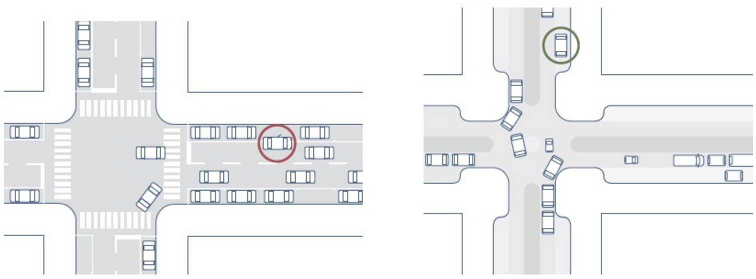
Attribute	Comments	Reference
Action Item	Phase out local buses in favor of auto-jitneys and mobility-as-a-service	[20]
Category	Infrastructure/Mobility & Traffic	
Code	I-02/MT-11	
Description	General description: - Auto-jitneys are 8- to 12-seater cars that can be used for "public transportation" instead of buses. They are faster, more efficient, and safer. However, trains and buses can run only between social hubs. Consider providing skip-stop service where demand justifies it. Some auto-buses might go straight downtown, for instance, bypassing neighborhood social hubs on the way. Context-specific description: Auto-jitneys can replace both the bus system and "hoppers" in mid-sized regions.	
Stakeholders	Transit agency, regional planning agencies, municipality	
Scale	Local	
Impact/Benefit	Direct: More efficient transportation Improved accessibility Reduced emissions Potentially increased congestion/VMT Indirect: Chnages in road design, street network and allocation of land uses	
Barriers	Financing	
Cost	Cost of apps, vehicles, maintenance ($$$)	
Time horizon	Medium term, low CAV adoption	
Example/ visualization	N/A	

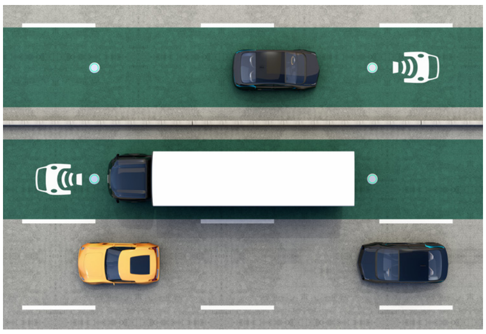
Attribute	Comments	Reference
Action Item	Modify speed limits to low speeds	[25]
Category	Infrastructure	
Code	I-03	
Description	General description: - NACTO's policy statement proposes a maximum 25 mph speed limit within cities and typically lower (15 to 20 mph) in downtown cores, residential areas, and near schools and other sensitive areas. - Reduce current speed limits in cities to allow for safe roadway travel by pedestrians given human capabilities (both pedestrian and vehicle operator), unpredictability, and vulnerability - Cap neighborhoods' speeds at 20 miles per hour. Given the realities of stopping distance and safe deceleration, this is approximately the maximum safe speed for pedestrians around drivers and CAVs. - Streets would be safer and quieter immediately. Quiet side streets and active main streets are a popular combination. - Refine and regularly update the database of speed limits supplied to motor vehicle and GPS navigation manufacturers to support context-based speed limiters in motor vehicles	[16] [1] [20] [15] [25]
Stakeholders	Municipality, regional planning agencies, police, public works, transit agencies	
Scale	Regional	
Impact/Benefit	Direct: Safer roads Inirect: Changes in road design, drop-off/pick-up locations, and land use distributions	
Barriers	Opposition from residents	
Cost	$ -Low investment	
Time horizon	Medium/long term, medium CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Introduce smart intersections	[25]
Category	Infrastructure	
Code	I-04	
Description	General description: - Instead of having a fixed green or red light at the intersection, these cycles can be adjusted dynamically, and this control can be adjusted to allow for platoons of cars to pass - Coordinate the platoon size and the gap length between cars and platoons to enable efficient mobility and reduced congestion - Smart intersections: Traversing intersections using a first-come first-serve reservation system	[25] [52]
Stakeholders	State department of transportation, public works, municipality	
Scale	Regional	
Impact/Benefit	Direct: Better reception of CAVs Reduced congestion provide better safety for passengers, pedestrians, and bikers Indirect: through efficient management, emissions are reduced	
Barriers	Waiting for high penetration percentages	
Cost	Technology and infrastructure installment ($$$)	
Time horizon	Medium term, high CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Add electric vehicle charging stations	[25]
Category	Infrastructure	
Code	I-05	
Description	General description: - Introduce electric charging stations around the region and in hotspots. Requireparking spots (residential and retail) to provide electric charging options. - Consider the future uses and charging needs of autonomous, shared, and electric fleet vehicles when evaluating investments in EV charging infra- structure. - Promote grid-optimized charging to manage the grid impacts and max- imize the environmental and economic benefits of autonomous electric fleets. - Establish EV charging pilot programs for fleets of human-driven mobility service vehicles (such as TNCs and on-demand services) to provide insight into the charging needs of autonomous electric fleets. Context-specific description: - Convert existing parking spaces to charging spots - Explore updating road infrastructure to have electric charging abilities rather than charging stations	[49]
Stakeholders	Manufactures, private sector, transportation network analysis, regional planning services, municipality, public works, state department of transportation	
Scale	Local	
Impact/Benefit	Direct: Strong infrastructure for electric CAVs Reduced emissions Indirect: Potential equity gaps due to distribution of stations Change in land use to accommodate electric charging	
Barriers	Low utilization of stations in the short term Scarcity of funding	
Cost	Feasibility and transition ($$$)	
Time horizon	Medium/long term, medium CAV adoption	

Attribute	Comments	Reference
Action Item	Reduce lane width	[16] [25] [39]
Category	Infrastructure/Street Design	
Code	I-06	
Description	General description: - Narrow lanes reduce speeds. Narrow lanes are also a possibility since CAVs don't require the wide safety margins that human drivers require. Therefore, lane widths should be 10' or less in most urban contexts. - As CAVs will be better able to stay in lanes, those without full-size passenger buses or trucks could be reduced to 8 or 9 feet in width. Context-specific description: - Some studies suggest that CAVs (especially private ones) will first start in the suburbs due to the demographic landscape (i.e. higher income and preference for private vehicle ownership). This implies that future suburban developments should adopt narrower roads in preparation for CAVs.	[25] [16] [37]
Stakeholders	Transportation network companies, regional planning agencies, municipality, public works, state department of transportation, developers	
Scale	Local	
Impact/Benefit	Direct: Additional space for active transportation or other pedestrian-friendly uses Improved safety Indirect: Impact congestion	
Barriers	N/A	
Cost	Cost of revising current road design standards Cost of modelling and assessing traffic load and congestion ($$$/$$)	
Time horizon	Medium/long term, high CAV adoption	
Example/ visualization	 	[38]

Attribute	Comments	Reference
Action Item	Establish clear CAV (as well as TNC) drop-off and pick-up zones	[5] [16]
Category	Street Design/Infrastructure	
Code	SD-07/I-07	
Description	General description: - Add drop-off/pick-up areas around hot spots - To drop off passengers, vehicles on major streets will first turn right. - Turning off of the main street to stop reduces congestion on main corridors and allows more space along the curb to be dedicated to other uses. Where bicycle traffic is heaviest, right-turn pick-ups and drop-offs may be less ideal. Context-specific description: - Drop-off areas are part of flex zones where they are used for drop-off/pick-up, loading/unloading, transit stops, vendors, parklets and rideshares - Drop-off/pick-up locations are located at every other block, making it convenient for people to move things from their vehicle to their homes and reduce distance required to travel to individual stops.	[5] [16] [44]
Stakeholders	Regional planning agencies, municipality, public works, transportation network companies	
Scale	Regional	
Impact/Benefit	Direct: Safer and better reception of CAVs and SAVs Reduced VMT New road design Indirect: Reduced congestion as there will be less cars on the road and effective allocation of drop-off and pick-up locations	
Barriers	Opposition from developers	
Cost	Retrofitting existing roads Including requirements as part of building codes ($$)	
Time horizon	Short/medium term, medium CAV adoption	
Example/ visualization	Image from the Blueprint for Autonomous Urbanism, Courtesy of NACTO (National Association of City Transportation Officials 	[16]

Attribute	Comments	Reference
Action Item	Designate roads for CAVs as they are ready	[25]
Category	Infrastructure	
Code	I-08	
Description	General description: - Design freeway network with exclusive lanes for CAVs. Context-specific description: - This solution is suggested for freeways and highways with high traffic volume rather smaller arterial roads. Therefore, this solution might not be one of the first solutions to be adopted by smaller to mid-sized regions. - Also, these can be dynamic lanes that can allow all types of vehicles in non-peak hours.	[40]
Stakeholders	Regional planing agencies, municipality, public works, state department of transportation	
Scale	Regional	
Impact/Benefit	Direct: Reduced congestion Higher safety as CAVs interact less with traditional vehicles Impact road design Indirect: Positive economic impacts Efficient CAV deployment, especially in mixed-fleets (CAVs and traditional cars) Reduced VMTs	
Barriers	Waiting for higher CAV adoption percentages	
Cost	Retrofitting existing roads Modelling and assessing network efficiency with CAV lanes only ($$$/$$)	
Time horizon	Medium term, medium/high CAV adoption	
Example/ visualization	Shutterstock 	[40]

Attribute	Comments	Reference
Action Item	Develop new models for pavement maintenance	[25]
Category	Infrastructure	
Code	I-09	
Description	General description: - Since CAVs use sensors and detection technology to maneuver, it is important that the process and frequency of infrastructure (i.e. pavement) improvements are updated accordingly. - Construction and maintenance design: Change construction and maintenance approaches if needed to facilitate CAV use.	[25]
Stakeholders	Public Works, local transit agencies, municipality	
Scale	Local	
Impact/Benefit	Direct: Better reception of CAVs Indirect: Increased emissions from transforming all roads with new material Environmentally better material in the long rung	
Barriers	Financing, expert labor	
Cost	$$	
Time horizon	Medium term, high CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Update traffic signs/markings; adjust signal locations and timing	[25]
Category	Infrastructure	
Code	I-10	
Description	General description: - Follow universal manuals for optimal street/traffic signage (MUTCD) - Signage must be clear for CAV detection	[48]
Stakeholders	State department of transportation, public works	
Scale	Local	
Impact/Benefit	Direct: Higher throughput/reduced congestion Better/safer reception of CAVs Higher safety	
Barriers	Require high adoption of connected vehicles Require update transportation modeling for optimal locations	
Cost	$$	
Time horizon	short term, medium/high CAV adoption	
Example/ visualization	N/A	

Planning

Planning action items relate to any policies and design guidelines that pertain to issues of planning and zoning

Attribute	Comments	Reference
Action Item	Align CAV policy with local greenhouse-gas (GHG) reduction goals	[3]
Category	Planning/General	
Code	P-01/G-01	
Description	**General description:** - Strategic deployment of CAVs can help communities meet GHG-reduction goals through their Climate Action Plans. CAV policies should encourage shared and electric CAVs and incentivize lower vehicle miles traveled (VMT).	[3]
Stakeholders	State departments of transportation, mass transit agencies, municipality, regional planning organizations, Environmental Protection Agency (EPA)	
Scale	Regional	
Impact/Benefit	**Direct:** Lower GHG emissions, achieve environmental sustainability goals **Indirect:** Lower VMT, congestion, and infrastructure costs	
Barriers	Dependent on CAV adoption rates and ownership model (shared vs. private)	
Cost	Stricter fuel economy standards (varies) Advancing electric-based charging infrastructure ($$)	[13]
Time horizon	Long term, high CAV adoption -CAVs will require time to significantly impact GHG emission reductions -Requires high electric-based vehicles	[13]
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Reposition transportation-related revenues	[4] [19]
Category	Planning/General	
Code	P-02/G-02	
Description	**General description:** - Communities rely on revenues from gasoline taxes to fund road maintenance, transportation infrastructure, and transit subsidies. Additionally, significant sources of municipal revenue include parking fees, parking tickets, and moving violation fines. CAVs may speed up revenue decline in multiple ways. CAV may self monitor parking and driving behavior and reduce fines. If CAV fleets are heavily comprised of electric vehicles, gas tax revenues may also decline, potentially leading to budget shortfalls in communities that reply on such revenues. Communities can look to make up for lost funds through transportation charges, such as per-mile fees, and new land use/property taxes on, for example, parking lots converted to higher-value uses. - Communities should: 1. Understand their revenues structures and the policy levers. 2. Identify existing curb demand and areas for flexible curb space. 3. Ensure all loading zone signage is specific, visible, and managed. 4. Confirm current tax code does not incentivize parking lots. 5. Determine appropriate areas for eliminating parking minimums.	[4] [19]
Stakeholders	State Departments of Transportation, Mass transit agencies, Metropolitan Planning Organizations, local parking authority, and municipal public works	
Scale	Regional	
Impact/Benefit	**Direct:** Alternative revenues and resources; More job opportunities from new developments **Indirect:** Reduced congestion	
Barriers	Context-based	
Cost	The cost of this policy is based on how an entity decides to reposition it revenues (varies)	
Time horizon	Medium term, medium/high CAV adoption	
Example/ visualization	-Calgary, Alberta showed that if the city could consume a quarter less land through a denser growth pattern, it could save $11 billion in capital costs alone. -Washington and Oregon are experimenting with vehicle miles traveled (VMT) fees.	[19]

Attribute	Comments	Reference
Action Item	Provide equitable mobility	[16]
Category	Mobility & Traffic/Planning	
Code	MT-16/P-03	
Description	General description: - IImprove mobility for all, contributing to a more equitable transportation system, where benefits reach all demographics and any negative effects are not unjustly concentrated. Context-specific description: - Since mid-sized regions generally have less-efficient public transit systems (if any), areas/users that are dependent on any mode other than private vehicle should be given priority in the CAV planning process.	[16]
Stakeholders	Regional planning agency, mass transit agencies	
Scale	Regional	
Impact/Benefit	Direct: Higher accessibility and equity Indirect: Reduced congestion Reduced emissions Higher safety Reduced VMT Changes in urban form, land use distributions, and density	
Barriers	Identifying equity communities	
Cost	Varying based on type of investments and strategies adopted	
Time horizon	Short term, low CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Promote safety	
Category	Planning	
Code	P-04	
Description	General description: -Promote safety for pedestrians, bicyclists, transit riders, CAV passengers, and all street users within the multimodal urban context -Design nature-rich spaces, with high tree densities to facilitate perceptions of safety and security. -Clarify safety and liability requirements. -Take a Complete Streets approach to roadway design. -Establish and implement a Vision Zero policy or approach, moving toward zero fatalities on roadways. -Consider the safety of pedestrians and cyclists when approving planning routes for CAV testing on public roads or shared-use paths. -Set licensing and registration laws that focus on safe operations and maintenance requirements to ensure the testing of CAVs on public roadways addresses the safety of all road users, including pedestrians and cyclists. -Pedestrians detected, not connected: CAV technology should be able to detect and identify pedestrians rather than depend on thier cyber connectivity through sensors. -Low, steady speeds: manage CAV speeds to be low (15-25mph) and maintained to promote better safety for the different vehicles and active transporters -Places to rest: build spaces for people to rest such as plazas and parks -Children are the design user: consider designing for children to assure high safety measurements. These include markings, speeds, and regulations	[5] [16] [10] [15]
Stakeholders	Any city agency concerned with safety, CAV manufactures, APBP, etc.	
Scale	Regional	
Impact/Benefit	Direct: Improved safety Greater use of active transportation modes Reduced VMT (due to higher use of shared vehicles) Indirect: Reduced emissions/congestion	
Barriers	Coordination across multiple agencies Defining new safety measures Collaborating with private sector to voice safety needs	
Cost	Varying based on types of startegies adopted	
Time horizon	Short term, low CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Convert surface parking lots/garages to new development, public plazas, or green space	[16]
Category	Planning	
Code	P-05	
Description	General description: Introduce new developments/uses in place of parking lots, parking garages, and parking spaces. Context-specific description: - With less need to own cars, suburban developments are likely to have extra open space. This space can be either developed as mixed use, or for other recreational purposes	[43]
Stakeholders	Regional planning agencies, municipality, developers	
Scale	Local	
Impact/Benefit	Direct: Denser development Strategic use of obsolete spaces Indirect: Economic benefits (e.g., increased tax base) Reduced congestion Inequitable access to new developed spaces	
Barriers	Opposition from residents and legacy vehicle users Rezoning in accordance with transportation and land used demands	
Cost	$$/$$$	
Time horizon	Medium/long term, medium CAV adoption	
Example/ visualization	Shutterstock 	

Attribute	Comments	Reference
Action Item	Reduce parking requirements or institute parking maxima	[17]
Category	Planning/Street Design	
Code	P-06/SD-10	
Description	General description: - Some cities are already reducing parking requirements for new construction (i.e. reducing the so-called "parking minimums"), while others like San Francis- co have even begun to institute "parking maximums" for new construction. Some new parking garages are being built so that they could later be converted to other uses, such as office or residential space. - The first goal is to provide the city with more flexibility to reduce min- imum parking requirements as the demand for parking is expected to change. - Develop flexible parking policies	[44] [17] [30]
Stakeholders	Municipality, regional planning agencies, planning and zoning commission, public works, transportation department	
Scale	Regional	
Impact/Benefit	Direct: Reduced VMT Better use of developable space Potential for denser development Indirect: Reduced congestion Reduced emissions Reduce parking burdens	
Barriers	Coordination with the different agencies	
Cost	Minimal since this would be an amendment through a memorandum($)	
Time horizon	Short/medium term, low CAV adoption	
Example/ visualization	City of Chandler: Ride Sharing and Autonomous Vehicles Zoning Code Amendment This zoning amendment aims to prepare the City of Chandler, Arizona for changes in land use as a result of changes in transportation behavior resulting from an increase in ride sharing and autonomous vehicles. 1-The first goal is to provide the city with more flexibility to reduce minimum parking requirements as the demand for parking is expected to change. 2-The second goal of the zoning amendment is to encourage developments to install passenger loading zones.	[34] [45]

Attribute	Comments	Reference
Action Item	Remove on-street parking in residential/commercial streets	[17]
Category	Planning/Street Design	
Code	P-07/SD-11	
Description	General description: - On-street parking lanes can be removed when they are not required anymore (due to curb management strategies and pick-up/drop-off). This should happen in phases. For example, keeping only one lane, then moving to the opposite lane. - Example of a transitional, mixed-vehicle type design: 1. On-street parking reduced by 50 percent from current conditions 2. One 20-foot-wide, two-lane, two-way traffic way for CAVs and other vehicles 3. One or two four- to 12-foot-wide pedestrian sidewalks 4. Reclaimed space used for creative purposes: parklets, stormwater, plant- ers, bike parking, etc. - Example of a long-term, no-conventional-vehicle design: 1. On-street parking reduced by 80 percent from current conditions 2. One eight-foot-wide, flex-direction traffic way for CAVs 3. One or two four- to six-foot-wide pedestrian sidewalks 4. Reclaimed space given back to adjacent parcels for extended yards, home additions, or auxiliary housing units	[17] [44] [46]
Stakeholders	Municipality, regional planning agencies, planning and zoning commission, public works	
Scale	Regional	
Impact/Benefit	Direct: Containment of unutilized space Encourage denser development Reduced VMT Indirect: Reduced congestion/emissions Provide more space for pedestrains and CAVs	
Barriers	Backlash due to limited parking options	
Cost	Minimal cost since this would be an amendment through a memorandum ($)	
Time horizon	Medium/long term, high CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Densify low density areas	[20]
Category	Planning	
Code	P-08	
Description	General description: - With reduced parking requirements, developers and cities that want to maximize land value can double or triple their current density. - This could include developing vacant parcels with townhouses and affordable housing options.	[20]
Stakeholders	Regional planning agencies, municipality, housing agencies	
Scale	Regional	
Impact/Benefit	Direct: Environmental sustainability Greater walkability and active transportation Reduced VMT/emission Increased congestion Indirect: Affordable housing options	
Barriers	Opposition from developers and residents	
Cost	Updating zoning and building codes ($)	
Time horizon	Medium/long term, low CAV adoption	
Example/ visualization	Stages for densification	[44]

Attribute	Comments	Reference
Action Item	Redevelop non-utilized space such as front yards and garages	[20]
Category	Planning/Street Design	
Code	P-09/SD-12	
Description	**General description:** - Consider capturing the space in front yards and garages for additions or even new construction. Just as drivers have a "shy distance" of a few feet from jersey barriers, residents have a shy distance from wide, noxious streets. If the streets are placid, then front yards become buildable space. **Context-specific description:** - With reduced private ownership of vehicles, a substantial share of housing stock may be transformed, with garages converted to other uses such as studios, rented short-term lodging, or granny flats. In theory, driveways may no longer be needed either. These could be turned into greened front yards, spaces for children to play, and/or spaces for residents to walk and meet their neighbors.	[20]
Stakeholders	Municipality, developers	
Scale	Local	
Impact/Benefit	**Direct:** Increased density Increased property values Uncertain impact on physical safety since developments/additions are closer to the street Potential impacts on equity **Indirect:** Reduced congestion	
Barriers	Political opposition Requires approval and change in building codes/zoning ordinances	
Cost	($$)	
Time horizon	Long term, medium CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Design certain land uses for optimal accessibility by active transportation	[5]
Category	Planning	
Code	P-10	
Description	General description: Site schools and other civic institutions (e.g., community centers, libraries, etc.) for optimal accessibility on foot and by bicycle.	[5]
Stakeholders	Municipality, developers, public works, regional planning agencies, transportation department, pedestrian and bicycle advocacy groups	
Scale	Local	
Impact/Benefit	Direct: Improved physical safety for pedestrians, cyclists, and all users/modes Possible equity gaps if accessibility improvements are unevenly distributed Indirect: Reduced congestion Reduced emissions Improved public health	
Barriers	Opposition from developments and residents	
Cost	($)	
Time horizon	Medium term, low CAV adoption	
Example/ visualization	N/A	

Attribute	Comments	Reference
Action Item	Update transportation and land use models to include CAVs	[25]
Category	Planning	
Code	P-11	
Description	General description: - Update travel demand models - Evaluate capacity needs - Analyze transit plans and requirements in the future - Forecast financial impacts - Leverage transportation-planning tools. Context-specific description: - Building scenarios should not follow bigger city assumptions. These include road capacity, transit ridership, shared CAV usage, residential location preferences. Inputs should accommodate for slower adoption rates	[25]
Stakeholders	MPO	
Scale	Regional	
Impact/Benefit	Direct: Better reception of CAVs Indirect: Identification of transportation equity communities/opportunities Reduce congestion Update land use distributions and street network	
Barriers	Limited staff capacity	
Cost	Depends on the extent of intervention (various)	
Time horizon	Short term, low-high CAV adoption	
Example/ visualization	Champaign County Land use transportation model	[50]

Attribute	Comments	Reference
Action Item	Plan for vibrant social hubs	
Category	Planning	
Code	P-12	
Description	General description: - Support the future vision of communities as great places to live, work, and play by using technology as a tool to change land use as well as how streets are built. - Facilitate and promote social interactions and encounters with plazas, parks, playgrounds, and pedestrian zones. This approach is consistent with the large body of literature showing that a mix of older and younger residents, medium population density, and well-designed walkable public spaces enhance the social cohesion of communities. - Plan for the diffusion of CAVs by designing, financing, and instituting vibrant social spaces that are equitably distributed in terms of residents socio-economic status, race, ethnicity, gender, and age. - Explore smart city design principles to better understand their infrastructure options and funding Context-specific description: Leverage CAVs to achieve improvements in street and neighborhood design, particularly in the inner suburbs.	[16] [25] [27]
Stakeholders	Regional planning agencies, municipality	
Scale	Regional	
Impact/Benefit	Direct: Reduced congestion Increase in public spaces Indirect: Improved safety Improved equity and accessibility	
Barriers	Political opposition Clearly defining 'how' to achieve vibrant social hubs	
Cost	Various; depending on what type of policies and guidelines are deployed	
Time horizon	Short term, low CAV adoption	
Example/ visualization	N/A	

TAKING ACTION

Navigating the Action Items

Choosing Your Action Items

As the previous chapter has shown, communities have options when preparing for CAVs. Our template for action items is designed to assist practitioners and decision-makers as they navigate the choices available to them and identify actions that fit their specific contexts and goals. In this chapter, we first illustrate how to navigate this information. We then discuss how communities may create their own deliberative processes and scenarios that accommodate their own priorities and conditions.
Following are three attributes from the template that may be of greatest interest:

By Category
As noted earlier, we organize actions under a total of six categories: General Data & Digitization, Mobility and Traffic, Street Design, Infrastructure, and Planning. Organizing by category may help assign roles based on expertise or subdomains. Some action items cover more than one category.

By Impact
We explore six types of impacts: safety, vehicle miles traveled (VMT), congestion, emissions, land use/urban form, and equity & accessibility. This facilitates navigating the list of action items based on the nature and extent of their potential influence. The impact of an action could vary based on timing, scope, and coordination with other efforts, to name a few. The impacts presented in this handbook are expected or potential impacts only; they are based on the current (and ever-evolving) literature, rather than on any modeling or direct measurements. Furthermore, impacts are categorized into direct (or primary) and indirect (or secondary) impacts. Not all possible impacts are included. Communities will need to carefully consider whether these relationships apply to their specific context.

By Cost
Our cost estimates fall into one of five areas: low, medium, high, uncertain, and varying. As with potential impacts, these are estimates based only on the literature and expertise of the researchers, and are not based on any modeling or measurements. More details can be found under the profile of each action item.

It should be noted that impacts and costs are based on outcomes of specific actions. These do not account for impacts or costs of inaction.

We have created a matrix for each of the above attributes to facilitate comparing the different action items.

Navigating by Category

		G General	DD Data & Digitization	MT Mobility & Traffic	SD Street Design	I Infra-structure	P Planning
DD-01	Establish a standardized data report for collisions						
DD-02	Require data reporting						
DD-03	Promote data sharing that preserves data privacy and security						
DD-04	Establish centralized repositories to hold and provide structured access to mobility data						
DD-05	Digitize existing transit infrastructure						
G-03	Prepare and educate staff about the CAV technology and its possible impacts						
G-04	Designate regulatory roles						
G-05/ MT-17	Run CAV pilot program(s)						
G-06	Plan for equity						
I-01	Deploy 5G infrastructure						
I-03	Modify speed limits to low speeds						
I-04	Introduce smart intersections						
I-05	Add electric vehicle charging stations						
I-06	Reduce lane width						
I-08	Designate roads for CAVs as they are ready						
I-09	Develop new models for pavement maintenance						
I-10	Update traffic signs/markings; adjust signal locations and timing						
I-02/ MT-11	Phase out local buses in favor of auto-jitneys and mobility-as-a-service						
MT-01	Limit CAV access in certain community, social space, and high pedestrian and cyclist densities						
MT-02	Invest in autonomous rapid transit (ART) dedicated lanes						
MT-03	Incentivize CAV business models that operate in a shared fleet (SAVs)						
MT-04	Make multi-modal transportation seamless						
MT-05	Develop and enforce regulations of empty driving						
MT-06	Foster mobility-as-a-service (MaaS)						
MT-07	Manage and reduce congestion						
MT-08	Assign curb-space dynamically and flexibly						
MT-09	Consider tailoring auto-jitneys to each neighborhood						

		G	DD	MT	SD	I	P
MT-12	Manage lanes through dedicated lanes for CAVs						
MT-13	Introduce tolling and demand management						
MT-16/ P-03	Provide equitable mobility						
P-04	Promote safety						
P-05	Convert surface parking lots/garages to new development, public plazas, or green space						
P-08	Densify low density areas						
P-10	Design certain land uses for optimal accessibility by active transportation						
P-11	Update transportation and land use models to include CAVs						
P-12	Plan for vibrant social hubs						
P-01/ G-01	Align CAV policy with local greenhouse-gas (GHG) reduction goals						
P-02/ G-02	Reposition transportation-related revenues						
MT-14	Introduce geofencing (geographical restriction) to SAVs, CAVs, or empty CAVs for better management of their impacts						
MT-15	Support public transit so it doesn't become obsolete						
P-06/ SD-10	Reduce parking requirements or institute parking maxima						
P-07/ SD-11	Remove on-street parking in residential/commercial streets						
P-09/ SD-12	Redevelop non-utilized space such as front yards and garages						
SD-01	Rethink curb design and street space allocation						
SD-03	Design and implement separated/protected bike lanes						
SD-04	Create temporary or flexible dedicated lanes for cycling with movable barriers or time restrictions on lane use						
SD-05	Introduce improvements in lighting, pedestrian crossing islands, and gateway treatments						
SD-06	Update road markings						
SD-07/ I-07	Establish clear CAV (as well as transportation network company) drop-off and pick-up zones						
SD-08	Introduce road diets						
SD-09	Introduce tight corner radii						
SD-13	Manage the curb for high people of volumes, not cars						
SD-02/ MT-10	Prioritize right-of-way for pedestrians						

Navigating by Impact

Indirect relationship | Direct relationship

		Safety	VMT	Congestion	Emissions	Urban form	Equity
DD-01	Establish a standardized data report for collisions	Direct		Direct			
DD-02	Require data reporting	Direct	Direct	Direct	Direct		Direct
DD-03	Promote data sharing that preserves data privacy and security	Direct	Direct	Direct	Direct		Direct
DD-04	Establish centralized repositories to hold and provide structured access to mobility data	Direct	Direct	Direct	Direct		Direct
DD-05	Digitize existing transit infrastructure		Direct	Direct	Direct	Indirect	Direct
G-03	Prepare and educate staff about the CAV technology and its possible impacts						
G-04	Designate regulatory roles						
G-05/ MT-17	Run CAV pilot program(s)	Indirect	Indirect	Indirect	Indirect	Indirect	Direct
G-06	Plan for equity	Indirect	Indirect	Indirect	Indirect	Indirect	Direct
I-01	Deploy 5G infrastructure	Indirect	Indirect	Indirect			Direct
I-03	Modify speed limits to low speeds	Direct				Indirect	
I-04	Introduce smart intersections	Direct		Direct	Indirect		
I-05	Add electric vehicle charging stations				Direct	Indirect	
I-06	Reduce lane width	Direct		Indirect		Direct	
I-08	Designate roads for CAVs as they are ready	Direct	Indirect	Direct		Direct	
I-09	Develop new models for pavement maintenance				Indirect		
I-10	Update traffic signs/markings; adjust signal locations and timing	Direct		Direct			
I-02/ MT-11	Phase out local buses in favor of auto-jitneys and mobility-as-a-service		Direct	Direct	Direct	Indirect	Direct
MT-01	Limit CAV access in certain community, social space, and high pedestrian and cyclist densities	Direct	Direct	Direct	Direct	Indirect	Direct
MT-02	Invest in autonomous rapid transit (ART) dedicated lanes	Indirect	Direct	Direct	Indirect	Indirect	Direct
MT-03	Incentivize CAV business models that operate in a shared fleet (SAVs)		Direct	Indirect	Direct	Indirect	
MT-04	Make multi-modal transportation seamless	Direct	Direct	Indirect	Direct	Indirect	Direct
MT-05	Develop and enforce regulations of empty driving		Direct	Indirect	Direct	Indirect	
MT-06	Foster mobility-as-a -service (MaaS)		Direct	Indirect	Direct	Indirect	Direct
MT-07	Manage and reduce congestion		Direct	Direct	Direct	Indirect	Direct
MT-08	Assign curb-space dynamically and flexibly	Direct	Indirect	Direct		Direct	
MT-09	Consider tailoring auto-jitneys to each neighborhood	Direct	Direct	Direct	Direct		Indirect

Indirect relationship   Direct relationship

MT-12	Manage lanes through dedicated lanes for CAVs	Direct	Direct	Direct	Indirect		
MT-13	Introduce tolling and demand management		Direct	Direct	Direct	Indirect	Direct
MT-16/ P-03	Provide equitable mobility	Indirect	Indirect	Indirect	Indirect	Indirect	Direct
P-04	Promote safety	Direct	Indirect	Direct	Indirect		Indirect
P-05	Convert surface parking lots/garages to new development, public plazas, or green space		Indirect			Direct	Indirect
P-08	Densify low density areas		Direct	Direct	Direct	Direct	Indirect
P-10	Design certain land uses for optimal accessibility by active transportation	Direct	Direct	Direct	Direct	Direct	Direct
P-11	Update transportation and land use models to include CAVs		Indirect			Indirect	
P-12	Plan for vibrant social hubs	Indirect	Direct			Direct	Indirect
P-01/ G-01	Align CAV policy with local greenhouse-gas (GHG) reduction goals.		Direct	Indirect	Direct	Indirect	
P-02/ G-02	Reposition transportation-related revenues						
MT-14	Introduce geofencing (geographical restriction) to SAVs, CAVs, or empty CAVs for better management of their impacts	Indirect	Direct	Direct	Indirect	Indirect	
MT-15	Support public transit so it doesn't become obsolete		Direct	Direct	Direct	Indirect	Direct
P-06/ SD-10	Reduce parking requirements or institute parking maxima		Indirect	Direct	Indirect	Direct	Indirect
P-07/ SD-11	Remove on-street parking in residential/commercial streets		Indirect	Direct	Indirect	Direct	Indirect
P-09/ SD-12	Redevelop non-utilized space such as front yards and garages		Indirect			Direct	Indirect
SD-01	Rethink curb design and street space allocation	Direct	Direct	Direct	Indirect	Indirect	
SD-03	Design and implement separated/protected bike lanes	Direct	Direct		Indirect	Indirect	
SD-04	Create temporary or flexible dedicated lanes for cycling with movable barriers or time restrictions on lane use	Direct	Direct	Indirect		Direct	
SD-05	Introduce improvements in lighting, pedestrian crossing islands, and gateway treatments	Direct	Indirect	Indirect	Indirect	Indirect	Indirect
SD-06	Update road markings	Direct					
SD-07/ I-07	Establish clear CAV (as well as transportation network company) drop-off and pick-up zones	Direct	Indirect	Direct		Direct	
SD-08	Introduce road diets	Direct	Direct	Direct	Indirect	Indirect	Indirect
SD-09	Introduce tight corner radii	Direct				Indirect	
SD-13	Manage the curb for high people of volumes, not cars	Direct	Indirect	Direct		Direct	Indirect
SD-02/ MT-10	Prioritize right-of-way for pedestrians	Direct	Direct	Indirect	Indirect	Indirect	Direct

Navigating by Cost

		$	$$	$$$	%	?
		Low	Medium	High	Varying	Uncertain
DD-01	Establish a standardized data report for collisions		■			
DD-02	Require data reporting		■		■	
DD-03	Promote data sharing that preserves data privacy and security		■		■	
DD-04	Establish centralized repositories to hold and provide structured access to mobility data					■
DD-05	Digitize existing transit infrastructure	■				
G-03	Prepare and educate staff about the CAV technology and its possible impacts		■			
G-04	Designate regulatory roles	■				
G-05/ MT-17	Run CAV pilot program(s)		■			
G-06	Plan for equity	■			■	
I-01	Deploy 5G infrastructure		■	■		
I-03	Modify speed limits to low speeds	■				
I-04	Introduce smart intersections		■	■		
I-05	Add electric vehicle charging stations		■	■		
I-06	Reduce lane width		■	■		
I-08	Designate roads for CAVs as they are ready		■	■		
I-09	Develop new models for pavement maintenance		■			
I-10	Update traffic signs/markings; adjust signal locations and timing		■			
I-02/ MT-11	Phase out local buses in favor of auto-jitneys and mobility-as-a-service			■		
MT-01	Limit CAV access in certain community, social space, and high pedestrian and cyclist densities	■				
MT-02	Invest in autonomous rapid transit (ART) dedicated lanes	■				
MT-03	Incentivize CAV business models that operate in a shared fleet (SAVs)				■	■
MT-04	Make multi-modal transportation seamless		■		■	■
MT-05	Develop and enforce regulations of empty driving				■	
MT-06	Foster mobility-as-a -service (MaaS)		■		■	
MT-07	Manage and reduce congestion		■		■	
MT-08	Assign curb-space dynamically and flexibly		■		■	■
MT-09	Consider tailoring auto-jitneys to each neighborhood		■			

		$	$$	$$$	%	?
MT-12	Manage lanes through dedicated lanes for CAVs			■		
MT-13	Introduce tolling and demand management				■	■
MT-16/ P-03	Provide equitable mobility				■	
P-04	Promote safety				■	
P-05	Convert surface parking lots/garages to new development, public plazas, or green space		■	■		
P-08	Densify low density areas	■				
P-10	Design certain land uses for optimal accessibility by active transportation	■				
P-11	Update transportation and land use models to include CAVs				■	
P-12	Plan for vibrant social hubs				■	
P-01/ G-01	Align CAV policy with local greenhouse-gas (GHG) reduction goals.			■	■	
P-02/ G-02	Reposition transportation-related revenues				■	
MT-14	Introduce geofencing (geographical restriction) to SAVs, CAVs, or empty CAVs for better management of their impacts					■
MT-15	Support public transit so it doesn't become obsolete				■	
P-06/ SD-10	Reduce parking requirements or institute parking maxima	■				
P-07/ SD-11	Remove on-street parking in residential/commercial streets	■				
P-09/ SD-12	Redevelop non-utilized space such as front yards and garages		■			
SD-01	Rethink curb design and street space allocation					■
SD-03	Design and implement separated/protected bike lanes		■			
SD-04	Create temporary or flexible dedicated lanes for cycling with movable barriers or time restrictions on lane use	■				
SD-05	Introduce improvements in lighting, pedestrian crossing islands, and gateway treatments	■				
SD-06	Update road markings	■				
SD-07/ I-07	Establish clear CAV (as well as transportation network company) drop-off and pick-up zones		■			
SD-08	Introduce road diets		■	■		
SD-09	Introduce tight corner radii				■	
SD-13	Manage the curb for high people of volumes, not cars		■			
SD-02/ MT-10	Prioritize right-of-way for pedestrians				■	

Create Your Own Scenarios

Guiding Steps

The following section offers a simplified outline of scenario building guidance. Please refer to the section on scenario planning in the handbook and report for information on various scenario planning techniques, how the scenarios presented in this handbook were created, and more detailed guidance on how to create your own scenarios.

To be able to create your own scenario, gather your team and think about the following questions:
1-Which drivers are most uncertain and most relevant for our community? 2-What are the best measures of how these changes may impact our community?
3-What are the best tools or levers that can manage these drivers and impacts, and help achieve a desirable future for our community?

Step 1

Think about: Forces that impact your community and over which you have little control. Check the list of drivers we have provided on the following page.
Pose questions: For example: How can technological advances impact the proliferation of CAVs in our community? How might local preferences drive the forms of adoption of CAVs?
Coordinate with: DOTs, transit authority, research institutions, private sector, TNC companies

Step 2

Think about: TThe different impacts that CAVs might have on communities. Check the list of impacts we have provided on the following page.
Pose questions: Which impacts are most important to our community? Which CAV impacts align well with our current goals as a region?
Coordinate with: DOTs, transit authority, research institutions, private sector, TNC companies

Step 3

Think about: TThe different action items which your organization has the power and the authority to implement. Check the list of levers we have provided on the following page.
Pose questions: Which actions will help us in achieving our goals? Which actions are most feasible? Which actions are most effective?
Coordinate with: DoT, Transit authority, private sector

Your Dimensions

Based on our research, we have created a list of drivers, impacts and levers that can be chosen from the figure below. These can vary from one application to another depending on each entity's procedures and final goals. Once the most important dimensions are selected, they can be placed in the two-dimensional framework to create scenarios and evaluate their impacts.

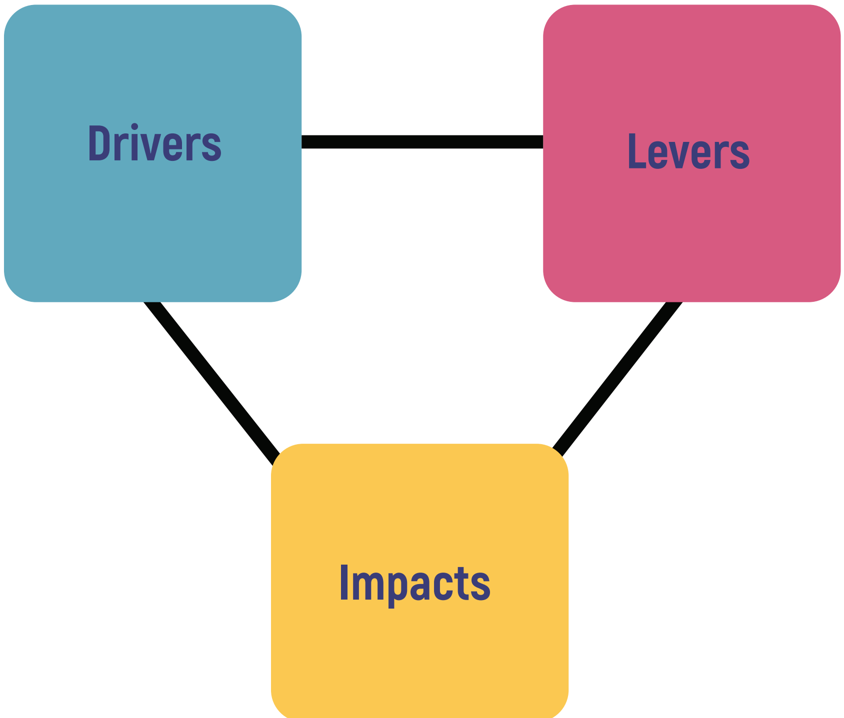
Drivers	Technological change -Infrastructural -Vehicular Consumer preferences -Adoption percentages/rates -Types of ownership -Electric vehicles share Demographic shifts
Impacts	-Safety -Vehicle miles traveled (VMT) -Congestion -Emissions -Urban form -Accessibility -Equity -Economic shifts
Levers	-Infrastructure investment -Travel pricing -Parking policy -Multimodal transportation investment -Land use planning

Your Framework

Now that you have gone through these three main steps, start developing your own scenarios. For this task, narrow down the list of drivers, impacts, and levers you have assessed in the previous task and start developing your scenario structure. Select the two primary dimensions (x and y axes) from the list of drivers and levers. Assign two extremes or poles (i.e., low-high, positive-negative, shared-private, etc.) for each dimension and develop the scenarios based on the intersection of these dimensions.

Feel free to add an additional dimension (i.e. secondary dimension) if that is necessary in your framework. Remember, these dimensions are based on your needs, which may be driven by your goals as an organization or research such as a survey of residents in your region. Once the scenarios are created, start developing a profile for each scenario. The scenario profile consists of characteristics based on the dimensions you have selected as well as the possible impacts. The impacts of each scenario can be assessed preliminarily by using the list we have provided. Keep enhancing these scenarios to include all the important factors which will allow for comparison. This facilitates looking at scenarios from a likelihood and desirability perspective. Consider consulting with subject-matter experts or consultants for specific assessments.

Finally, review the Action Items chapter for suitable options for your community depending on the scenario your community may be aiming to achieve or prepare for. Choosing and prioritizing these action items can be based on their category, cost, and/or expected impacts.



Your Scenarios

Characteristics:
1) ....
2) ....
3) ....

Impacts:
1) ....
2) ....
3) ....

Characteristics:
1) ....
2) ....
3) ....

Impacts:
1) ....
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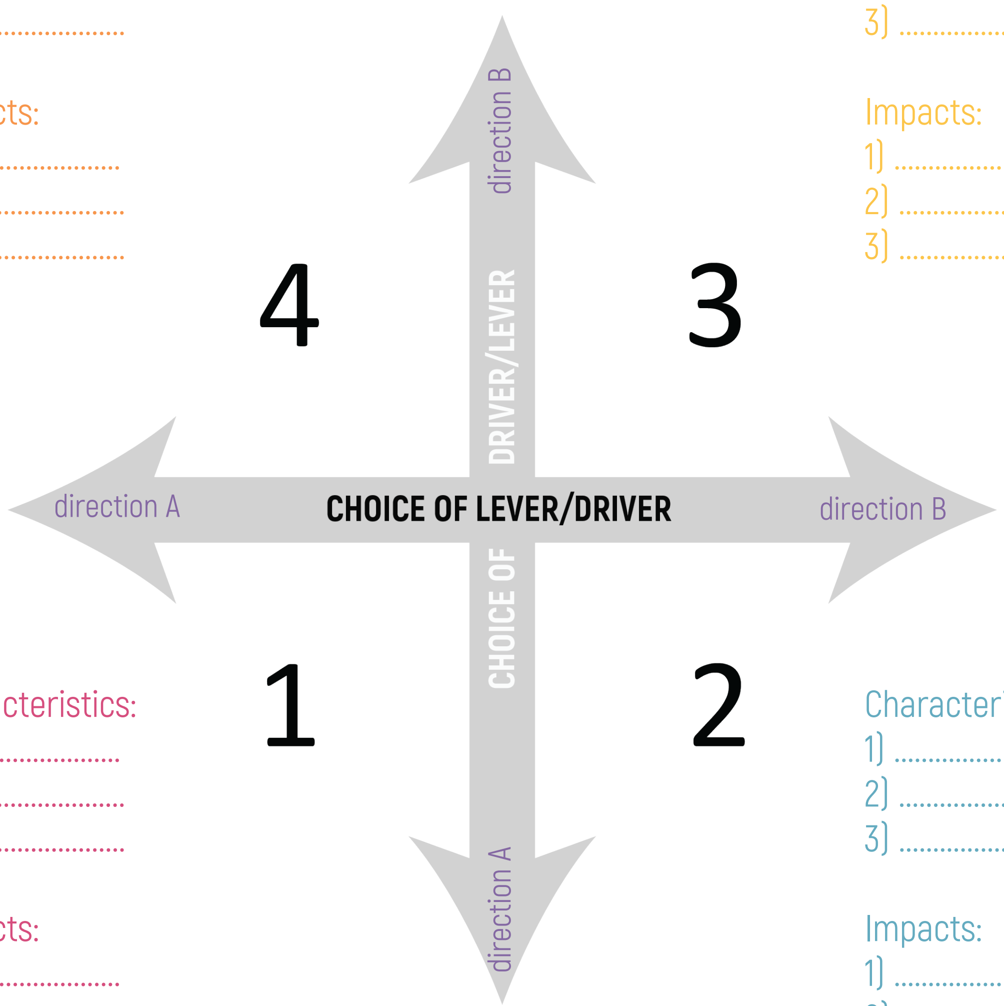
3) ....



Characteristics:
1) ....
2) ....
3) ....

Impacts:
1) ....
2) ....
3) ....

Characteristics:
1) ....
2) ....
3) ....

Impacts:
1) ....
2) ....
3) ....

Fill this chart based on your selections and analysis

What's next?

Proactive Planning

CAVs are likely to become a reality in the near future. Although adoption rates, human behavior, and impacts on society more broadly remain uncertain, we know that this technology can be transformational and, as such, planning for them becomes a necessity. Some large metropolitan areas and big cities are already receiving CAVs on their roads whether through pilot programs or private ownership. For mid-sized regions, we recommend the following urgently:

-Stay aware of updates on CAVs technologies and impacts
-Learn from similar size communities who are experimenting with CAV technologies
-Be aware of state and federal guidance
-Familiarize yourself with the needs and aspirations of your local communities
-Center equity in your conversations about CAVs and mobility in general

Concluding Remarks

The potential impacts of CAVs on communities are multifaceted and associated with considerable uncertainty. While CAVs are generally expected to be beneficial in terms of traffic safety, their impacts on VMT and congestion are less certain and are highly dependent upon rates of CAV adoption, SAV usage, vehicular ownership, driving behavior, number of trips, and other critical elements of travel behavior. CAVs are also likely to have impacts on the built environment by either increasing core densities, expanding suburbanization, or both. Although CAVs are likely to provide greater mobility and accessibility for non-drivers such as the elderly and people with disabilities, CAVs might also have negative impacts on active transportation, social equity, and the environment.

The ultimate impacts of CAVs, however, will also be highly influenced by the actions taken by MPOs. While the literature on CAV levers is currently less robust than the literature on CAV drivers and impacts, some levers are addressed. Suggested levers found in CAV research and by MPOs can be translated into traffic control strategies (e.g.: VMT- based taxation, congestion pricing, etc.), Infrastructural changes (e.g.: road markings, signage, adjustment of speed limits, smart intersections, etc.), Commuting incentives (e.g.: usage of SAVs, usage of public forms of transportation, improvement of multi-modal transportation), and design guidelines (e.g.: parking policies, reduce right of way, charging stations, incentivize denser developments, etc.).

Although there is an extensive discussion about the possible levers, research falls short in providing a detailed layout of how, when, and where to implement these recommendations. It is difficult for planners to take these levers and translate them into policies and guidelines without knowing which levers to prioritize and which would have the greatest impacts. Additionally, many of the levers are conveyed in a general manner where no contextualization or a critical understanding of the area is reflected. This is where scenario planning would play a valuable role in trying to contextualize these drivers, impacts, and levers, providing the detailed information and direction that are needed for MPOs to plan accordingly.

This document provides a starting point for practitioners to start planning for CAVs. Scenario planning is one method that facilitates tackling the uncertainties of CAVs and their possible impacts on our cities. The scenario planning framework can also be helpful to envision a desirable future for the community, and links planning for CAVs to other issues and decision-making at different scales. According to (Cottam 2018), it is vital for agencies planning for CAVs to be able to collectively define the city's desired future. The scenario planning framework allows for compiling various possible future and identifying and more clearly defining this 'desired future.' For example, the framework may be employed to project trends on important drivers and estimate (or imagine) their impacts. Such an approach may also allow integrating the CAV analysis with broader planning process (Chakraborty and McMillan 2015). This may include considerations such as the nature of the agency in charge of the project or need for planning resources.

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