Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies

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FOREWORD

By B. Ray Derr
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Connected vehicle (CV) and automated vehicle (AV) technologies are rapidly entering the fleet and are expected to profoundly change personal, freight, and public transport. The potential benefits to society of these technologies are immense but there are also substantial risks. This report assesses policy and planning strategies at the state, regional, and local levels that could influence private-sector AV and CV choices to positively affect societal goals. The report will be useful to staff responsible for developing plans for reacting to these technologies and is accompanied by a briefing document that may be appropriate for agency decision makers.

Vehicle manufacturers and third-party vendors are continually introducing new AV technologies into the marketplace. CV technologies are also moving towards implementation, with the National Highway Traffic Safety Administration's rule-making being a key driver. Vehicles that are increasingly automated and connected (to each other and/or to infrastructure) offer many benefits in areas such as safety, mobility, and the environment. However, there is a gap between the consumer benefits that motivate vehicle manufacturers and owners and the societal goals of public agencies. Without action by governments, there is a risk that some of the public benefits from these transformative technologies will not be realized.

In NCHRP Project 20-102(01), the Texas A&M Transportation Institute, RAND Corporation, Southwest Research Institute, and the University of Utah identified and described mismatches between potential societal impacts and factors that influence private-sector decisions on CV and AV technologies. Policy and planning actions that might better align these interests were then identified. After meeting with the project oversight panel to identify the most promising actions, the research team conducted in-depth evaluations of the feasibility, applicability, and impacts of 18 strategies.

This report is intended for use by experienced agency staff as they explore actions their agency might take to increase the likelihood that CV and AV technologies will have beneficial impacts on traffic crashes, congestion, pollution, land development, and mobility (particularly for older adults, youths under the age of 16, and individuals with disabilities). Some actions are likely to be infeasible for a particular agency, but every agency should find a few of the actions to be worth pursuing. Agencies are encouraged to share their experiences with any of the strategies at the National Operations Center of Excellence (http://www.transportationops.org/).

The research team also developed a briefing document that concisely conveys the key findings of the research. It is available on the TRB website (http://www.trb.org/) along with a PowerPoint® presentation that can be adapted for presentations to agency decision makers.

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SUMMARY

Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies

This report assesses policy and planning strategies at the state, regional, and local government levels that, if implemented, could nudge private-sector choices regarding automated vehicles (AVs) and connected vehicles (CVs) toward outcomes that would benefit society. Why would these governments want to do this? State, regional, and local governments use available policy levers to ensure the safe and efficient operation of public roadways and to foster equity across users of the system; overseeing AV and CV technologies is a natural extension of this longstanding mission.

Technology and Regulatory Contexts

For the purposes of this work, an AV is one that takes full control of all aspects of the dynamic driving task for at least some of the time. Using the Society of Automotive Engineers (SAE) International taxonomy, this research focuses on the role of higher levels of AVs in mitigating or exacerbating the negative effects of driving, or in creating new effects. Higher levels of automation are designated SAE Levels 3, 4, and 5 and are referred to in federal policy guidance as highly automated vehicles (HAVs). HAVs are not currently deployed on public roads for consumer use in the United States, although several tests of such vehicles are being implemented.

A CV has internal devices that connect it to other vehicles, as in vehicle-to-vehicle (V2V) communication, or a back-end infrastructure system, as in vehicle-to-infrastructure (V2I) communication. V2V applications enable crash prevention, and V2I applications enable telecommunication, safety, mobility, and environmental benefits. Dedicated short-range communication (DSRC) standards are currently the leading medium for V2V and V2I safety applications. At present, V2V and V2I applications solely provide driver alerts; they do not control the operation of the vehicle.

The National Highway Traffic Safety Administration (NHTSA) released the official Federal Automated Vehicle Policy in December 2016. While this policy itself does not represent a regulatory action, it identifies potential future rulemaking activities. The policy outlines areas of safety that developers should address. The policy also outlines federal and state roles. It affirms that states retain their responsibilities for licensing and registering vehicles, defining and enforcing traffic law, and regulating insurance and liability requirements and policies. It recommends that states review current laws and regulations to address unnecessary impediments to the safe use of AVs, and update references to human drivers in motor vehicle codes. States are encouraged to work together to standardize roadway signs, traffic signals, lights, and pavement markings for uniformity of the operating environment. The policy envisions that each state's AV-related activities will be administered by a single lead agency and associated technology committee. This report could serve as an important resource for these entities.

As of August 2016, eight states and the District of Columbia have enacted legislation related to AVs, beginning with Nevada in 2011 and followed by Florida and California in 2012. In 2015, 16 states introduced AV legislation, and 34 states and districts in total have considered AV legislation since 2012 (National Conference of State Legislatures 2016). Some of the adopted legislation relates primarily to terminology and taxonomy, such as a bill introduced in Louisiana. The adopted legislation in a number of states and districts including California, Nevada, and the District of Columbia authorizes operation and testing of AVs on public roads. In North Dakota and Florida, the legislation calls for studies and pilots of AV technology. Several enacted bills, including those in California and the District of Columbia, require a human driver to be sitting in the driver's seat while the AV is in operation. The Tennessee bill prohibits local governments from banning vehicles equipped with AV technology.

Potential Impacts of Automation and Connectivity

Vehicles that are increasingly automated and connected have the potential to profoundly change personal, freight, and public transportation. The potential benefits to society are immense. As producers sell AVs and CVs and consumers buy them, crashes, traffic congestion, air pollution, and other negative externalities associated with driving may significantly diminish. On the other hand, AVs and CVs may have drawbacks and pose risks. Technology will solve some problems but could also create new ones. For example, cybersecurity vulnerabilities associated with CVs could compromise safety. Congestion could increase with the proliferation of AVs as driving becomes less onerous and individuals who do not drive today have more opportunities for travel. With this document, transportation agencies can examine the kinds of strategies that lead to positive societal outcomes as AV/CV technologies proliferate.

The analytical foundation for identifying potential policy strategies was an examination of the role of AVs and CVs in mitigating or exacerbating existing transportation externalities (listed below). An externality is an effect produced by either a consumer or producer that affects others yet is not accounted for in the market price (i.e., occurs external to the market). Externalities result in suboptimal societal outcomes because the true costs and benefits of actors' choices are not reflected in market prices.

- **Traffic crashes:** When individuals drive a vehicle, they not only increase their own risk of a crash and its associated costs, they also increase (but do not fully pay for) crash risks and costs for other motorists, pedestrians, cyclists, and society in general. As such, the market for safe vehicles and motoring behavior is distorted. V2V safety applications could reduce the magnitude of this externality by addressing a majority of vehicle crash types if the V2V applications are demonstrably effective and widely used, and the driver-vehicle interface performs well. A marginal increase in benefit could be obtained through V2I safety applications depending upon V2I extent. Even without CVs, AVs could reduce a majority of driver-related errors, which account for a vast majority of traffic crashes, but AVs also might introduce new types of errors.
- **Congestion:** As the number of vehicles on a road increases past a certain density, vehicle speed and throughput decrease, causing congestion. Each additional driver adds to the congestion but does not bear the full cost of that effect. Thus, there is less incentive for individuals to take actions that reduce congestion. It is unclear how AVs and CVs will affect congestion. CV applications could mitigate congestion by reducing delays caused by safety incidents and by increasing system efficiency. Widespread adoption of V2V capabilities, widespread V2I infrastructure, and interoperability among mobility applications would maximize these effects. AVs that are safer than human drivers could enable the reduction of crash-related delays, but a proliferation of on-demand AVs could put more vehicles on the road, increasing congestion.

- **Pollution:** Vehicles emit local and global air pollutants. When someone drives a vehicle, he or she reduces the air quality and adds to noise pollution in surrounding areas. That person also imposes the costs of climate change on the global society. These costs are largely excluded from the transportation market. AVs could mitigate this externality by leading to reduced vehicle production rates and parking needs, and to increased use of smaller, electric vehicles and eco-driving. AVs and CVs could also increase this externality by increasing safety and improving the convenience of vehicle travel, lowering transportation costs. While the associated increased vehicle miles traveled (VMT) may facilitate additional economic activity or enhanced quality of life, the increased VMT may or may not bring negative environmental impacts that would need to be mitigated.
- **Land development:** Land devoted to automobile infrastructure and to inefficient development patterns, while historically increasing mobility and decreasing travel costs, may also pose negative environmental, economic, and public health effects on society. These costs are largely not borne by travelers specifically but by society as a whole. AVs and CVs could increase safety, improve convenience of vehicle travel, and lower transportation costs. These effects might lead consumers to take more trips and travel more miles in order to access lower-priced land and rural locations, exacerbating the negative effects. However, society could benefit if HAVs reduced the need for parking adjacent to destinations in dense urban areas so that land dedicated to parking in urban areas could be repurposed for other uses.
- **Mobility:** Older adults, youths under age 16, and individuals with disabilities have limited access to desired destinations, activities, and services. Because of implicit and explicit subsidies for personal automobile travel, these can be viewed as a negative externality of the existing transportation system. Fully automated vehicles may offer a reduction of the existing negative externality by enabling significant improvements in access and mobility for such individuals. This is particularly true for those who live in areas with few alternative modes. The benefits of less-than-full automation and CVs in reducing this negative externality are unclear, however.

Policy and Planning Strategies

Society could benefit if state, regional, and local governments were to implement policy and planning strategies to (a) internalize these externalities in decision making by consumers and (b) reduce negative societal effects and increase positive societal effects of AVs and CVs, regardless of whether they are internal or external to market decisions. Both types of strategies would result in better societal outcomes.

Eighteen strategies—organized by desired outcome—are provided for transportation agencies to consider. The strategies represent the common types implemented by state and local governments. The viability of each has been assessed by the following criteria: effectiveness and efficiency in achieving the desired outcome, political acceptability, operational feasibility, geographic impact, who would implement, and hurdles to implementation. The feasibility of achieving the desired outcomes was deemed more likely with some strategies than others, as noted in the bottom line assessments presented.

Outcome: To Mitigate Safety Risks through Testing, Training, and Public Education

1. Enact legislation to legalize AV testing.
   Assessment: Legislation will provide a necessary policy framework to allow AV testing on public roads. Testing is a critical path step for mitigating safety risks. The key hurdle to implementation is passing legislation; there must be political will to do so.

2. Enact legislation to stimulate AV or CV testing.
   Assessment: Legislation will provide a necessary policy framework to stimulate others to test AVs and CVs on public roads. Testing is a critical path step for mitigating safety risks. Direct funding may be needed to stimulate CV testing. The key hurdle to implementation is passing legislation; there must be political will to do so.
3. Modify driver training standards and curricula.
   Assessment: Driver training standards and curricula will be essential to safe operation of AVs and CVs. Hurdles to implementation are mainly operational; altering driver training and licensing requirements for AV Level 3 vehicles will require significant restructuring of driver training and of licensing requirements and testing. AV Level 4/5 vehicles could eventually lead to the elimination of driver training, examining, and licensing as they currently exist. However, there is not enough clarity on the specifics of CV and AV roll-out to determine how to proceed with new training standards in the near term.
4. Increase public awareness of benefits and risks.
   Assessment: AV and CV technologies have the potential to bring immense societal benefits but also pose new risks, both of which need to be made known to the general public to ensure market acceptance as well as safe operation. Public education campaigns are expensive and complicated endeavors. Their effectiveness and ability to achieve a positive societal outcome will be determined by the credibility of the messenger and perception by the receiver about the necessity and validity of the message. A major hurdle will be the development of trusted messages given the uncertainties in the technology deployment, benefits, and drawbacks.

Outcome: To Encourage Shared AV (SAV) Use

5. Subsidize SAV use.
   Assessment: Based on what is currently happening with transportation network companies like Uber and Lyft, a strategy to encourage SAV alternatives to AVs is not needed since demand for such services has been strongly market-driven. However, a strategy that incentivizes SAVs to provide first/last-mile service and service for targeted populations could be effective in achieving positive societal outcomes. Hurdles will be in implementation—reallocation of public transit subsidies for SAVs and political opposition from some driver-reliant industries (i.e., taxis and livery services).
6. Implement transit benefits for SAVs.
   Assessment: Transit benefits, a type of economic incentive provided to employees to pay for transit or vanpool fares, are not by themselves particularly successful in increasing transit use. Evidence has shown that use depends much more heavily on extent of service provision and user convenience. This economic incentive could be more effective with an SAV fleet because of the flexibility in origins and destinations served, but service characteristics would still be important. The key hurdle to implementation is regulatory. Congressional action is required to alter the existing transit benefit program.
7. Implement a parking cash-out strategy.
   Assessment: Parking cash-out is a type of existing economic incentive wherein employers offer employees a choice between retaining a free parking space and taking a cash payment. While parking cash-out has been fairly successful where adopted, its success depends on the availability of commute alternatives. The key hurdle is institutional; there is no particular incentive for employers to implement this, other than a mandate. Still, even making the offering of the program mandatory for employers would not necessarily encourage SAV use since the employees might opt for the free parking instead.

8. Implement location-efficient mortgages.
   Assessment: Location-efficient mortgages (LEMs) are special mortgages available to homeowners whose properties are located close to transit stations. Price is undoubtedly an important component of home buying decisions, but there is no evidence that LEMs make a major difference. The additional increment available to qualified buyers in pilot programs was generally in the range of $15,000, which is probably not sufficient in many markets to make a difference in the number of homes affordable to the borrower. Major hurdles to implementation are political. There are a number of stakeholders who might have concerns about such a program.
9. Implement land use policies and parking requirements.
   Assessment: Land use strategies allow, incentivize, or mandate development features, and these can be used to realize the best use for the public good. However, land use policies do not necessarily ensure that developers will provide for the best use or that the realized design will function as envisioned. The likelihood that such policies will generate a large shift to SAV use must be compared to existing efforts to promote shared mobility. These examples are still quite limited, though they show signs of success where they do exist. Hurdles are political, with potential objections from private developers and local residents.
10. Apply road use pricing.
   Assessment: Pricing applications are currently implemented in numerous forms through the United States. Road use charges have been effective in achieving specific objectives related to minimizing the impacts of driving, such as congestion and pollution. However, road use charges are also among the most unpopular of pricing applications in society. Thus, hurdles to implementation will be public and political opposition.

Outcome: To Address Liability Issues That May Impact Market Development

11. Implement a no-fault insurance approach.
   Assessment: A no-fault approach to auto insurance allows crash victims to recover damages from their own auto insurers rather than from another driver. State-level no-fault automobile insurance would likely accomplish goals of clarifying assignment of liability and, depending on the statutory language, reducing or eliminating manufacturer liability. The political feasibility of implementing such an approach in certain states is uncertain due to potential opposition from powerful stakeholder groups.
12. Require motorists to carry more insurance.
   Assessment: Raising mandatory insurance minimums would very likely produce a net-positive socially beneficial outcome because it would eliminate the existing subsidy for unsafe vehicles and drivers. Without enforcement, the strategy may have unintended consequences, namely increased incidence of consumers not purchasing *any* insurance. Hurdles include the effective enforcement of insurance minimums and the likely unpopularity of higher mandatory insurance requirements among the general public.

Outcome: To Enhance Safety, Congestion, and Air Quality Benefits by Influencing Market Demand

13. Subsidize CVs.
   Assessment: The strategy uses an economic incentive to encourage the adoption and penetration of CV technology. If NHTSA requires DSRC/CV equipment on new vehicles, there is no need to subsidize new vehicles. The needed role of incentives is for existing vehicles that would not be covered by a new vehicle mandate. Subsidies will likely require authorization and legislation at their respective levels that create barriers to implementation.

14. Invest in CV infrastructure.
    Assessment: The strategy encourages the adoption and penetration of CV technology by making sure that necessary physical and digital infrastructure is in place to support V2V and V2I applications. Hurdles include funding availability and the associated fact that investing agencies will want concrete evidence of return on investment. Currently, it is still unclear whether the benefits of increased funding for CV infrastructure will be greater than the costs. An additional hurdle is clarifying what data will be freely available to public agencies and whether they could monetize such data, potentially defraying some of the CV infrastructure cost.
15. Grant AVs and CVs priority access to dedicated lanes.
    Assessment: For minimal cost, the societal benefits of fast and safe travel on dedicated lanes for AVs and CVs are very large. However, implementation will require the right situation. If the intent is to increase market penetration of equipped vehicles, effectiveness will depend on road operators' willingness to dedicate lanes to AVs and CVs. If the intent is to reduce VMT in a restricted district or area (like an urban center), effectiveness will depend on how well the supply of SAVs matches demand.
16. Grant signal priority to CVs.
    Assessment: Signal priority involves sophisticated signal timing algorithms that estimate the arrival of specific vehicles and coordinate the signal timing to give them green light priority. It is unlikely that this policy will be the driving force to increase market penetration because the travel time benefits will be minimal. It may also have the negative outcome of reduced priority treatment for transit.
17. Grant parking access to AVs and CVs.
    Assessment: Priority parking, which grants priority reserved parking in desirable locations, will have zero effect on the market penetration of AVs and CVs. The ability of an AV to park itself will likely be more of a market incentive. If implemented, the strategy would reduce some parking availability for non-AVs, which would incur opposition from the general public.
18. Implement new contractual mechanisms with private-sector providers.
    Assessment: Public-private partnership (P3) arrangements have a long history of creating net-positive benefits to society, so this strategy that requires potential reinvestment of private-sector revenue to deploy CV/AV-enabling technologies would likely have similar outcomes—facilitating adoption and market penetration and creating an ecosystem of innovation. However, P3s are generally perceived as a more expensive mechanism to realize those benefits, so identifying a suitable revenue stream to support the marketplace for AV and CV technology is a necessary precursor.

Conclusions

The strategies provided through this research offer considerations for state and local agencies using the best information available at the time. Technology direction may change, consumers may not adopt certain products, and any number of global economic or environmental drivers could alter the policy course. Even within such uncertainty, it is incumbent upon state and local agencies to use available policy and planning strategies to nudge private-sector choices regarding AVs and CVs toward outcomes that would benefit society, thus aligning public- and private-sector interests in the technologies. Ultimately, transportation planning and policy making for AVs and CVs will be informed through a cycle of learning and leveraging early-adopter agencies that support testing, evaluation, research, and continuous knowledge creation.

CHAPTER 1

Introduction

Vehicles that are increasingly automated and connected have the potential to transform the country's transportation paradigm by providing significant safety and efficiency benefits to many modes of travel, and they could have significant environmental and land use impacts. Just as passive safety systems (e.g., airbags and seat belts) and entertainment features (e.g., radios and in-vehicle displays) became ubiquitous and revolutionized travel in the mid- to late 20th century, automated vehicle (AV) and connected vehicle (CV) technologies are set to revolutionize travel in the early to mid-21st century. While these two technologies are undergoing rapid evolution and development, trends are arising such that the public can begin to understand how and when they will find their way into vehicles and onto public roads.

The benefits of AVs are potentially vast and include improved safety, mobility, environmental and land use considerations, productivity, and convenience. CV technology similarly has the potential to dramatically improve the safety and efficiency of travel for many drivers. AVs and CVs also may have drawbacks and pose risks. These technologies will solve some problems but could also create new ones. For example, cybersecurity vulnerabilities associated with CVs could compromise safety. Congestion could increase with the proliferation of AVs as driving becomes less onerous and individuals who previously did not drive have more opportunities for travel.

This research report presents and develops a rationale for policy and planning strategies at the state, regional, or local levels that, if implemented, could help nudge private-sector choices toward outcomes that would benefit society. *Why would these governments want to do this?* State, regional, and local governments seek to ensure the safe and efficient operation of public roadways and to foster equity across users of the system; overseeing AV and CV technologies is a natural extension of this longstanding mission. The policy and planning strategies were developed using the best information currently available. To place the research and its recommendations in context, a review of the current state of AV and CV technologies and regulatory activity is provided in this chapter.

State of the Technologies

AVs

For purposes of this work, an AV is one that takes full control of all aspects of the dynamic driving task for at least some of the time. This study focused on the role of higher level AVs in mitigating or exacerbating the societal effects of driving or in creating new effects. The higher levels of vehicle automation are designated Levels 3, 4, and 5, according to the SAE International (2014) taxonomy (see Table 1). Recently released federal policy guidance adopts the SAE International definitions to encourage consistency in describing automated functions.

This study, while focused on the higher levels of automation, recognized that many of the required components of the driving task that are performed by humans, however imperfectly, are hard to replicate using technology. Sensors may suffer from insufficient range or resolution, and from occlusions and blind spots, and may perform differently depending on the time of day (or night). Computers need to mimic human intuition, learn from mistakes, and understand situational context. This will include responding to atypical scenarios and conditions, including degraded (or absent) lane markings, inclement weather, temporary construction zones or work zones, emergency vehicles, and a host of other challenging situations. Despite these challenges, AV technology is diffusing through the vehicle fleet.

Level 1 automation technology is available in the form of adaptive cruise control systems. Tesla integrated and deployed its autopilot technology in its Model S via a software over-the-air update. This system combines automated steering/lane-keeping with an adaptive cruise control capability, as well as automated lane change (triggered by manually activating a turn signal). Tesla has billed the system as Level 2; however, there is some dispute as to whether it actually meets the definition of Level 3 because the system monitors some aspects of the driving environment. Google's initial prototype AVs qualified as Level 3 since the driver still needed to monitor the driving environment and take control in certain conditions.

Table 1. Levels of driving automation (SAE International 2014).

Level	Name	Description
Human driver monitors the driving environment		
0	No automation	The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems.
1	Driver assistance	The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver will perform all remaining aspects of the dynamic driving task.
2	Partial automation	The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver will perform all remaining aspects of the dynamic driving task.
Automated driving system monitors the driving environment		
3	Conditional automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene.
4	High automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene.
5	Full automation	The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver.

Several original equipment manufacturers (OEMs) have indicated that they failed to find the value in Level 3 automation compared to the cost to develop (Visnic 2016), and human factors studies have shown that the requirement to provide the human driver sufficient time to retake control is hard to achieve (or expect)(Merat et al. 2014). As such, many OEMs are now focusing their efforts on development of Level 4 automation technologies, with a few exceptions (Audi is reported to offer Level 3 capabilities on its A8 in 2018) (Blackburn 2016). Many of the OEMs and technology companies are actively testing their prototype vehicles on public roads, including Google in Mountain View, California, and Austin, Texas; Uber in Pittsburgh; and Nissan in Sunnyvale, California. There have been a number of safety incidents involving these prototype systems, although many have been caused by other human-driven vehicles. In February 2016, Google's AV was involved in a minor crash with a transit bus, the first in which the firm's AV was at fault (Davies 2016). Tesla has also garnered much attention after the first fatality occurring while its autopilot feature was engaged, although reports indicate that the driver had set the speed higher than the posted speed limit and that the driver may not have been monitoring the driving environment at the time of the crash (Shepardson 2016).

Many OEMs have made bold claims about when Level 4 technology will be available in new models, beginning with Volvo's claims of readiness in 2017 (albeit in a limited deployment) and Tesla's claims of readiness in 2018 (Volvo 2016; Korosec 2015). Others have followed suit, estimating readiness in the 2020–2021 time frame, including Nissan, BMW, Ford, and Toyota (which claims it will have Level 4 AVs available in time for the 2020 Tokyo Olympic Games). The time frame for bringing Level 5 automation technology to market is hard to project; however, several industry analysts estimate this technology will be available on public roads in the late 2020s (Cellan-Jones 2015; Ulanoff 2016).

CVs

CV technology generally refers to a combination of equipment (e.g., DSRC onboard units and roadside equipment) and V2V and V2I applications (e.g., forward collision warning, intersection collision avoidance, emergency vehicle alert, signal priority, etc.). Several manufacturers are actively developing and testing DSRC devices and CV applications, including Kapsch, Savari, Cohda Wireless, DENSO, and Arada Systems. Other companies are developing vehicle-to-everything (V2X) equipment that uses other forms of wireless communications, including cellular, Wi-Fi, and Bluetooth® (Qualcomm, Savari, etc.); however, USDOT and others are committed to DSRC being the primary mechanism for vehicle safety applications. General Motors was the first domestic OEM to commit to integrating DSRC-based V2X technology into its newer vehicles, initially planned for its 2017 Cadillac CTS model. Delphi will supply the V2X equipment, which was developed by Cohda and NXP (Yoshida 2014).

The federal government has played a significant role in supporting the research, development, and piloting of CV technology. The USDOT Connected Vehicle Safety Pilot Program sought to demonstrate that DSRC-based CV technology was ready for large-scale deployments. Executed in Ann Arbor, Michigan, this program equipped vehicles with vehicle awareness devices, aftermarket safety devices, and retrofit safety devices, and deployed DSRC infrastructure to assess the functional performance of V2V and V2I safety applications (Bezzina and Sayer 2015).

USDOT is also currently sponsoring three additional CV pilot deployments in New York, Florida, and Wyoming. The pilot program in New York provides an opportunity to study and evaluate the use of CV technology in a dense urban environment with significant pedestrian and cyclist traffic, in addition to vehicular traffic. The pilot will install in-vehicle equipment on up to 10,000 city and fleet vehicles to test V2V applications, such as intersection movement assist and forward collision warning, and will install roadside infrastructure in Manhattan and Brooklyn to test V2I applications, such as pedestrian in signalized intersection and red light violation warning (Galgano et al. 2016). The pilot program in Wyoming is focusing on applying CV technology along freight-intensive corridors that experience significant weather-related incidents and delays. DSRC onboard equipment will be installed in a combination of maintenance vehicles, emergency vehicles, and private trucks, and infrastructure will be installed along Interstate 80 to communicate road conditions, variable speed limit zones, and detour information (Gopalakrishna et al. 2015). The pilot program in Tampa will evaluate CV technology deployed in a suburban-to-urban corridor that includes managed lanes that experience significant congestion and delays while bringing thousands of vehicles to and from a dense urban center with high pedestrian traffic. V2V safety applications such as forward collision warning and intersection movement assist will be evaluated, as well as V2I applications such as curve speed warning and transit signal priority (Waggoner et al. 2016).

Significant research and standardization have gone into the development of CV technology, specifically related to DSRC. SAE and the Institute of Electrical and Electronics Engineers (IEEE) have been actively working on standards documents for DSRC (SAE J2735, IEEE 1609.2/3/4) and V2V performance (SAE J2945/1). The various DSRC manufacturers will be required to certify that their equipment conforms to these standards to ensure interoperability of vehicles from different OEMs using different hardware. USDOT has organized several CV "PlugFests" throughout the country where CV vendors were able to test their devices' performance, interoperability with other equipment, and conformance to aforementioned standards (Abuelhiga 2013).

Regulation, Legislation, and Standards

AVs

NHTSA (2016b) released the official Federal Automated Vehicle Policy in September 2016, issued "as guidance rather than in a rulemaking in order to speed the delivery of an initial regulatory framework and best practices to guide manufacturers and other entities in the safe design, development, testing, and deployment of HAVs." It focuses on HAVs (SAE Levels 3–5) and includes guidance for AV performance, a model for state policy, references to NHTSA's existing regulatory tools, and a discussion of potential new regulatory tools that could help the government facilitate the development of AVs. This policy applies to all organizations developing and testing AVs, including OEMs, suppliers, technology firms, and other research and development organizations. The guidance includes a 15-point safety assessment that encourages AV developers to give serious consideration to designing a robust system as it applies to things such as operating domains, minimum risk fallback conditions, data recording and sharing, post-crash behaviors, cybersecurity, and ethical considerations. The model state policy reaffirms that states retain their responsibilities for licensing and registering vehicles, defining and enforcing traffic laws, and regulating insurance and liability requirements and policies. The framework envisions that each state's AV-related policies and regulations will be administered by a single lead agency and associated technology committee, with stakeholder consultation included. This agency would be tasked with defining and coordinating processes for registering and licensing AVs and their test drivers, issuing test vehicle permits, handling applications for testing on public roadways, and involving jurisdictional law enforcement. The policy also outlines NHTSA's existing regulatory tools, which include interpretation letters, exemptions, rulemaking, and enforcement. It also outlines potential new tools and authorities that NHTSA could use, such as safety assurance, where manufacturers are required to provide pre-market testing data and results; post-sale regulation of software changes, where any changes to AV software after the sale are regulated; functional and system safety requirements, where the 15-point safety assessment is made mandatory; and enhanced data collection, which would require enhanced data recorders and reporting requirements.

As of June 2017, 18 states—Alabama, Arkansas, California, Colorado, Florida, Georgia, Louisiana, Michigan, New York, Nevada, North Dakota, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, and Vermont—and Washington, D.C., have passed legislation related to autonomous vehicles. Since 2012, at least 41 states and D.C. have considered legislation related to autonomous vehicles

(National Conference of State Legislatures 2016). Some of the adopted legislation relates primarily to terminology and taxonomy, such as a bill introduced in Louisiana. The adopted legislation in a number of states and districts including California, Nevada, and the District of Columbia authorizes operation and testing of AVs on public roads. In North Dakota and Florida, the legislation calls for studies and pilots of AV technology. Several enacted bills, including those in California and the District of Columbia, require a human driver to be sitting in the driver's seat while the AV is in operation. The Tennessee bill prohibits local governments from banning vehicles equipped with AV technology.

CVs

In 1999, the Federal Communications Commission (FCC) set aside 75 MHz of spectrum in the 5.9 GHz band for intelligent transportation system (ITS) vehicle safety and mobility applications, and it has been the basis of DSRC research and development ever since. While USDOT and seemingly much of the auto industry remain committed to the use of 5.9 GHz DSRC, technology and telecommunications companies have been recommending that the band be shared between DSRC and Wi-Fi enabled devices. Given the time frame since the original allotment was made and the tremendous advances and changes in technology, FCC recently issued a public notice that invited organizations to submit plans for testing equipment within the band and committed to completing that testing by early 2017 (Alleven 2016). This shift has caused concern among OEMs and others that altering the plan for 5.9 GHz DSRC could negate years of research and development and could delay a broad deployment of CV safety applications.

Even given this potential policy shift, USDOT has continued to move forward with its plans for CVs. In early 2014, NHTSA indicated its intention to move forward with the regulatory process regarding CV technology, specifically V2V communications capability. In August of that year, an advance notice of proposed rulemaking (ANPRM) initiated that process, which proposed creating a new Federal Motor Vehicle Safety Standard that would require all light-duty vehicles to be equipped with V2V communication capability (NHTSA 2014). This notice followed a significant amount of research funded by USDOT to study the feasibility of using this technology to improve safety for many drivers (Harding et al. 2014). NHTSA developed a notice of proposed rulemaking (NPRM) based on comments and a readiness report of the ANPRM and issued it in December 2016. While this proposed rulemaking signals a positive step toward CV technology beginning to be present on public roads, it does not include any requirements on specific safety or mobility applications that must be running on the equipment. Additionally, CV infrastructure falls outside the scope of the proposed rulemaking, meaning CVs will only be able to take advantage of V2I safety and mobility applications if a state or local government or transportation organization has made the commitment to invest and deploy roadside equipment and applications.

Relevant Stakeholders

This research analyzed potential policy and planning strategies that could be used to encourage public- and private-sector interests in advancing the technologies. The private-sector actors that were the focus of this research are producers and consumers of AV and CV technologies:

- Producers include automobile manufacturers, technology firms, and Tier 1 suppliers (i.e., Tier 1 companies are direct suppliers of parts to automobile manufacturers). USDOT and university research institutions are also producers of CV technology but not relevant actors for this research because of the focus on private-sector actors.
- Consumers include private individuals and private-sector fleet owner/operators.

In addition, the research was concerned with the state and local transportation agency perspective in two ways:

- Determining the impacts that AVs and CVs might have on these agencies.
- Identifying actions that state and local agencies could take to realize societal benefits of the technologies.

Per the latter bullet, the study identified 18 policy and planning strategies for consideration by state and local agencies.

Report Organization

Following this introduction, the report is organized into the following sections:

- **Chapter 2:** Examines potential impacts of AVs and CVs and describes outcomes most beneficial for society.
- **Chapter 3:** Summarizes the role of state and local policy and planning in nudging the private sector to make choices to benefit society.
- **Chapter 4:** Describes and assesses each of the 18 policy and planning strategies (associated assessment tables are provided in the appendix).
- **Chapter 5:** Provides conclusions and recommendations from the research.

CHAPTER 2

Realizing Societal Benefits of AVs and CVs

This chapter summarizes the potential impacts of CVs and AVs in five areas in which there are major transportation externalities: safety, congestion, pollution, land development, and mobility. Resource papers covering each area can be found in the interim report for this research, which is available on the website of the Transportation Research Board. This chapter also describes the outcomes that would be most beneficial for society, examines the roles of the primary private-sector actors, and discusses why the actions of the private sector alone may not be enough to realize those outcomes.

Potential Impacts of AVs and CVs

Safety

In 2015, there were 35,092 people killed in motor vehicle crashes in the United States, and an additional 2.44 million were injured (NHTSA 2016d). While fatalities have decreased in the long run—25 percent from 2005 to 2014—the past year has shown a marked increase. The 7.2 percent increase from 32,744 fatalities in 2014 represents the largest increase in over 50 years. This is partly because Americans drove more and partly because they drove more poorly.

Drivers, vehicles, and environmental conditions can all cause crashes, but human errors are a critical cause of more than 90 percent of them (NHTSA 2016a). "Critical cause" is defined as the immediate reason for the pre-crash event as collected in NHTSA's National Motor Vehicle Crash Causation Survey, conducted from 2005 to 2007. CV and AV technology have the potential to significantly reduce human error. Safety warnings provided by V2V and V2I technology enable drivers to take actions that could reduce the severity of collisions or avoid them. AVs can avoid many of the common perception, decision, and execution mistakes that humans make, and AVs do not suffer from fatigue or cognitive impairment.

However, AVs and CVs may also introduce new safety risks. AVs may potentially be safer than human drivers, but flawed hardware or software could cause accidents, including those caused by the types of errors that humans would not make. AVs and CVs could create cybersecurity risks, which could lead to serious crashes if the vehicles are hacked. Level 3 AVs also introduce risks posed by inattentive drivers being unable to jump in and take safe control of the vehicle when requested. Overall, there is enormous room for improvement over human drivers' performance, and early research suggests that these technologies have promise, but the safety benefits of AVs and CVs are not guaranteed.

Congestion

Congestion occurs both regularly (i.e., recurring) and sporadically (i.e., non-recurring) due to accidents, construction, weather, and so forth. It has enormous societal costs. Travel delays due to traffic congestion caused drivers to waste more than 3 billion gallons of fuel and kept travelers stuck in their cars for nearly 7 billion extra hours—42 hours per rush-hour commuter (Schrank et al. 2015). The total cost to the United States was $960 per commuter, or $160 billion for the nation as a whole.

CV safety applications could mitigate non-recurring congestion events by reducing delays caused by safety incidents through informing CVs of the delay, thus enabling them to choose a different route. CV mobility applications could positively impact recurring congestion by increasing system efficiency and enabling CV-facilitated platoons. These impacts would be maximized if there were widespread adoption of V2V capabilities, widespread V2I infrastructure, and interoperability among mobility applications.

AVs that are safer than human drivers would enable the reduction of crash-related delays. AVs that operate with more precision and control than human drivers could eventually enable infrastructure operators to redesign aspects of their facilities to accommodate more traffic (e.g., narrower lanes and shorter headways), thereby increasing supply.

Simultaneously, AVs and CVs are likely to decrease the cost of driving, and are thus expected to induce additional demand for driving and increase VMT (Anderson et al. 2014). SAE Level 4/5 AVs could also increase travel demand by enabling individuals who were previously unable to drive to do so (Smith 2012). Additionally, with fully automated (SAE Level 4/5) vehicles, the opportunity costs of a motorist's time could be completely removed through the motorist not even being present in the vehicle. This could enable many different services and opportunities for motorists, which would also likely increase demand for vehicular travel. As with any disruptive technology, the net effects of its complex forces cannot be predicted.

Pollution

Automobiles emit local air pollutants (e.g., particulate matter, hydrocarbons, nitrogen oxides, and carbon monoxide) and global air pollutants (greenhouse gases) when they combust fuels, primarily fossil fuels. This pollution poses an enormous environmental and public health cost, both locally and globally in the case of greenhouse gases.

The total emission in the road transportation segment can be described across four primary categories (Transportation Research Board 2000). CVs and AVs could have an effect in each category. The following list highlights some but not all the complex potential effects.

1. **Travel-related factors.** The effect of AVs and CVs on travel demand (whether an increase or a decrease due to the factors as described in the congestion discussion) would have corresponding effects on pollution, to the extent that vehicles continue to burn fossil fuels.
2. **Vehicle-related factors.** To the extent that CVs and AVs are safer, and AVs are shared among multiple users, there could be reductions in vehicle production rates and reduced parking needs. The use of right-sized vehicles (i.e., vehicles that have capacity equivalent to the number of passengers or goods) could also reduce emissions. On the other hand, passengers may prefer larger AVs to allow them to take better advantage of the opportunity to do things other than driving, resulting in lower fuel economy and greater emissions. AV and CV capabilities could also lead to an increase in electric, hydrogen, or other renewable/low-emission vehicles because vehicles would be lighter and could potentially drive themselves to refueling areas.
3. **Driver behavior.** AVs could encourage or enable eco-driving, increasing fuel economy of vehicles. Shared AVs (SAVs) may encourage higher vehicle occupancies, but AVs may also reduce vehicle occupancies with the ability to have zero-occupancy vehicles.
4. **Highway-related factors.** Increased effective capacity enabled through CV and AV capabilities may result in less need for new capacity projects and lower construction-related emissions.

Land Development

Automobile use has influenced the form and extent of land development in the United States, leading in large part to sprawl (i.e., low-density, inefficient land use patterns; Burchell et al. 2002). The land allocated to automobile infrastructure poses a cost to society: it could otherwise be used for farms, open space, homes, businesses, and other facilities, with associated environmental, economic, and public health effects (Delucchi and Murphy 2008).

Factors that have influenced land development patterns in the United States can be divided into two categories—market forces and public policy decisions. In terms of market forces, CVs/AVs could increase safety and convenience of vehicle travel, lowering transportation costs and thus increasing people's willingness to travel farther and adding to sprawl. On the other hand, if the technology is incorporated into transit vehicles and shared vehicles, the effect would be the opposite—decreasing vehicle ownership and use in favor of transit and shared mobility. The result could be growth in higher-density areas.

As another effect, Level 5 AVs could reduce the need for parking adjacent to destinations, which is currently mandated through parking minimums for new developments. If this were the case, then parking requirements may be altered or eliminated, and parking in urban areas could be reused for other land uses that more directly benefit society.

Mobility

Access to transportation is essential for a high quality of life for nearly all Americans yet is often a significant challenge for aging adults, youth under age 16, and individuals with disabilities. Many live in car-dependent areas but do not drive, and transit alternatives may be geographically inconvenient or inaccessible.

AVs represent an opportunity to reduce this negative externality. By leveraging the existing infrastructure that favors motor vehicles, fully automated vehicles (Level 4/5) may offer significant—potentially transformative—improvements in mobility for aging adults, youths, and individuals with disabilities. This is particularly true for those who live in areas with limited alternative modes. The benefits of less-than-full automation and CVs are unclear and probably fewer because of the demands on the human driver behind the wheel, but this limitation may depend on the specific disability.

Positive Societal Outcomes

There are several potential ways in which the private sector could create desirable outcomes for society. The first is safety. If safe AVs and CVs were developed and used wisely and responsibly, the current public health crisis in the U.S. trans-

Table 2. Private-sector actions enabling positive outcomes of CVs.

Actions of Producers and Consumers	Externalities				
	Crashes	Congestion	Land Development	Air and Noise Pollution	Mobility
Producers develop and sell interoperable V2V or V2I mobility applications		X		X	
Producers develop and sell interoperable V2V or V2I environment applications				X	
Consumers purchase vehicles with V2V/V2I capabilities	X	X		X	
Consumers purchase and use aftermarket V2V safety applications	X	X		X	
Consumers are attentive to V2V and V2I safety warnings in vehicles	X	X		X	
Consumers use V2V/V2I mobility applications		X		X	
Consumers are attentive to V2V and V2I mobility messages in vehicles		X		X	
Consumers use V2V/V2I environment applications				X	
Consumers are attentive to V2V and V2I environmental messages in vehicles				X	

Note: X indicates a reduction of a negative externality.

portation system could be reduced, if not mitigated. This outcome may take many decades, given rates of vehicle turnover, but the long-term impact could be significant. The second relates to mobility. If safe and usable Level 5 AVs were developed, mobility could be increased for millions of Americans who currently have limited mobility. A third relates to pollution and congestion. If the potential increase in VMT created by AVs and CVs were mitigated, or if VMT were decoupled from fossil fuels, there could be enormous environmental and public health benefits. Similarly, if SAVs were widely available and widely used, congestion, pollution, and land use benefits could occur. The fourth relates to liability issues. Uncertainty over the magnitude of the liability risks may deter and delay introduction of these technologies, which have the potential to greatly benefit society.

A review across externalities shows common actions in which the private sector (i.e., consumers or producers of AVs and CVs) should engage to enable these positive societal outcomes. For CVs, producers need to implement effective safety, mobility, and environmental applications (through evaluation and testing), and consumers need to use them widely and appropriately. The analysis assumes that V2V safety applications will be implemented through federal mandate, so this implementation is not one of the enabling actions. Such actions will benefit crash, congestion, and pollution externalities. However, there is little evidence from the literature that CV applications will affect land development or mobility externalities.

For AVs, producers need to develop and sell AVs that are safe and efficient. They also need to act upon communications with road operators to ensure that the infrastructure (e.g., lane striping) is in place to support safe and efficient operation or to enable the changes and maintenance necessary to ensure operation. To maximize social welfare, consumers need to purchase safe AVs and use them appropriately but not increase their appetite for travel (more trips, more VMT, and more sprawl) or vehicle size (larger vehicles). SAVs in particular could offer many of the benefits of AVs while not increasing travel. If, in addition, vehicles are coordinated with transit to solve last-mile connectivity, they could increase the use of transit.

These enabling actions are listed in Table 2 for CVs and in Table 3 for AVs. However, not all enabling actions lead to positive outcomes. Some conflicts exist. In particular, the increased mobility for aging adults and individuals with disabilities may increase VMT, leading to more congestion and pollution.

Aligning Public- and Private-Sector Interests

Producers and consumers of AVs and CVs are the primary private-sector actors whose market decisions will determine whether and how AVs and CVs benefit society. Producers include automobile manufacturers (e.g., Ford, Toyota); technology firms (e.g., Google, Apple); and Tier 1 suppliers (e.g., Delphi, Bosch).[1] Consumers include private individuals

[1] USDOT and university research institutions are also producers of CV technology but not private-sector actors.

Table 3. Private-sector actions enabling positive outcomes of AVs.

Actions of Producers and Consumers	Externalities				
	Crashes	Congestion	Land Develop-ment	Air and Noise Pollution	Mobility
Producer Actions					
Producers develop and sell safe AVs	X	X		X	
Producers of AVs act upon communications with road operators about infrastructure/maintenance necessary to ensure safe operations and system efficiency (across different use cases/operating conditions)	X	X		X	
Producers develop and sell connected AVs that harmonize traffic flow		X		X	
Private, shared-vehicle services purchase and operate SAVs		X		X	
Private, shared-vehicle services prioritize ride-sharing and linkages with line-haul mass transit		X	X	X	
Developers build fewer parking facilities or build parking facilities that can be adapted to other purposes			X	X	
Producers develop and sell AVs that are lower polluting				X	
Producers develop and sell AVs with eco-driving operating objectives				X	
Producers develop and sell Level 4/5 AVs that are usable by aging adults and individuals with disabilities		X(-)		X(-)	X
Consumer Actions					
Consumers purchase safe AVs	X	X		X	
Consumers follow safe AV maintenance and operating procedures	X	X		X	
Consumers purchase connected AVs that harmonize traffic flow		X		X	
Consumers of AVs minimize VMT growth, though the technology decreases travel cost and enables mobility among some who cannot otherwise drive		X		X	
Consumers of AVs do not drive farther for housing, even though the technology decreases travel cost		X	X	X	
Consumers use SAVs rather than privately owned AVs to minimize VMT growth		X	X	X	
Consumers use Level 5 vehicles to avoid parking in urban centers		X(-)	X	X(-)	
Consumers purchase AVs that are lower polluting				X	
Consumers purchase AVs with eco-driving operating objectives				X	
Aging adults and individuals with disabilities (consumers) purchase Level 4/5 AVs		X(-)		X(-)	X
Aging adults, youth, and individuals with disabilities (consumers) use Level 4/5 SAVs		X(-)		X(-)	X

Note: The term AVs in this table refers to Levels 3–5. When a specific level of automation is the subject of the action, it is labeled accordingly (e.g., Level 5). X indicates a reduction of a negative externality. X(-) indicates an increase of a negative externality.

and private-sector fleet owner/operators who would buy and use AVs and CVs. Their choices about what technologies to develop, when to deploy them, and how to use them could lead to (or fail to lead to) beneficial mechanisms and outcomes.

However beneficial, the desired outcomes may not actually be realized because many of them accrue to society rather than to either the producers or consumers of AV and CV technology. Consumers may be unwilling to pay for expensive technology if most of the benefits go to others, and consequently, producers may be less willing to develop them. Thus, there is less incentive for producers and consumers to take actions that would achieve beneficial outcomes.

Congestion offers a useful illustration of this phenomenon. Each driver that takes to a busy road not only experiences congestion but also adds to the congestion of his or her fellow travelers. While drivers bear their own congestion costs (their own time spent in traffic, added fuel use, etc.), they do not bear the costs they impose on other drivers. This means that drivers have only some incentive to reduce congestion, even though it would be enormously beneficial to society. Much of the cost of congestion (and the benefit of reducing it) is *external* to each driver's decision making. This leads to a suboptimal level of congestion for society, and society is worse off than it would be if the drivers bore the full cost of adding to congestion or received the full benefits of reducing it.

This is an example of an *externality.* An externality is an effect that one party imposes on another party without compensating for the effect if it is negative or charging for it if it is positive (Buchanan and Stubblebine 1962). The free market allocates resources inefficiently and produces suboptimal outcomes in the presence of externalities (i.e., when the costs faced by individual actors do not include the costs of their actions upon fellow citizens).[2]

Externalities have important implications for realizing the benefits of AVs and CVs. Suppose, for example, that AVs were more efficient than traditional vehicles—reducing the sharp acceleration and braking that contributes to congestion and perhaps decreasing the required safe following distance between vehicles (due to faster and/or coordinated reaction time among AVs through connectivity). Users of such AVs would increase roadway efficiency and reduce congestion not only for themselves, but for all other road users (all other things being equal). This would have positive effects on public health, the economy, and the environment. However, if the costs of congestion (or the benefits of reducing it) remain external, the market for efficient AVs would be weaker. There would be less of an incentive to produce and consume efficient AVs, even though this would be better for society.

This effect is not limited to congestion. All of the five areas of AV and CV impact (safety, congestion, pollution, land use, and mobility) involve existing driving externalities that could result in suboptimal social welfare because the producers or consumers of the AVs and CVs might not consider the full social costs and benefits when making choices.

Externalities are one reason governments interfere in markets. Social welfare can be increased if externalities are internalized so that the costs faced by individual actors represent the social costs of their actions (including the externalities). This can be done with subsidies, user fees, mandates, and privileges to equalize the public and private benefits. As one example, carpooling reduces congestion, but the costs and inconvenience of doing so accrue to the driver, while the benefits of carpooling (reduced congestion) typically accrue to other travelers. There is little incentive for anyone to carpool. High-occupancy vehicle (HOV) lanes attempt to change that. They internalize the positive externalities of reducing congestion by enabling carpoolers to themselves bypass congestion and get to their destinations faster. Social welfare can also be improved if the negative externalities are reduced, even if the externalities are not necessarily internalized in market decisions.

[2] Even if individual actors do not pay for the costs they impose on others, those costs still exist and are real, but are borne by society at large.

CHAPTER 3

Role of State and Local Policy and Planning

This chapter examines why and how state and local transportation agencies can intervene in the market to nudge private-sector choices in ways that would benefit society. Simultaneously, it describes the potential of AV and CV technologies to disrupt the traditional activities of state and local transportation agencies, making such interventions difficult.

Policy and Planning to Mitigate Impacts

The role of state and local transportation agencies is to develop, maintain, manage, and improve the transportation system in a way that enables individual mobility, supports economic activity, and improves quality of life. As government entities, these agencies aim to serve a broad public interest and provide services that might not otherwise be provided in the market. In many cases, public agencies further achieve these goals by providing services for vulnerable and disenfranchised populations and planning for the future. In order to continue to meet these expectations, state and local transportation agencies must strive to understand the impacts of AV/CV technology. Planning and policy decisions should be made to maximize the positive effects and minimize the negative effects on society.

Conventionally, public agencies intervene in market activities when there are goods or services that may not be efficiently or equitably provided by the market. Private actions that generate externalities are a classic example of a situation in which government intervention in markets is warranted. Pollution, for example, may be created by the otherwise-desirable operation of a steel-producing company. The consequences of that pollution are imposed on individuals living near the factory in the form of higher medical expenses, poorer quality of life, reduced property values, and so forth. A government agency may be justified in imposing a regulation that charges the company in proportion to the negative consequences. Society would benefit from the internalization of these externalities into private-sector decision making. Intervention into market activities can also be designed to maximize the benefits of activities that might otherwise be under-provided in markets. Education is an example of a positive externality because the long-term benefits of investing in education are not always internalized by individuals or the organizations that would receive those benefits.

Public agencies, unlike private companies, are expected to consider the range of societal goals (equity, economic, safety, security, quality of life) in their decisions. One challenge lies in the fact that public and private interests do not always align. Public agencies are expected to consider the interests of individuals and organizations with the understanding that individual interests and the common good do not always align perfectly. The deployment of AV/CV technologies in the market will have effects on producers and consumers in the market, on public agencies themselves, and on third parties who are not involved in the market of buying and selling AVs and CVs. It is the role of a public agency to consider the interests of all these groups, and, in cases where those interests do not align, intervene in the market to maximize potential benefits and minimize negative consequences.

Mechanisms to Align Public- and Private-Sector Interests

The mechanisms by which public agencies typically achieve their broad goals include economic, regulatory, and planning instruments. Strategies from all categories can internalize externalities; the main distinction lies in how these tools accomplish their goal.

Economic Instruments

Economic instruments are tools that "provide an explicit price signal to regulated firms and individuals" (Hepburn 2006). With these tools, governing bodies are able to affect an externality in two ways:

- Directly, by changing the price or by imposing a tax or providing a subsidy.
- Indirectly, by imposing controls on the quantity of a good that is produced or sold—most often through a cap-and-trade-style system.

Either of these economic instrument types provides an incentive to market participants to, ideally, change their behaviors that negatively affect society (van Essen et al. 2012).

The literature identifies two circumstances where economic instruments are most useful (Hepburn 2006). The first occurs when the appropriate policy response varies between different firms or actors. In other words, if a market has a wide variety of different actor types to be influenced, the appropriate response for all these different actors may vary. An economic signal affecting price or quantity will, however, send a uniform signal that will influence all actors in the market, despite their differences.

The second circumstance under which economic signals are most useful occurs when the regulator has imperfect information about the cost structure of firms or entities to be regulated (Hepburn 2006). In other words, if the governing entity has very good information about the costs of producing a good, a regulator might be able to put specific regulations on the industry to address the issue without imposing undue burden or cost. Without good information, however, the governing body would be unable to craft such targeted regulations and would be better off sending a clearer signal affecting price or quantity with an economic policy instrument.

Regulatory Instruments

Regulatory instruments, also known as command-and-control instruments, require "firms or individuals to comply with specific standards, such as technology or performance standards" (Hepburn 2006). With these tools, governing bodies can affect behaviors or processes related to externalities by establishing or changing regulations directly, rather than relying on price signals to encourage actors to make socially optimal choices.

Regulatory instruments can take a variety of forms. For example, a requirement that all vehicles have safety equipment (e.g., seat belts) and a requirement that motorists use the safety equipment are regulatory instruments. The literature notes a few criteria to help identify when regulatory instruments are useful (Hepburn 2006):

- The regulator has good information.
- The risk of government failure is low.
- The objective is best achieved by imposing similar requirements on different firms and individuals.

Good information implies that the regulator has sufficient knowledge about the industry to determine the optimal level of the regulated good. For example, the United States has determined that certain particulates and pollutants, such as lead, are unacceptable at any level. In this case, a regulator can determine that the socially optimal level of lead in gasoline is zero; the optimal policy would be an outright ban. The risk of government failure is an important consideration since a regulation is only binding if it can be enforced. The government already regulates petroleum production, processing, and sale, so removing lead as a gasoline additive—for example—would be relatively easy and unlikely to fail. The final criterion implies that, despite differences in the actors and firms in the market, the same standard or requirement will be effective. To continue with the example, despite the variety of actors in the market (e.g., manufacturers, distributors, and users), banning lead additives would be both appropriate and effective.

Structure of Private Rights

Agencies may, if they have the authority, restructure civil and criminal liabilities in order to shift risk and alter producer and/or consumer behavior. One method for addressing the issue of risk associated with driving is requiring vehicular liability insurance by drivers. At the time of publication, the states of Nevada, Florida, Michigan, and California have specific insurance requirements for the testing of AV systems. The current structure of the insurance market may be changed significantly if AVs and CVs do, in fact, reduce vehicular crashes. Researchers have posited that liability for vehicular incidents may ultimately shift from the driver to the auto manufacturer (Douma and Fatehi 2016).

Service Provision

By providing or investing in particular services, an agency can change how it provides its current range of transportation services. For example, an agency in charge of operating a managed lane facility might adjust eligibility rules for free access in order to encourage use by certain user classes. Or, an agency might make changes in transit operations to accommodate new user groups. In some cases, it may be that a private-sector market for a good or service does not exist or cannot exist absent government intervention.

Financing and Contracting

In some cases, it may be that a private-sector market for a good or service does not exist or cannot exist absent government intervention. In these cases, a transportation agency may establish the market itself or work in partnership with the private sector to establish the necessary environment for the market to flourish. State and local agencies are also generally free to enter into an array of public-private partnerships in order to provide enhanced transportation services. States may need to pass enabling legislation to facilitate these partnerships.

Information and Outreach

Public involvement and education are used to inform the planning process. This step is also a planning activity that can have a direct influence on the behavior of consumers and producers in the market. Transportation agencies may, through any number of mediums and strategies, provide information to consumers as a means of encouraging desired behavior. For example, to encourage consumers to purchase CVs with safety, mobility, or environmental applications, transportation agencies can report and communicate the various benefits that have been identified through analysis and evaluation. Agencies may also coordinate with departments of transportation, metropolitan planning organizations, other rural and regional planning organizations, transit agencies, and other stakeholders. For example, agencies can report information about AV/CV system performance and the effectiveness of plans and programs. They can also coordinate and form partnerships with the private sector to speed commercialization of CV technologies. In general, as AV and CV technology is developed and deployed, new information should be relayed to the public to expand its understanding of the technologies.

Potential Public-Sector Impacts

Adopting mechanisms to align public- and private-sector interests in AVs and CVs will be complicated by the potential of these technologies to also disrupt the traditional activities of state and local transportation agencies. Such disruption has happened before. The rapid development and future deployment of AV/CV technologies in the U.S. market has the potential to produce positive and negative effects on society. These changes will likely affect the way that transportation agencies function as well. The central issues that transportation agencies typically address—safety, mobility, congestion, and land use—may be transformed by the introduction of AV/CV technologies, although exactly how is still uncertain. As these developments unfold, transportation agencies will need to prepare for changes in their own activities and in how they serve the public interest through the provision of transportation infrastructure.

New innovations, like AV and CV technologies, can disrupt an industry by improving on existing technologies and expanding rapidly in a market, often in unexpected ways. In the transportation realm, the introduction of global positioning systems that automate the manual process of mapping transportation assets, along with the proliferation of mobile devices, changed the way that individual travelers find routes and traffic information. Traditional skills—such as surveying—and traveler information systems—such as radio reports—once central to the activities undertaken by transportation agencies are being replaced by these new technologies. The deployment of AV/CV technologies has the potential for even greater upheaval. The research team summarized the potential impacts to transportation agencies in three categories: institutional, operational, and funding/financing aspects.

Institutional Impacts

Institutional impacts affect a transportation agency's focus, areas of authority, and/or organizational structure. This includes how an agency prioritizes its responsibilities and chooses to allocate its funding. Proliferation of AVs and CVs could increase transportation agencies' focus on non-safety goals; increase responsibility for data integrity, security, privacy, and analytics; and increase reliance on outsourcing to the private sector for functions better suited to it.

Operational Impacts

These are impacts on how an agency develops, maintains, operates, and manages transportation infrastructure and transportation-related services. Proliferation of AV and CV technologies could cause existing ITS investments to become outdated, reduce or shift demand for transit and parking services, or increase maintenance requirements. It is uncertain whether the technologies will mitigate or exacerbate current deficits in available roadway capacity.

Funding and Financing Impacts

These are impacts to the funding and financing sources available for transportation infrastructure and related services. AV and CV systems could exacerbate funding deficits through increased costs for maintaining and operating roadways. A proliferation of shared AVs (SAVs) could reduce the amount of revenue from driver licensing, vehicle sales tax, vehicle registration, moving violations, transit fares, and federal funding associated with ridership levels. CV technology could potentially increase revenue from road user charges by providing a platform that supports usage-based revenue measurement and reporting.

Table 4 summarizes potential impacts of AVs and CVs on transportation agencies. While presented independently, all three of these families of impacts are related. Funding and financing impacts may shift how a transportation agency prioritizes its activities at the *institutional* level, which in turn impacts how assets are deployed and managed at the *operational* level.

It is critical that policy strategies at the state and local levels are mindful of these potential impacts to transportation agencies. Agencies may have to adjust their institutional, operational, and financial frameworks.

Table 4. Impacts on transportation agencies.

Potential AV/CV Outcome	Transportation Agency Impacts
Institutional Impacts	
AV and CV systems could reduce crashes and increase overall safety	Increase focus on non-safety goals, such as maintenance and preservation, systems management and operations, and data management
Commercial and transit AV fleets could reduce reliance on professional drivers, which increases safety by reducing vehicle incidents	
AV and CV systems could raise road users' expectations for ITS-related services for which transportation agencies lack institutional expertise	Increase reliance on contracting, new relationships with the private sector
AV and CV systems could require physical infrastructure assets, data management, and ITS services for which agencies lack funding	Increase reliance on private-sector investment models
AVs could require changes in basic road design and geometry in the long run to accommodate safe and efficient operations	Change roadway construction practices
AV and CV systems could increase reliance on data-intensive services and applications	Increase responsibility for data integrity, security, privacy, and analytics
AV and CV systems could provide added value to existing operations and maintenance, particularly safety benefits in transit operations	Change maintenance/operations practices
CV applications could provide asset health information	Improve operational awareness
Operational Impacts	
Technology assets could become obsolete with rapidly changing technology	Outdate ITS investments
SAVs could increase average vehicle occupancy and usage, improving system management and reducing congestion without the need for traditional ITS	
Various communications technologies used in CV and AV applications could provide ITS-type traveler information to drivers within the vehicle itself	
AVs or SAVs could reduce demand for transit and other non-passenger vehicle modes, including traditional paratransit	Reduce emphasis and stimulate loss of value in transit investments
SAVs or usage of Level 5 AVs could reduce need for urban parking	Reduce emphasis and stimulate loss of value in parking investments
AV systems could increase need for visible lane striping, more visible signs, and removal of roadway obstructions	Increase maintenance requirements
Commercial AV fleets could increase volumes (by lowering shipping costs), thereby increasing wear and tear on the system	
AV systems could increase the development of low-density suburban development by lowering the cost of commuting, thereby increasing the infrastructure network to be maintained	
CV systems could facilitate the more efficient movement of vehicles through congested intersections	Mitigate capacity issues associated with recurring and non-recurring congestion
AV and CV systems could provide enhanced transportation system asset awareness by transportation agencies	
AV and CV systems could allow transportation agencies to better use existing capacity through various ITS management and operations practices	
CV systems could provide travelers with dynamic, real-time information on construction projects that impact mobility	
AV and CV systems could provide drivers with information on impending bad weather and weather-related road conditions	
AV systems could lower the cost of driving, thus increasing VMT	Exacerbate capacity deficit
AV applications could require additional headway relative to human drivers, thus reducing available capacity	

(continued on next page)

Table 4. (Continued).

Potential AV/CV Outcome	Transportation Agency Impacts
Funding Impacts	
AV and CV applications could increase passenger and commercial VMT, increasing the costs associated with maintaining and operating roadways	Exacerbate funding issues
AV and CV systems could increase need for visible lane striping, more visible signs, removal of roadway obstructions, physical infrastructure to support CV applications, and detailed infrastructure-related data to support CV applications	
SAVs could reduce the amount of revenue derived from vehicle registration fees	Reduce vehicle registration, sales tax, or licensing revenue
SAVs could bring about a decline in vehicle ownership and then a decline in vehicle production (and associated decline in vehicle sales)	
SAVs could result in fewer professional drivers and traditional taxi services, thus bringing about a decline in revenues from sources such as commercial driver's licenses and taxi medallions	
AVs could be deployed with electric-motor-based technologies	Reduce fuel tax revenue
AV and CV systems could increase VMT and include technology for usage-based revenue measurement	Increase revenue from mileage-based usage
AV and CV systems could reduce driver error	Reduce revenues from moving violations
AVs or SAVs could reduce mass transit utilization	Reduce transit fares and federal funding associated with ridership levels

CHAPTER 4

Policy and Planning Strategies

This chapter identifies and presents assessments of 18 policy and planning strategies that states or localities could implement that would incentivize the development of AVs and CVs in ways that maximize benefits to society by influencing private-sector decisions. Many different policy and planning strategies were reviewed and analyzed to identify the ones presented here. Of the many potential strategies, two questions were used to narrow the possibilities to these 18.

1. Which policy, regulatory, and planning instruments fall within the general purview of state, regional, and local governments?
2. Which policy, regulatory, and planning instruments have the greatest near-term applicability?

About half of the 18 strategies are economic and half are regulatory or planning strategies. Because the study was focused on strategies to align public- and private-sector interests, the strategies were categorized by their intended outcomes, which include the following:

- To mitigate safety risks through testing, training, and public education.
- To encourage SAV use.
- To address liability issues that may impact market development.
- To enhance safety, congestion, and air quality benefits by influencing market demand.

An assessment of each policy strategy was prepared to determine the potential viability to address the consequences of AV/CV deployment. The range of criteria that were used included:

- Effectiveness and efficiency in achieving the desired outcome.

Strategies by Desired Societal Outcome

Outcome: To mitigate safety risks through testing, training, and public education

1. Enact legislation to legalize AV testing.
2. Enact legislation to stimulate AV or CV testing.
3. Modify driver training standards and curricula.
4. Increase public awareness of benefits and risks.

Outcome: To encourage SAV use

5. Subsidize SAV use.
6. Implement transit benefits for SAVs.
7. Implement a parking cash-out strategy.
8. Implement location-efficient mortgages.
9. Implement land use policies and parking requirements.
10. Apply road use pricing.

Outcome: To address liability issues that may impact market development

11. Implement a no-fault insurance approach.
12. Require motorists to carry more insurance.

Outcome: To enhance safety, congestion, and air quality benefits by influencing market demand

13. Subsidize CVs.
14. Invest in CV infrastructure.
15. Grant AVs and CVs priority access to dedicated lanes.
16. Grant signal priority to CVs.
17. Grant parking access to AVs and CVs.
18. Implement new contractual mechanisms with private-sector providers.

- Political acceptability (e.g., stakeholder, equity, and political considerations, including winners and losers, disruptive or incremental change, and unintended consequences).
- Operational feasibility (e.g., implementation considerations, including legal barriers, technological development, and funding challenges).
- Geographic impact in urban, suburban, or rural areas.
- The implementing entity ("who").
- Key hurdles to strategy implementation.

The presentation of and rationale for the assessment scores given to each strategy are presented in the appendix.

Enact Legislation to Legalize AV Testing

Strategy Overview

The strategy aims to accelerate the development, adoption, and implementation of AVs and CVs by enacting legislation to establish the legality of AV testing.

General Description

The strategy of a state enacting legislation to legalize AV testing aims to accelerate the development, adoption, and implementation of AVs. States or local governments could implement a version of the model state policy recently released by the USDOT to avoid any concerns about interstate inconsistencies in regulating AVs. Recently NHTSA has stated its intent to update the policy.

Advancing these technologies could provide societal benefits by reducing the frequency and severity of crashes, improving traffic flow, and reducing pollution and inefficient land use. Specific desired private-sector behavior that the strategy would influence (Tables 2 and 3 in Chapter 2) include the following:

- Producers develop and sell safe AVs.

The process of accomplishing this strategy would require a state legislature gathering enough votes to enact a law legalizing AV testing, and the governor of the state would have to sign the law. Ideally, testing these vehicles would create conditions favorable to implementing the technologies—like fostering institutional knowledge and experience, and gauging public and political support—which would in turn increase the likelihood that these systems would be implemented.

As of June 2017, 18 states—Alabama, Arkansas, California, Colorado, Florida, Georgia, Louisiana, Michigan, New York, Nevada, North Dakota, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, and Vermont—and Washington, D.C., have passed legislation related to autonomous vehicles. The policies in these states vary dramatically, with some simply choosing to pronounce the legality of AVs, while others have taken a more in-depth approach and created regulations on testing and/or operation.

The AV industry often raises concerns about the challenges of developing vehicles capable of complying with the patchwork of regulations (Wagner 2015) that would arise should many states enact different regulations governing AVs. As a result, the potential policy approaches to legalizing AV testing discussed herein intentionally avoid any measures that would require a state to regulate AVs. As an alternative, states could adopt a legislative and regulatory path consistent with NHTSA's (2016b) recent model policy guidance on regulating the testing and operation of HAVs. NHTSA's proposed model legislation was developed and released partially as a result of the concerns about state legislation and regulations governing AVs. If states wish to pass laws regulating AV testing and operation, following NHTSA's model could help to reduce the inconsistency across state policies, which could in turn mitigate industry fears of regulations.

To legalize testing, a state could pronounce the legalization of AVs, or otherwise explicitly allow testing on public roads. While authorizing legislation is ultimately unnecessary for legal operation of AVs (Smith 2012), legislation provides a powerful bully pulpit, which could signal to the market that the state is welcoming the technologies' development. While several states have already passed similar policies, the efficacy of such measures to actually attract AV testing to a given state or locality is unclear. Other external factors may play a larger role.

When asked during an interview, a private company developing AVs felt that legislation and regulation had more of a negative effect than a positive one. The company was testing in a state that passed legislation and regulation but relocated aspects of its testing operations to another state due to the new regulations banning testing AVs without a driver. When asked, the representative noted that testing in a given area may make it more likely to implement AV systems in the area; some AVs rely heavily on mapping data, and any company testing in an area will have developed the maps necessary for its vehicles to function. This catalyst provides a logical entrée to implement vehicles in the same area.[3]

Externalities Targeted

The strategy could potentially target all of the externality areas (crashes, congestion, land development, pollution, and mobility). The strategy could indirectly affect all existing externalities of driving through a multistep causal chain. Establishing the legality of testing could serve as an advertisement to attract companies to a given state or locality, although the value of this strategy in attracting testing activity is unproven. Conversely, some states have taken the position that AV testing is not necessarily illegal, and have claimed to have a more favorable, less burdensome regulatory environment for testing without it. The safety risk associated with a non-regulatory position has not been quantified.

Applicable Technologies

Legalizing testing through a policy built around NHTSA's (2016) model legislation would focus on higher-level AVs (SAE Level 4 or 5), as lower-level AVs are already in production and operating on the roads. Current states with testing regulations or legislation, like California, define autonomous in such a way to explicitly exclude lower-level automation with language exempting systems using advanced driver assistance systems (ADASs) like adaptive cruise control or emergency braking (California Department of Motor Vehicles 2014a).

Implementing Entities

Implementing entities include the state legislature, along with any agencies it directs to carry out or otherwise oversee the testing. This would likely require some coordination and collaboration among state and local agencies since there are often overlapping and shared jurisdictions in transportation management and operations. Departments of Transportation (DOTs), motor vehicle departments, and local government agencies such as metropolitan planning organizations (MPOs), mobility authorities, transit providers, and other similar agencies could all play roles in testing AVs. Several states that have already implemented regulations on testing have delegated the responsibility to the Department of Motor Vehicles (DMV) (California Department of Motor Vehicles 2014b). The responsible agency will depend on the state legislature's direction but is likely to include the state DMV and/or DOT.

Legal Authority

The state legislature would have sufficient legal authority, which it would delegate to other state or local agencies depending on its intent. It would delegate which agencies would have the authority to oversee or implement testing. For example, the California State Legislature passed a piece of legislation requiring the state DMV to develop regulations governing testing and operating AVs. The legislation granted the state government agency the powers to develop and carry out the testing regulations.

Geographic Scale

State legislatures would need to pass a law, although local governments could also choose to pass ordinances encouraging AV testing. The City of Austin (2014), for example, passed a local ordinance stating the city's goal of "becoming a leader in the public infrastructure adaptation [sic] of AC-V technology." Other cities have passed similar measures, including the City of Coeur d'Alene, Idaho (2014); Fayette County, Georgia (Stockman 2014); and Johnson County, Iowa (USA Today 2014). These measures' effectiveness is unclear. AV testing could occur in both urban and rural areas, at the state or local level of government.

Applicable Ownership Model: Private, SAV

Ownership models are irrelevant to this question since the policy addresses testing technologies.

Other Implementation Challenges

Amassing the political support to pass a law through a state legislature is the most notable challenge and likely a significant barrier in some states. Many states have attempted to pass legislation, but few have succeeded (National Conference of State Legislatures 2016). Adopting a regulatory scheme such as the one recommended by USDOT could require significant

[3]Confidential interview with a representative from a private AV developer. Interview conducted by Jason Wagner, August 8, 2016.

action by state or local agencies to understand rulemaking, which would involve assigning resources to accept, review, and issue decisions on testing proposals.

Effect on Implementing Entity

Agencies will gain valuable institutional knowledge and experience with the new technologies.

Stakeholder Effects

The stakeholders in this case would include the organizations, agencies, and companies advancing the testing agenda; the agencies overseeing or regulating testing; state legislators; the governor; state law enforcement and departments of public or highway safety; state insurance regulators and industries; any private suppliers or contractors involved in testing; vehicular OEMs and suppliers; and the general public.

These entities will each have a stake in the policy. Out of rational self-interest, the automotive manufacturers, suppliers, and private contractors would likely be in favor of the policies funding or advocating for the new technologies. The governmental entities charged with implementation or oversight of testing would require funding to carry out its goals. If the programs are successful, the general public could receive societal benefits relating to reducing externalities from transportation.

Winners and Losers

OEMs selling AVs would be the most direct beneficiaries of such a policy since it would result in more rapid market development. If the tests are successful and this leads to the technologies being adopted more broadly, the general public would be better off by receiving the safety (and other) benefits. There is insufficient evidence to determine if these policies are effective as a means of local or state economic development. It is unlikely that any socially disadvantaged groups will be disproportionately harmed or helped by the strategy.

Politically Powerful Stakeholders

As organizations with an economic interest in the policy, AV suppliers and vehicular OEMs and suppliers could all be powerful stakeholders.

Strategy Disruption

This is an incremental change since testing is only a step toward implementing a new system.

Technological Considerations

The research team interviewed a private company developing AVs and asked the representative if state legislation or regulation had played a role in its decision on where it tests its vehicles. The respondent stated that legislation and regulation had played a role, but that a state's regulations banning testing vehicles without a driver made it impossible for the company to test this type of vehicle in the state. It relocated this type of testing to another state without such regulations to allow for continued testing.[3] The interviewee went on to argue that his company disliked a rigid regulatory approach where testing and operations are largely distinct. The company preferred a graduated licensing or regulatory regime governing testing; the company would demonstrate the vehicle's safety under progressively more difficult conditions, and as it passed each level, it would be approved for testing at a higher degree of difficulty. For example, the vehicle would need to demonstrate a certain level of safe operations while a human was in the vehicle. Once it could demonstrate this, it would be approved for on-street testing with a human supervisor. Once it could demonstrate safe operations without a driver, it would then graduate to testing without a driver. Once the vehicle could demonstrate it functioned safely during testing without a driver, it could then progress to approval for deployment.

Affected by Market Penetration

Private companies are already investing significant sums into testing and refining AV systems across the country. These systems are developing rapidly: Google stated that it already believes its AV capable of NHTSA Level 4, full automation (NHTSA 2016c). Once AVs are fully developed and commercially available, there is no longer a need for state or local governments to test these systems.

Optimal Timing

Private companies are already testing AV systems on public roads across the country. Since private companies with a profit motive are investing significant sums to develop AV systems, it is not recommended that state and local governments invest heavily in testing AV systems. Once they are fully developed and capable of consistently safe operation, state and local governments should invest in and implement the systems to receive the societal benefits from the technologies.

Cost and Benefit Considerations

A law proclaiming the legality of AVs has little to no costs.

Potential Funding Sources

The issue of a potential funding source is moot since a law proclaiming the legality of AVs has little to no costs.

Benefits of Implementation

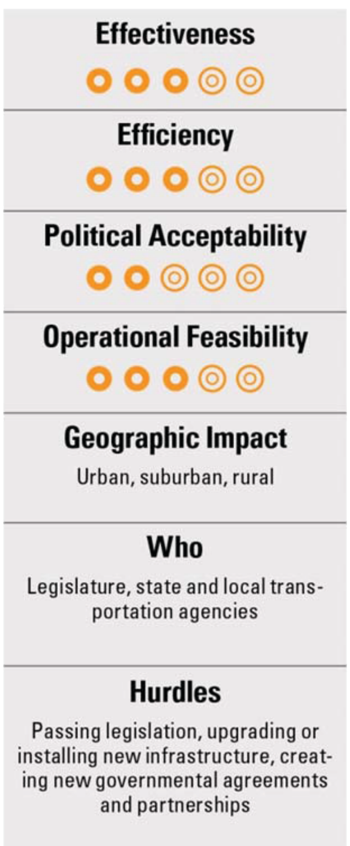
The benefits to society from legislation to legalize AV testing are indirect and would be the result of the testing taking place, which could include safety, mobility, and environmental benefits.

Bottom Line Assessment: Legislation will provide a necessary policy framework to allow testing of AVs on public roads. Testing is a critical path step for mitigating safety risks. The key hurdle to implementation is passing legislation; there must be political will to do so.

Enact Legislation to Stimulate CV or AV Testing

Strategy Overview

The strategy aims to accelerate the development, adoption, and implementation of AVs and CVs by enacting legislation to directly fund testing for CV or AV development.



General Description

The strategy of a state enacting legislation to stimulate CV or AV testing aims to accelerate the development, adoption, and implementation of CV/AV. Specific desired private-sector behaviors that the strategy would influence (from Tables 2 and 3 in Chapter 2) include the following:

- Producers develop and sell interoperable V2V or V2I mobility and environment applications.
- Producers develop and sell safe AVs.

Stimulating testing through direct funding would have legislators pass a law subsidizing or otherwise funding testing and deployments of AV or CV systems on public roads. State agencies could also independently fund testing if they have resources available or if they procure funding for a federal test bed. Some state government agencies have already begun testing AV systems, like truck platooning in Texas, for example (Texas A&M Transportation Institute [TTI] 2016). State and local governments can also receive funding from federal CV test beds, where they often serve as partners (USDOT Research and Innovative Technology Administration n.d.). In these settings, state and local agencies may have the opportunity to learn how to operate and efficiently run these systems. A state DOT employee involved in CV testing reported that the testing in his state increased the likelihood that further CV systems would be advanced.[4] Additionally, the testing helped the agency and its partner state agencies gain valuable knowledge, skills, and expertise that would help with future deployments.

In addition, the 2015 federal transportation authorization legislation known as the Fixing America's Surface Transportation (FAST) Act could provide a potential funding source for pilot activities. The act loosened restrictions on federal funding categories, like Category 2, to provide wider latitude for local agencies to fund ITS with federal dollars through their MPOs. This change is essential for the direct funding option: state and local agencies—under direction from their policy makers—can use their own state and local funding (or federal dollars) for testing if there is a clear value proposition to doing so, given the many other system needs that require financial resources.

Testing a new system will provide useful information to state agencies about how these technologies function and perform: implementation and operational processes and procedures, data on system effectiveness and efficiency, and more accurate cost information; in addition, the agencies will gain

[4]Confidential interview with a state DOT representative involved in CV testing. Interview conducted by Jason Wagner, August 31, 2016.

valuable institutional knowledge and experience with the new technologies.

In considering priorities for investments, agencies testing CV infrastructure and applications are of particular importance for two reasons. First, as the entities responsible for operating and maintaining roads, it is very likely state and local governments will eventually be responsible for implementing and operating CV systems. Testing a system can provide an agency valuable institutional knowledge, skills, and expertise with CV systems, which could facilitate accelerated adoption rates.

Second, to function optimally, many CV applications require roadside hardware that aggregates, processes, and distributes information to and from vehicles (Wright et al. 2014). Without such roadside equipment (RSE) and the supporting subsystems, society may lose out on many of the potential environmental, mobility, and safety benefits. Investments in both the requisite CV infrastructure and personnel recruitment/training to operate and maintain the new equipment will well position state and local agencies to leverage the new technologies.

AV systems could be considered a lower priority for public investments. Many private-sector companies are already investing large sums to develop and perfect AV systems (Kubota 2016). Once these profit-seeking firms perfect their automated driving systems, state and local governments can purchase the AVs to receive their societal benefits without needing to risk limited public dollars on their development.

Indeed, there is ample evidence AVs are rapidly developing, and at least one company claims its AVs are already capable of full self-driving automation (NHTSA Level 4; NHTSA 2016c). Additional funding from state and local governments' limited budgets to subsidize testing AVs is unlikely to create a significant additional incentive to refine the technologies or otherwise accelerate their deployment.

If funding directly, states may wish to consider CV systems as a priority for investments to gain early experience and facilitate societal benefits. CVs, especially the V2I systems, are heavily reliant on public infrastructure, agencies, and dollars to implement (Wise 2015). Without public investments in these systems, their potential societal benefits will be unlikely to come to fruition.

Externalities Targeted

Directly funding CV or AV testing could incentivize companies or public agencies to engage in testing AV or CV systems to ensure safe operation. If CV testing takes place in collaboration with state and local transportation agencies, for example, the agencies will gain valuable institutional information, which would better equip these agencies to implement CV systems in the future. CV RSE is required for societal benefits, and testing would provide an avenue for state and local governments to become familiar with the technologies. This experience and training may help speed successful deployments, accelerating societal benefits and addressing transport externalities, such as safety and congestion.

Applicable Technologies

Stimulating testing through direct funding would primarily focus on CV technology, especially V2I, since aspects of this program will require governmental funding and cooperation to efficiently and effectively operate.

Implementing Entities

Implementing entities include the state legislature, along with any agencies it directs to carry out or otherwise oversee the testing. This would likely require some coordination and collaboration among state and local agencies since there are often overlapping and shared jurisdictions in transportation management and operations. DOTs, motor vehicle departments, local government agencies such as MPOs, mobility authorities, transit providers, and other similar agencies could all play roles in testing CV/AVs. Many current CV test beds involve state DOTs but may also rely on local government agencies, who usually oversee and operate the local transportation network (USDOT n.d.). The Road Commission for Oakland County, Michigan, for example, is a named partner in USDOT's CV test beds.

Legal Authority

The state legislature would have sufficient legal authority, which it would delegate to other state or local agencies depending on its intent. It would delegate which agencies would have the authority to oversee or implement testing.

Geographic Scale

CV/AV testing could occur in both urban and rural areas, at the state or local level of government. Some CV systems are designed to address urban- or rural-specific issues and would be best applied in their appropriate context.

Applicable Ownership Model: Private, SAV

Ownership models are irrelevant to this question since the policy addresses testing technologies.

Other Implementation Challenges

Amassing the political support to pass a law through a state legislature is the most notable challenge and likely a significant barrier in some states. Training staff, developing interagency agreements, and actual testing could all prove challenging as well for directly funded testing activities. Installing the infrastructure and communications backhaul, integrating the data with current infrastructure and ITSs, and optimizing the transportation system to leverage the new technologies and capabilities are just a few of the tasks relating to testing CV/AV systems (Wise 2015). USDOT provides guidance for V2I deployment and offers advice for implementation.

Effect on Implementing Entity

Testing a new CV system will provide much useful information to state agencies about the technologies: implementation and operational processes and procedures, data on system effectiveness and efficiency, and more accurate cost information. In addition, the agencies will gain valuable institutional knowledge and experience with the new technologies.

Stakeholder Effects

The stakeholders in this case would include the organizations, agencies, and companies advancing the testing agenda; the agencies overseeing or regulating testing; state legislators; the governor; state law enforcement and departments of public or highway safety; state insurance regulators and industries; any private suppliers or contractors involved in testing; vehicular OEMs and suppliers; and the general public.

These entities will each have a stake in the policy. Out of rational self-interest, the automotive manufacturers, suppliers, and private contractors would likely be in favor of the policies funding or advocating for the new technologies. The governmental entities charged with implementation or oversight of testing would require funding to carry out their goals. If the programs are successful, the general public could receive societal benefits relating to reducing externalities from transportation.

Winners and Losers

Contractors and suppliers selling CV/AV equipment or services would be the most direct beneficiaries of such a policy since it would result in new contracts for these organizations. If the tests are successful and this leads to the technologies being adopted more broadly, the general public would be better off by receiving the safety (and other) benefits from CV/AV technologies. There is insufficient evidence to determine if these policies are effective as a means of local or state economic development. It is unlikely that any socially disadvantaged groups will be disproportionately harmed or helped by the strategy.

Politically Powerful Stakeholders

As organizations with an economic interest in the policy, CV/AV suppliers, vehicular OEMs and suppliers, contractors, or service providers could all be powerful stakeholders. There could be concern that this sort of legislation could be perceived as directly benefiting private equipment vendors.

Strategy Disruption

This is an incremental change since testing is only a step toward implementing a new system.

Technological Considerations

The strategy attempts to affect technology development and use by funding testing of new technologies. Absent significant public investment from the state and local level, CV systems (especially applications reliant on V2I) will likely fail to provide many of the potential societal benefits (Wise 2015). Gaining institutional knowledge and skills through test deployments, CV systems could increase the likelihood that state and local governments will implement future systems.

Since there are already substantial private investments in developing and refining AV systems, additional public dollars would likely have only a marginal impact on their rate of development. For these reasons, it is recommended that state and local governments prioritize spending their limited funds on CV systems.

The research team spoke with a state DOT employee who played a role in and was familiar with CV tests that took place in his state over the previous decade.[4] The individual reported that the agency had been extremely involved with CV tests, and the testing improved the agency's institutional knowledge, skills, and expertise with CV systems. The representative felt confident that the state's past experiences with the technologies increased the likelihood it would adopt and implement future CV systems. In fact, the representative reported that the agency was already including CV systems in its regular transportation operations planning activities. The individual reported his state had not been directly involved with testing AV systems, although he stated the agency was supportive of AV testing.

Affected by Market Penetration

Many of the benefits from CV systems depend on reaching a sufficient percent of equipped vehicles in the fleet. If CV equipment is being tested, this testing could accelerate or otherwise increase the market penetration of these technologies, which would provide societal benefits. Agencies should carefully monitor developments in the federal regulatory process (Anderson 2016). NHTSA has begun the rulemaking process to require CV hardware on all new vehicles, but if the mandate fails to occur, the technology is unlikely to ever significantly penetrate the market. Without equipped vehicles, the roadside infrastructure is rendered useless. If the mandate occurs, states may wish to begin heavily investing in the roadside infrastructure to reap societal benefits.

Optimal Timing

Testing could begin today or in the near term. NHTSA is expected to mandate CV equipment on vehicles in coming years, and tests of the systems are already ongoing. If transportation agencies wish, and have sufficient discretionary or research funding, they can dedicate these dollars to testing CV systems absent legislation. If the mandate fails to occur, states could investigate the feasibility of alternative technologies to facilitate CV systems, like the anticipated 5G wireless networks. Private companies are already testing AV systems on public roads across the country. Since private companies with a profit motive are investing significant sums to develop AV systems, it is not recommended that state and local governments invest heavily in testing AV systems.

Cost and Benefit Considerations

The costs could range considerably, depending largely on what the legislature passes. Previous single-site test deployments of CV systems ranged in the tens of thousands of dollars (Wright et al. 2014).

Potential Funding Sources

This would be a decision that state lawmakers would address, but many states use driver's license fees, vehicle registration, and taxes on motor fuels as the primary funding source for transportation projects. Redirecting existing funds, widening the tax base, or increasing tax and fee rates are all possible approaches to developing funding. The federal government has been a traditional source of funding for CV research—especially testing—and it is possible funds could be available for future testing as well. The 2015 FAST Act could provide a potential funding source for pilot activities. The act loosened restrictions on federal funding categories, like Category 2, to provide wider latitude for local agencies to fund ITSs with federal dollars through their MPOs.

Other Costs to Society

The cost categories associated with testing would depend heavily on the type of testing but would likely be similar to other ITS projects. The costs from previous tests of CV systems are described in a recent Federal Highway Administration (FHWA) report and are broken into two broad categories: deployment costs and additional costs (Wright et al. 2014). Each category is broken into multiple sub-categories; deployment cost categories included purchasing and deploying new DSRC equipment, upgrading and deploying backhaul communications equipment, and upgrading traffic signals and controllers. The costs are included in Table 5, reproduced from the source.

The additional cost categories include DSRC site operation and maintenance (O&M), back-end system O&M, vehicle fleet data collections, and costs to purchase data from third-party traffic data providers. The report provides a breakdown of average DSRC site O&M but does not provide cost estimates for the other additional cost categories (see Table 6).

Benefits of Implementation

The benefits to society from legislation encouraging CV/AV testing are indirect and would be the result of the testing taking

Table 5. Total potential DSRC site costs of CV infrastructure deployment.

Element	Cost (2013$) at Signalized Intersection with Controller Upgrade	Cost (2013$) at Signalized Intersection without Controller Upgrade	Cost (2013$) at Other (Non-signalized) Location
(DSRC) Equipment and Site Deployment	$17,600	$17,600	$17,600
Backhaul Upgrades and Deployment (Weighted Average)	$30,800	$30,800	$30,800
Traffic Signal Controller Upgrades	$3,200	-	-
Total Potential Site/Unit Cost	$51,600	$48,400	$48,400

Source: Wright et al. (2014), p. 106.

Table 6. Estimated annual DSRC site operations, maintenance, and replacement costs.

Cost Element	Per Device Cost per Year
Power	$100
Traditional Maintenance	$500
License/Maintenance Agreements	$200
SCMS Certificate License	$50
Annualized Replacement Cost (every five to ten years)	$1100 - $2200
Total	**$1950 - $3050**

Source: Wright et al. (2014), p. 108.

place, which could include safety, mobility, and environmental benefits. A previous FHWA analysis estimated that CV V2I safety applications alone could address crashes that result in $202 billion in economic losses each year (2013 dollars) (Eccles et al. 2012).

Bottom Line Assessment: Legislation will provide a necessary policy framework to stimulate others to test AVs and CVs on public roads. Testing is a critical path step for mitigating safety risks. The key hurdle to implementation is passing legislation; there must be political will to do so. Direct funding may be needed to stimulate CV testing, but AV testing appears to be driven by the private sector.

Modify Driver Training Standards and Curricula

Strategy Overview

This strategy would address the requirements for operating vehicles equipped with CV or AV technologies by establishing, codifying, and enforcing CV and AV operator/owner/passenger requirements and modifying driver training standards and curricula to reflect use of CV/AV applications.

Effectiveness

●●●○○

Efficiency

●●●○○

Political Acceptability

●●●○○

Operational Feasibility

●●○○○

Geographic Impact

State

Who

State legislators, state licensing/training agencies

Hurdles

Operational issues

General Description

The strategy's objectives are to maximize the potential safety and mobility benefits of CV and AV technologies by supporting appropriate matches between vehicle and driver capabilities and by maximizing vehicle owner/operators' knowledge of the capabilities and limitations of vehicle technologies. The desired outcomes of establishing new operator requirements for CVs and AVs, including updated licensing and training criteria, would be a raised awareness among consumers and road users about the advantages, limitations, and correct operation of vehicles with advanced technologies. Specific desired consumer behaviors (from Tables 2 and 3 in Chapter 2) would include the following:

- Consumers are attentive to V2V and V2I safety warnings in vehicles.
- Consumers purchase safe AVs.
- Consumers follow safe AV maintenance and operating procedures.

Updating vehicle operator requirements for technically advanced vehicles will require assessments of the physical, perceptual, and decision-making skills that will be needed to interact with each level of vehicle automation; the results of these assessments would then guide the development and implementation of new driver licensing and driver training requirements, based on the capabilities and demands of highly autonomous vehicles.

The strategy will function very differently for different categories of vehicle technologies, as shown in Table 7. CV technologies, which provide the driver with enhanced warnings and information, are likely to represent a minimal departure from current driver requirements and result in minimal changes to driver training or licensing requirements. AV technologies, which take over some to all of a vehicle's operation, will have a much greater potential effect on vehicle operator requirements, driver training, and licensing.

Some states have already begun to address licensing changes or clarifications pertaining to advanced technologies,

Table 7. Potential changes to vehicle operator licensing and training.

	Licensing	Training
V2I/V2V	Requirements do not change significantly; driver testing may incorporate alternate skills using CV technologies (e.g., backing using both rear-view camera and turning to look behind the vehicle).	Driver training and/or public outreach/education may expand to include instructions about V2V and V2I warnings and appropriate driver responses to those warnings.
AV Level 3	Driver testing and licensing requirements will similarly need to reflect the driver's mastery of this knowledge and ability to take over driving when necessary.	Driver training may expand or change to reflect the driver's dual role, as vehicle/roadway monitor and as driver when needed; part of this training must include criteria for how AV systems operate, when the human driver should and should not engage automated driving functions, and how to recognize when to take over vehicle control (Douma and Fatehi 2016). Training for driver educators and examiners must be similarly updated (Mashayekh et al. 2015).
AV Level 4/5	The person controlling the initiation of a vehicle trip may not need to be a licensed driver, and/or licensing requirements may change significantly (Douma and Fatehi 2016). Some driver's license requirements may be traded for vehicle operating requirements, and liability for accidents or illegal roadway actions by the vehicle may shift more heavily to vehicle manufacturers (in the form of product liability), with vehicle owners liable only to the extent that they actively violate intended vehicle operating parameters or fail to follow vehicle maintenance recommendations. Skills testing for driver's licenses may become obsolete (Mashayekh et al. 2015).	Driver/operator training may become largely obsolete; training or education may be limited to basic rules governing the use of self-driving vehicles.

particularly AV technologies. Florida enacted legislation in 2016 that removes the requirement for a driver to be present in an AV, though the law still requires that the vehicle's operator (defined as the person who initiates the vehicle's autonomous operation) hold a valid driver's license. Nevada's 2011 legislation prohibits texting and other handheld cell/device use for drivers of traditional vehicles but permits these activities for people traveling in AVs. Michigan's current law (as of 2016) requires an operator who can take over driving if necessary to be present in an AV; a proposed law (under consideration in the state Senate Economic Development and International Investment Committee as of July 1, 2016) would remove the requirement to have an operator present. Also as of July 2016, legislation to establish a driver's license endorsement for AVs is under consideration in New Jersey (National Conference of State Legislatures 2016).

Externalities Targeted

Updating driver training and license requirements for AV Level 3 is an essential component of manufacturing and marketing AVs for use on public roads. Vehicle automation at these levels has the potential to reduce crashes on the roadway by replacing a human driver's slower and more error-prone decision making and reaction times. However, reducing the human driver's direct control of the vehicle can also result in reduced situation awareness, skill degradation, and overreliance on the automation (Saffarian et al. 2012). These behavioral adaptations reduce the likelihood of a driver being ready and able to take over control of the vehicle when conditions warrant. To mitigate these risks, driver training, testing, and licensing requirements need to reflect the vastly altered role and responsibilities of a driver using a Level 3 AV.

AV Level 4/5 in particular may vastly increase the mobility options for people who are unable to drive or for whom driving is unacceptably high risk. By eliminating the need for an active human driver, full AVs may replace or alter the service model of traditional transit and paratransit services, improving overall mobility of these user groups.

Applicable Technologies

Driver Licensing

Changes to driver/operator licensing requirements will apply most extensively to AV technologies (AV Level 3 through Level 5). Incremental revisions to existing driver skills tests will likely become necessary for drivers of vehicles with automated control of driving functions (e.g., braking, speed, lane-keeping, steering), particularly when the automated functions are the default operating mode of the vehicle and cannot be easily deactivated by the driver. Revised driver skills tests will need to assess the driver's familiarity with the vehicle's automated functions and his or her knowledge of when to take control back from the automated systems (Hayeri et al. 2015). Potentially, a new class of operator's license could be created specifically to authorize a driver to operate an AV Level 3 (versus a traditional driver's license authorizing the bearer to operate vehicles with lower levels of automation). AV Level 4/5 vehicles may mean a complete restructuring of operator licensing, eliminating many of the current requirements for and approaches to vehicle operation. Potentially, two classes of operator's license could be designated, one authorizing a person to operate an AV Level 4/5 and one authorizing a person to drive a vehicle with lower levels of automation (or no automation; American Association of Motor Vehicle Administrators [AAMVA] 2015).

Driver Training

As with driver licensing, changes to driver training requirements will likely apply most significantly to AV Level 3 through AV Level 5 technologies. Driver training should start to incorporate information about how and when to engage (or disengage, as applicable) automated systems, and how to recognize, for AV Level 3 systems, when control is being transferred back to the driver and to respond appropriately. Widespread adoption of AV Level 4/5 vehicle technologies may result in an eventual phase-out of traditional driver skills training.

Driver training and/or consumer education may need to be updated somewhat to educate drivers on the effective use of the added warnings and roadway information provided by V2V and V2I technologies. Testing requirements for driver's licenses may potentially be modified to incorporate use of some CV technologies.

Implementing Entities

State legislatures would likely be the entities to codify new training and licensing criteria for operators of AV Level 3 through Level 5, incorporating any applicable federal standards. Commercial vehicle driver/operator license requirements would likely be addressed at the federal level (Glancy et al. 2016).

The agency responsible for implementation of revised licensing and training requirements would vary by state. In some states, the DMV manages driver licensing; in others, driver license programs are under the jurisdiction of the Department of Public Safety or the Secretary of State. In many states, DMVs work with state departments of education to implement and/or oversee driver training programs (American Driver and Traffic Safety Education Association [ADTSEA] 2008).[5]

Legal Authority

State legislatures should, generally, have the legal authority to determine driver's license requirements for non-commercial vehicles and to set requirements that will be implemented by the applicable state driver licensing agencies. The degree of modification needed to existing laws and rules will vary by state; some states' laws, rules, and/or policies may be more detailed than others and will need more extensive modification as a result. An issue arising from this is that of interstate consistency and reciprocity, which is managed within the AAMVA context.

An exception is commercial driver licensing and training, which is regulated on a national level by the Federal Motor Carrier Safety Administration (FMCSA). In early 2016, FMCSA proposed a new rule for entry-level commercial driver training requirements that would mandate minimum classroom and on-road training hours for new commercial drivers, using an FMCSA-approved curriculum. Any CV/AV-related changes to rules and policies pertaining to commercial driver licensing and training would need to conform to FMCSA's regulations.[6]

Geographic Scale

Driver licensing and testing changes can be implemented at a state level (with the exception of commercial driver licensing), similar to current driver testing and licensing practices.

Driver training changes are implementable at the state level, though the amount of oversight currently provided by states over driver training varies; this is due more to availability of state funding to provide active oversight rather than to the legal ability to do so (Greenblatt 2015).[5]

[5]Interview with Cathie Curtis, AAMVA, August 9, 2016.
[6]Interview with Larry Boivin, Maine Bureau of Motor Vehicles, July 19, 2016.

Applicable Ownership Model: Private, SAV

In a private-ownership model, licensing and training requirements to operate V2V, V2I, and AV Level 3 would apply to individual owners/operators of a private vehicle. In an SAV model, licensing requirements for AV Level 3 would be analogous to those for a chauffeur license (with requirements determined at the state or municipal level) or a commercial/transit driver license (which may require changes to licensing requirements for commercial drivers at the federal level).

AV Level 4/5 licensing, whether in a private-ownership or an SAV model, may apply to the vehicle itself as a certification that it meets the operational and safety requirements to operate autonomously on the roadway (UMTRI 2015).

Other Implementation Challenges

Driver Licensing

Potential funding challenges in the long term include effects on several of the revenue streams connected with use of automobiles, including license fees, gas taxes, and parking tickets. Reduced revenues could impact staffing levels at agencies responsible for driver licensing and testing.[6]

A second challenge is a lack of understanding and acceptance on advanced vehicle technologies among many of the state agency staff who are directly responsible for conducting driver's license testing, resulting in widespread reluctance to integrate new vehicle technologies into driver testing procedures. Changes to driver test requirements to accommodate the use of CV and AV technologies would likely meet with resistance from testers. A current example is the use of backup cameras during road tests. The prevailing opinion among driver examiners is that in-vehicle backup cameras aid the driver too much and interfere with testing a driver's skill in safely reversing a vehicle, so use of these cameras is generally forbidden during driver testing, although this technology will soon become standard equipment on all new vehicles. States will have to put significant resources into educating their staff on the benefits of CV and AV technologies and how to test drivers using them.[5]

Driver Training

Public funds to support driver training have dropped considerably in recent years (Greenblatt 2015), so funding changes to driver training curricula and materials (and implementing re-training for driving instructors) is likely to be a significant challenge. Changes would need to be made not only to beginning-driver training courses but also to defensive-driving curricula.

Effect on Implementing Entity

Driver Licensing

New licensing requirements for AV Level 3 will necessitate re-training of driving license examiners and may require the development of multiple new licensing classes. For AV Level 4/5 vehicles, licensing requirements may change dramatically enough to eliminate the need for driving examiners, reduce or eliminate driving instruction, and potentially eliminate the need for vehicle operator licenses. This could eliminate a significant source of state revenue from licensing, unless other fees are instituted in place of driver licensing fees (such as vehicle use fees), or unless vehicle operator licenses are retained in a different form.

Driver Training

Many states have to provide their driver training material in written form in many different languages, and in electronic format, so any changes will have to be incorporated into all of these, plus associated curricula. Training videos will need to be updated. If simulators are still in use, those would have to be modified as well.[5] Widespread adoption of AV Level 4/5 vehicles may eventually reduce or eliminate traditional driving instruction.

Stakeholder Effects

There are numerous potential stakeholders who may affect or be affected by changes to driver licensing requirements and/or by changes to driver training and education.

Driver Licensing

Agencies and organizations that may influence or have input to driver licensing standards (besides state driver licensing agencies) include state governor's offices and law enforcement agencies, state agencies representing the aging and disabled communities, the insurance industry, transportation research centers, and national associations such as AAMVA, American Association of State Highway and Transportation Officials, ADTSEA, the National Conference of State Legislatures, and the Governors Highway Safety Association. AARP may be a potential champion for changes to driver licensing requirements (in particular, to the reduction or elimination of driver perception and skills testing) because of the potential that AVs represent for increased mobility over the lifespan.

The law enforcement community will be affected by changes to vehicle licensing requirements in different ways. Enforcing traffic laws is likely to become far more complex when some road users are driving mostly manual vehicles while others are driving vehicles with various degrees of automation. Impaired or distracted driving laws may not apply to vehicles that do not need a driver to be actively engaged but will still apply to less-automated vehicles.[5] Eventually, less traffic law enforcement may be needed overall if a significant portion of the vehicle fleet is largely automated.

The transit and taxi industries, as well as ride-share providers such as Uber and Lyft, may be affected by licensing requirement changes for AV Level 4/5 vehicles since fewer people may need these transportation services.[5] However, these types of services may be re-tooled to use self-driving vehicles in a service model, providing trips for people who do not own a vehicle (Isaac 2015).

The American Trucking Association and motor carriers as a whole may influence the adoption of new licensing requirements for commercial drivers and will be affected by those changes; AV implementation has the potential to proceed more quickly in the commercial driving industry than for passenger vehicles due to the anticipated financial benefits of truck platooning (UMTRI 2015).[6]

Vehicle owners and operators will be affected by revisions to licensing requirements that require them to demonstrate knowledge on applicable AV systems. For AV Level 3 vehicle automation, drivers will need to exhibit an understanding of the systems' capabilities and limitations and demonstrate correct operation of the automated systems, including how to override the automation and take over control of the vehicle when necessary. Traditional driving skills and capabilities will remain a component of driver licensing for V2V, V2I, and AV Level 3 technologies. With AV Level 4/5 vehicle automation, vehicle owners and operators may no longer need to demonstrate traditional driving skills in order to obtain a vehicle operating license. For this reason, AV Level 4/5 technologies will affect all road users, but particularly people who are nondrivers due to age, disabilities, or medical conditions, who may be able to obtain a license to use a self-driving vehicle.

Driver testing/licensing agencies will affect the implementation of this strategy by developing and implementing new testing methods (as applicable) and standards for licensing operators of vehicles with Level 3 through Level 5 automation, according to their states' legislative decisions. These agencies will also be affected by the strategy: driver's license examiners will need re-training to effectively test and assess drivers of vehicles with AV Level 3 technologies or (to a lesser extent) V2V/V2I technologies. Some aspects of driver licensing, along with associated agency functions such as driver testing, may be phased out entirely if the majority of the vehicle fleet is self-driving (AV Level 4/5). However, some form of licensing or registration for operators/passengers of self-driving vehicles may remain.

Vehicle manufacturers will affect the strategy through the design and degree of standardization of CV and AV systems, which will affect the development by state agencies of driver/operator education and testing. Vehicle manufacturers may also be affected by the strategy if changes in vehicle operator requirements either encourage or discourage purchase of vehicles with CV/AV technologies.

Driver Training

Driver educators in both the public and private sectors will need re-training to provide instruction on the correct use of vehicles with AV Level 3 technologies and/or V2V/V2I technologies. If AV Level 4/5 technologies become the norm for the majority of the on-road vehicle fleet, driver educators may no longer be needed.

Driver education associations such as ADTSEA may affect the strategy by recommending specific changes to new driver and defensive-driving curricula and materials that reflect advances in vehicle technologies.

Winners and Losers

Many road users may benefit from modified licensing requirements pertaining to CV/AVs. At the highest levels of vehicle automation (AV Level 4/5), road users who would otherwise be dependent on a third party (another driver, transit/taxi/ride-share services) may benefit significantly if they have access to a self-driving vehicle (either via personal ownership or through a for-hire service).

The shipping/trucking industry is likely to benefit from changes to licensing requirements that allow truck platooning. Commercial drivers, transit drivers, and taxi/ride-share drivers may lose if driver licensing becomes obsolete.

Driver educators and driver's license testers may lose if skills-based driver licensing becomes obsolete with the widespread adoption of AV Level 4/5 technologies.

Elderly, young, and disabled road users may be disproportionately helped by the strategy at the AV Level 4/5. Evolution of CV/AV technologies could be of great benefit to the aging population in the United States by increasing their mobility past the age when they can safely drive.

If changes to licensing or training requirements cause an increase in the cost of driver education, then lower-income people will be impacted negatively.[5]

Politically Powerful Stakeholders

Manufacturers of vehicles with CV/AV technologies and automobile dealer associations are likely to be powerful stakeholders with an economic interest in the effects of changes to driver licensing requirements. Other politically powerful stakeholders include highway safety advocates, organizations that advocate for elderly and disabled persons, commercial trucking associations, and the taxi/ride-share industries. USDOT and partner/subsidiary agencies, including NHTSA and FMCSA, are also politically powerful stakeholders for driver licensing and training requirements.[5]

Strategy Disruption

Driver Licensing

Changes to licensing requirements have the potential to be very disruptive because CV/AV technologies in the overall vehicle fleet are not an all-or-nothing condition. Because different vehicles will have different levels of technology for many years to come, changes in licensing will have to accommodate people driving CV/AVs and those driving less technically enhanced vehicles; some road users will operate highly advanced vehicles some of the time and more traditional vehicles some of the time. Licensing requirements will either have to ensure that a driver can safely drive vehicles at multiple levels of automation or have to specify what type(s) of vehicle a driver is allowed to operate. Right now, licensing requirements for privately owned passenger vehicles are consistent for any type of vehicle a driver operates.[5]

Changes to driver licensing requirements for AV Level 4/5 vehicles may also cause a radical change from a socioeconomic perspective since some demographic groups (elderly, disabled, very young) may achieve independent mobility and the associated benefits of that mobility, while some driving-related professions eventually diminish or vanish. In this regard, the increasing automation of vehicle systems may represent as major a disruption and transformation as the automobile did a century ago.[6]

Driver Training

Changes to driver/operator requirements may also be very disruptive to driver training. Driver training curricula, materials, and standards will need to expand in scope to accommodate new warnings and in-vehicle information channels (V2V/V2I), or to accommodate changing roles and necessary skills for vehicle operators (AV Level 3).[6] Widespread adoption of AV Level 4/5 vehicles may mean an end to driver training as it currently exists.

Technological Considerations

Changes to driver licensing and training requirements will impact technology use.

Affected by Market Penetration

Technical viability of revisions to driver training and licensing will be affected, particularly for AV Levels 3 and 5, by the percentage of equipped vehicles in the vehicle fleet.

Optimal Timing

Revisions to licensing and training requirements for AV Level 3 through AV Level 5 should ideally be established and implemented prior to widespread availability of AVs to the general public. Driver's license revisions may be less crucial and time sensitive for V2V and V2I vehicles, though drivers of these vehicles should ideally have at least some training (formal or informal) about how the applicable CV systems work and how to use them effectively.

Cost and Benefit Considerations

Driver Licensing

Costs to implement revised driver's license requirements could include revision of current driver licensing test procedures and standards and re-training of driver examiners (in the case of AV Levels 3–5 technologies).

Driver Training

Costs to revise driver training to reflect updated driver's license requirements would include the development and production of new driving training curricula and materials, and the re-training of driving instructors.

It is too early to effectively estimate the costs of these and other changes to licensing/training; there is the potential for significant cost.

Potential Funding Sources

Driver Licensing

At AV Level 3, driver's license fees would be the primary funding source for implementing revisions to license requirements and new license classes (where applicable). These fees should offset the costs to implement the revisions. In the case of widespread adoption of AV Level 4/5 technologies, a potential increase in the number of people eligible to obtain an operator's license could significantly increase revenues to state licensing agencies (if operator's licenses are still required despite no longer being skills based) (Hayeri et al. 2015). Vehicle registration and title fees, as well as vehicle usage/mileage fees, are other potential sources of revenue.[5,6]

Driver Training

In many states, driver training will be partially or completely funded by training course fees (i.e., paid directly by drivers). In jurisdictions where new driver training and/or oversight of training programs are still publicly funded, funding sources may be similar to those for driver licensing.

Other Costs to Society

Employment displacement is a concern for professions that rely on licensed drivers; for example, the potential elimination of driver's licenses for AV Level 4/5 vehicles may eliminate for-hire and livery drivers as a profession. Urban sprawl is likely to increase with increased personal mobility, which will impact infrastructure costs and land values, as well as potentially increase total VMT (Isaac 2015).[6] The impacts that self-driving vehicles have on the overall roadway and travel experience will depend partly on whether self-driving vehicles are used primarily in a single-occupant mode or as part of a mixed-mode transportation system in which self-driving vehicles are a shared last-mile provider used in conjunction with high-occupancy transit services (UMTRI 2015).

Benefits of Implementation

The primary categories of societal benefits resulting from CV/AVs could include safety-related benefits such as reductions in crash and injury costs (both monetary and human costs) and increased mobility for some road users. Overall mobility may also improve via more efficient traffic movement on roadways (Isaac 2015). It is too early in the process to accurately estimate the magnitude of these benefits.

It is particularly difficult to estimate the magnitude of the impact of changes to driver training on these benefits, in part because it is difficult to definitively quantify the impact of driver training on traffic safety in general (Lonero and Mayhew 2010).

Bottom Line Assessment: The need for driver training standards and curricula will be essential to safe operation of AVs and CVs. Hurdles to implementation are mainly operational—altering driver training and licensing requirements for AV Level 3 vehicles will require significant restructuring of driver training and of licensing requirements and testing. AV Level 4/5 vehicles could lead eventually to the elimination of driver training, examining, and licensing as they currently exist. However, there is not enough clarity on the specifics of CV and AV roll-out to determine how to proceed with new training standards in the near term.

Effectiveness

●●●○○

Efficiency

●●●●○

Political Acceptability

●●●●○

Operational Feasibility

●●●●○

Geographic Impact

Urban, suburban, rural

Who

Any state and local agencies

Hurdles

Developing trusted messages given the uncertainties in technology deployment, benefits, and drawbacks.

Increase Public Awareness of Benefits and Risks

Strategy Overview

The strategy seeks to increase public awareness of benefits and risks of CV/AV technologies through education, training, communication, and outreach.

General Description

This strategy aims to increase the public's awareness of CV/AV technologies through education, training, communication, and outreach to stimulate consumer action and supportive public investment. Public education about the safety, congestion, mobility, privacy safeguards, and environmental implications of AVs and CVs could affect technology adoption and market penetration. Specific desired consumer behaviors that the strategy would influence include the following (from Tables 2 and 3 in Chapter 2):

- Consumers purchase vehicles with V2V/V2I capabilities.
- Consumers use and are attentive to V2V or V2I mobility and environment applications.
- Consumers purchase and use aftermarket V2V safety applications.
- Consumers purchase safe AVs and follow safe maintenance and operating procedures.

The strategy of increasing awareness entails communicating, educating, and reaching out to consumers and potential consumers of vehicles that may be equipped with CV and/or AV technology. However, beyond that, it is making consumers aware of the potential for these technologies to improve safety, enhance mobility, and promote eco-friendly objectives.

This awareness can happen through the market, by the private sector, by enticing customers with new products (e.g., Google's self-driving car), or through product enhancement (e.g., advance safety systems on current models of automobiles). Awareness can also occur through outreach by public entities that wish to demonstrate to their customers how these technologies can enhance and/or improve the services they provide. For example, the American Public Transportation Association has adopted 12 principles for integrated mobility and disruptive technologies (Woodland 2015). By bringing forth a policy framework that includes provisions of CV/AV technologies, the association is making a visible and concerted effort to increase public awareness. The Florida Legislature recently passed a law that requires the state's 26 MPOs to address emerging technologies in their long-range plans. Public entities may also offer communication and information to aid public understanding of how these technologies and public investments in the infrastructure to support these technologies can result in overall societal benefits.

This strategy objective also includes informing the public about the technologies' capabilities to support informed public debate, especially to support resource allocation and investment decision making. This can happen in many ways. A public entity can proactively choose to make investments to support CV/AV technology. For example, USDOT has been supporting extensive research in CV systems for more than 10 years. The agency has developed numerous informational pieces that communicate to the public how this technology works, how it can be used, what the benefits are to the public, and why this investment is important. The Joint Program Office makes people and resources available to conduct workshops and public meetings. This is done in an effort to educate the public. USDOT also supports test deployments. An important objective of deployments is demonstrating the viability of the technology and allowing the public to experience the technology in a real-life setting.

State and local agencies also make investment decisions that can impact public acceptance. In some instances, these agencies have identified specific strategic goals that require investments to support CV/AV technology. In other instances, policies may be adopted that can enhance advancement of testing and/or deployment. Likewise, political support can encourage or discourage the adoption and acceptance by the public of the laws and rules that are enacted. These are all examples of how the public sector communicates and educates the public to support its objectives.

Conversely, the public itself may initiate the debate by expressing a desire for a service or technology. A recent example of this is the public response to ride-sharing services of transportation network companies (TNCs) such as Uber and Lyft. The market met this need because the public expressed a strong desire for it. In some cases, state and local agencies are struggling to regulate a new service while being responsive to the public's needs. In this example, the ride-sharing technology itself and the market created by it are driving the policy discussions rather than a policy or investment to support a desired action by the public.

While the public sector has focused primarily on CV technologies, the private sector is leading the charge for AV technologies. Some levels of AV technologies are commonly advertised as standard features on vehicles available to consumers. It is a reasonable assumption that this mass media advertising is reaching a broader audience than public-sector efforts at this point. This, in turn, has generated interest on the part of the public to want to understand how AV technology will impact their lives. Information and education campaigns from the public sector may be seen as more believable than advertising by the private sector. The National Association of City Transportation Officials (NACTO, n.d.) recently released a policy statement on AVs. The statement offers support of the development of AV policies and regulations to support several transportation objectives that are common for urban communities.

Currently, there are no organized processes for deploying either technology (Mohaddes and Sweatman 2016). This can and will impact the outreach and education that is occurring and the public's acceptance of the various messages. Any number of factors surrounding the messages themselves may impact the public's acceptance of the messages. When there is not a message platform of key points, messages may be conflicting, be issued by various sources that seem at odds with one another, or even be sensationalized. This can all impact the public's receptiveness to the messages.

Externalities Targeted

This strategy can easily target all externalities depending on the outreach or education message. Safety in vehicular crashes, in particular, has the possibility and likelihood to improve social welfare with CV/AV vehicles. Overall, the economic effect of motor vehicle crashes in 2010 was $242 billion. When other factors such as pain and reduced quality of life were factored in, the total societal cost of motor vehicle accidents in 2010 was $836 billion (Aldana 2014). Human error accounted for 94 percent of all crashes at the national level in an NHTSA analysis of data from 2005–2007 (Zmud et al. 2016). Both AV and CV technologies are expected to reduce and/or minimize impacts of motor vehicle crashes. The extent of this will depend on the performance of the technology and the market penetration of the technologies. Public outreach and education about the safety implications of these technologies can possibly increase the market penetration of equipped vehicles through consumer purchase. Seat belt use has become nearly ubiquitous, albeit through laws and enforcement in addition to public education and outreach. In much the same way, the use of CV/AV technology to aid in driving decisions has the ability to significantly improve safety and thereby societal benefits.

Outreach and education about the possible environmental benefits of CV/AV technology can also increase the likelihood that consumers purchase vehicles with these technologies or install them as aftermarket features. While many consumers may be heeding the messages because of their desire to minimize their impact on the environment through driving, others may not be consciously aware that some technologies may indirectly have environmental benefits (e.g., traffic harmonization). Likewise, CV/AV technologies can impact congestion externalities and may have environmental benefits, but these are not messages that are used in communicating with the general public. Conceivably, consumers could also choose to use SAVs rather than privately owned vehicles, which could have environmental benefits. However, recent research shows that most people would not replace a currently owned vehicle with a shared vehicle (Miller et al. 2016). It is difficult to know the public reactions to environmental or congestion messages due to the limited messaging surrounding either technology. What outreach and education that has occurred in the mainstream tends to focus on the safety aspects of these technologies.

The externalities associated with mobility can be addressed through CV/AV technology, but public education and outreach have not specifically focused on how these technologies may improve mobility. Communication and messaging have focused on how these advances will improve the quality of one's commute or possible increases in fuel savings. While CV applications can increase system efficiency through coordinated actions and AV applications may allow the redesign of infrastructure to accommodate more traffic, mainstream communication by automakers to the general public focuses not on these externalities but on the liberation of the driver to engage in other activities. At the same time, AAA (2014) warns that motorists do not fully understand the limitations of ADASs. Furthermore, automakers recognize and explicitly state in owner's manuals that these systems have limitations. However, it is also plausible that many owners do not fully read their manuals. AAA also notes that television commercials highlight ADAS capabilities but make no note of system limitations and suggests that commercials are the primary source of motorist knowledge of systems.

CV/AV technologies can provide a new level of mobility access to people. Some people have never had the ability to make a trip independently due to physical or mental limitations, others are low income, and some reside in communities that are not well served by public or private transportation options. Collectively, these people are known as the transportation disadvantaged. The term is defined as "persons who lack the ability to provide their own transportation or have difficulty accessing whatever conventional public transportation may be available" (USDOT n.d.). In broad terms, there are some demographic characteristics of people who tend to become transportation disadvantaged. These include:

- Seniors, especially those that are frail, have disabilities, and/or are low income.
- Persons with physical, mental, or cognitive disabilities.
- Families in or near poverty.
- Youth and others who cannot or do not drive.
- Recent immigrants, non-English speakers (USDOT n.d.).

AV technology has the ability to significantly address some of the mobility challenges of transportation disadvantaged groups; however, to date, there have been no known concerted public education efforts aimed at these groups.

Applicable Technologies

Public awareness should apply to all levels of CV/AV technologies. Current education does not differentiate for the consumer what level of automation it is addressing. It may not be important for consumers to know a specific level of automation, but they should be aware of the possibilities and the limitations of the technology.

Public education will also need to convince the public that any technology is safe and reliable, regardless of who is using it. The public will need to trust that a city deploying CV technology that allows a vehicle to communicate with a traffic signal has done enough research and due diligence to ensure that technology is safe for a vehicle equipped with V2I technology and one that is not. Similarly, the public will need assurances from policy makers, and perhaps legislators, that drivers employing AV technologies are just as responsible as drivers that are not.

The public may not be explicitly interested in the kinds of technology that are used to improve their driving experience or increase their access to transportation, but they may be interested to know how public investments that contribute to the availability of the technology are made. Information and education should focus on how the public will benefit from these advances.

Implementing Entities

Coordinated messaging by both state and local agencies could instill confidence in consumers that these technologies and systems are advances that are supported locally, regionally, and statewide. Agencies at all levels should demonstrate how these technologies can benefit safety, mobility, and the environment, and these same agencies must acknowledge system limitations, if only to manage expectations. Joint messages by the private sector and the public sector could enhance credibility and build trust with the public. The public may see benefits associated with the public and private sectors working in partnership for greater societal benefits.

Consumers should see coordinated efforts, especially at the local level, by municipal transportation departments, MPOs, transit agencies, and other transportation service providers, public and private. Messaging at the state level should concentrate on how these efforts contribute to overall system efficiency and increase access to transportation options. More than extolling the virtues of advanced systems, which is often the position espoused by the private sector, public agencies should assuage the fears and/or doubts of consumers and potential consumers through non-biased, fact-based information. Limited real-world applications make it difficult for the public sector to engage the public, in much the same way as it is difficult to engage the public in long-range planning. Without widespread, tangible examples of how these technologies can personally affect the public, the public sector has to rely on pilots and testing. At the same time, the public sector needs to provide education and communication about the research and testing that is occurring to increase awareness by the public. The public can be more supportive of investment in infrastructure and/or technology when its impact can be demonstrated; therefore, it is incumbent on the public sector to increase the public's awareness through education. Interviews with members of communication team at the Atlanta Regional Commission (ARC) stressed the importance of field testing and pilots as a way to increase public awareness and understanding and noted that people need to experience technology first-hand. Yet, team members acknowledged that one must be either "part of a private company's development program, participate in a conference or by invitation only event, or be confined within a tightly controlled environment." This limits the role and effectiveness the public sector can play.

The private sector can increase credibility to the public by communicating how the advances in AV technologies work together with CV technologies and demonstrating a coordinated effort to achieve policy goals of both the public and private sector. Additionally, consumers will look to public agencies to ensure data safety, security, system reliability, and resiliency.

Legal Authority

There are no legal or regulatory barriers associated with increasing public awareness. However, the implementing agency(ies) will be well served to ensure a consistent, fact-based message that instills confidence in their programs to build trust and credibility with the public.

Geographic Scale

Public awareness can and should be tailored to specific audiences. Each audience is likely to have questions or concerns unique to their situations, and communication messages should speak to those questions or concerns specifically. It is very likely that these will differ between urban and rural areas. For example, in rural areas, it is reasonable to assume lesser market penetration of CV/AV technology and, based on past investment strategies, less infrastructure to support these technologies. If this is the case, the public will want assurances of how these technologies will serve transportation needs and interact in their current environments.

Specifically, public-sector agencies at the local level need to provide adequate information about CV technologies to foster support for public investment in the infrastructure to support these activities. The state should provide information to garner support for statewide policy decisions and subsequent investments to improve overall system efficiency and access.

Applicable Ownership Model: Private, SAV

Public awareness through outreach, education, training, and communication could and should occur in any model. A shared model may require additional education and outreach because it will be unfamiliar to most people. A public entity that has specific goals and plans to use technology policies and regulations to achieve those goals should clearly articulate why those goals are important and how the policies help to achieve the goals. The North Central Texas Council of Governments sees educating the public about the benefits of shared mobility, in general, as a first step to autonomous shared mobility. The agency believes this is a specific role for local governments. Additionally, long-range plans and land development should recognize and accommodate this.

Other Implementation Challenges

Consumer acceptance and adoption of CV/AV technologies are likely the biggest challenges associated with any deployment. They will influence the political will of state and local leaders and will drive funding decisions. That is why it is imperative that outreach and education to increase public awareness be considered from the beginning of policy development, strategic planning, and eventual implementation. This technology has the opportunity to revolutionize transportation, but the public must be aware of and supportive of the transformation for it to realize its full potential and societal good. Adequate staff, funding, and information resources must be dedicated to supporting outreach activities, especially from the public sector. The Florida Department of Transportation (FDOT) began an initiative as the result of legislation passed in 2012. The initiative provides the annual framework for efforts surrounding the implementation of CV/AV technologies. As part of the initiative, FDOT provides funding and staff resource support for outreach, education, testing, and research. Interviewees indicated that FDOT has spent $1.6 million in 2016 on consultant contracts to help achieve these goals, of which about $400,000 has gone to education and outreach efforts. In doing so, the department signaled the importance of the initiative. On the other hand, interviews with governmental agencies at a more local level indicated that there has not been a concentrated focus on this subject.

Effect on Implementing Entity

From the public's perspective, the implementing agency must be seen as credible, reliable, and trustworthy. Moreover, the public should see the implementing agency as the entity responsible for implementation to the degree that the implementation is within the mission of the agency. This is especially important for the public sector concentrating on CV technology. The public must be supportive of policies and investments that enable CV technology to work seamlessly with the advances of the private sector in AV technology.

Stakeholder Effects

The general public, as consumers of these products and technologies, are obvious stakeholders. Additionally, organizations, agencies, producers, suppliers, and other private companies along with investors, policy makers, and state legislators all have a vested interest in a successful outcome. Tangentially, the insurance and medical/health industries are all potentially affected by implementation. The way a public education effort is communicated and received will impact each of these audiences, and that impact will have an effect on the ability to internalize externalities. A successful example of this in the safety arena is the messaging related to seat belt use. Because the messaging has been and continues to be relevant, current, and tailored to specific audiences, seat belt use continues to increase. This results in an overall societal benefit.

Winners and Losers

An awareness campaign by itself cannot harm or help any group. The harm or help will be in the execution of the campaign. The messaging must speak to the issues important to a particular audience, and the implementation must be carried out in such a way as to ensure inclusivity. An interview with staff at ARC suggested that regional planning agencies have not begun policy discussions that consider using these technologies to broaden societal goals. There may be individual goals to reduce VMT or improve safety, for example, but how these technologies can contribute to those goals has not been considered. Therefore, public awareness campaigns to either educate, inform, or increase support for investment have not been initiated. In the interview, researchers were told that staff is only just beginning to explore what those goals may be internally, and no communication or education with the policy board has been initiated. However, at a statewide level, FDOT's outreach extends to a wide range of stakeholders including those that may be considered transportation disadvantaged.

Politically Powerful Stakeholders

The general public, when sufficiently motivated, can become a very powerful stakeholder. Likewise, major industries heavily investing in AV advances have ties to political forces. Any of these forces can achieve political objectives that will either benefit or hinder advances in these fields.

Strategy Disruption

These technologies themselves are a major change to the current system, but their implementation is happening gradually. As such, information campaigns to the public about them for the most part do not focus on the ability to transform the transportation sector. Instead, current campaigns, centered in the present day, relate features of the technology that are important to the consumer for the particular application (e.g., safety features). Some cities and MPOs are working with partners to develop information about how these technologies can change the future of travel in the region. This information is available to the general public, but it is not being marketed the way auto manufacturers are marketing features in car commercials.

Technological Considerations

The strategy itself does not impact development or use, but it can impact the *rate* of development and adoption. Pilot projects, demonstrations, and field testing can increase public awareness of the technologies. State and local agencies can also leverage those tests and demonstrations in public education and awareness campaigns. By proactively communicating with the public about the successes (and failures) of demonstrations, agencies are inherently increasing awareness. Increased awareness can lead to greater market penetration and could also result in greater support for public investment.

Affected by Market Penetration

Technical viability is not affected by market penetration of equipped vehicles, but public perception may be. As market penetration increases, exposure to the technologies increases. This can increase public support. As ARC noted, field testing and public awareness of this testing and the opportunity for first-hand experience is vitally important.

Optimal Timing

A best practice of public participation is engagement early and often (Geiselbrecht et al. 2012). Testing of these technologies is underway in various cities and states, numerous industry advocates have begun information campaigns, USDOT has made connected automated vehicle applications a priority program, and other agencies with regulatory authority have made certain equipment mandatory in coming years. Therefore, concerted public awareness efforts and education should be implemented. It takes time to conduct audience analysis and market research to identify which messages are most impactful, which are missing the mark, and what other concerns should be addressed in messaging. Conducting the research and analysis and then proactively engaging in an information campaign can prevent misperceptions and the spread of misinformation.

Additionally, outreach and education campaigns can provide the necessary information to induce the public to provide a necessary push to spur additional resources and investments in AV and CV technologies by both the public and private sectors. The public embraced the technology that enabled TNCs and other shared service providers and caused the market to expand, in many cases despite regulations that prohibited the activities. This same result could arise if AV technology experiences a similar rapid growth. Similarly, if the public were to become more aware of and informed about the benefits of CV technology, it may spur public investment because political interest may allocate resources in response to demands from the public. It is a precarious position for state and local agencies. It is difficult to proactively plan in a disruptive market with ever-evolving technology. The public may be unaware of and not considering what alternative futures may be. A public agency may try to proactively regulate and unintentionally stifle innovation and investment, or worse, reduce or eliminate market solutions that the public supports.

Cost and Benefit Considerations

FDOT has made over 70 presentations to stakeholders. Early on, a public relations firm was engaged to create informative videos. The department hosts a website, www.automatedfl.com, and has a YouTube channel to promote its activities and increase public awareness and understanding. The department is also engaged in several research projects and demonstrations. The extensive nature of the Florida AV program has not isolated cost specific to outreach but estimates that approximately $400,000 has been spent. Moreover, no specific evaluation has been done about the effectiveness of outreach efforts, but the department plans to engage state universities to conduct that research in the near future. For comparison purposes, in fiscal year 2015, the Texas Department of Transportation (TxDOT) spent $2.1 million on the successful *Don't Mess With Texas* anti-litter campaign. In that same time period, TxDOT spent $31,838,179 on litter pick-up expenses. A table of the costs and expenses back to fiscal year 1986 is available at http://watchdog.wpengine.netdna-cdn.com/wp-content/blogs.dir/1/files/2016/02/TxDOT-Litter-Chart.pdf (Lisheron 2016). These numbers cannot show if there is a correlation between the campaign and the clean-up costs, but other studies do show a reduction in litter (Lisheron 2016). This illustrative example is used to show the costs of a large, successful campaign that used a multipronged approach with television and radio commercials, collateral materials, and public education. It is likely that a statewide public awareness campaign focused on CV/AV technology would be similar in scale, scope, and cost.

Potential Funding Sources

Any funding source available for use in education, awareness, training, communication, or outreach may be used to launch an effective public information program. A local entity may wish to establish specific accounts to be used solely for this purpose. These funds could come from local sources or a pass-through from state or federal sources. State or local legislation may place restrictions on the use of the funds. For example, FDOT has made a significant investment into outreach activities surrounding CV/AV technologies, but state law prohibits purchase of specific items such as clothing.

Other Costs to Society

There are no other known costs to society for implementation of an awareness program. Again, it will be important to make any program as inclusive as possible.

Benefits of Implementation

In general, an informed society is a benefit to all members of a society, and a public that has had the opportunity to participate in the process is more likely to accept the outcome of the process. There is considerable literature related to the benefits and disadvantages of a public participation process but none directly related to this topic area (Irvine and Stansbury 2007). Most of the literature assesses the benefits of including the public in a decision-making process. The societal benefits of advancing these technologies are quantified, but it is impossible to estimate the benefits of implementation of a widespread public education campaign at this point.

Bottom Line Assessment: AV and CV technologies have the potential to bring immense societal benefits but also pose new risks, both of which need to be made known to the general public to ensure market acceptance as well as safe operation. Public education campaigns are expensive and complicated endeavors. Their effectiveness and the ability to achieve a positive societal outcome will be determined by the credibility of the messenger and perception by the receiver about the necessity and validity of the message. A major hurdle will be the development of trusted messages given the uncertainties in the technology deployment, benefits, and drawbacks.

Subsidize SAV Use

Strategy Overview

This strategy intends to subsidize SAV services to ensure alternatives to individually owned AVs and to support ride-sharing and transit services, including paratransit.

General Description

The policy strategy is to provide subsidies to incentivize SAV use to ensure alternatives will be available to individually owned AVs, in order to mitigate congestion and emissions. In addition, subsidies targeted to incentivize first/last-mile service or services for specific groups, such as disabled, elderly, and low-income populations, may enhance mobility and improve transportation equity. The private-sector decisions that the strategy seeks to influence are (from Tables 2 and 3 in Chapter 2):

- Consumers use SAVs rather than privately owned AVs to minimize VMT growth.
- Aging adults, youth, and individuals with disabilities (consumers) use Level 4/5 SAVs.
- Producers develop and sell Level 4/5 AVs that are usable by aging adults and individuals with disabilities.
- Private, shared-vehicle services purchase and operate SAVs.
- Private, shared-vehicle services prioritize ride-sharing and linkages with line-haul mass transit.

SAVs are on-demand driverless vehicles that operate as part of a privately or publicly managed fleet. SAV fleets would operate similarly to current TNCs such as taxi-like Uber and Lyft or micro-transit shuttles such as Bridj and Chariot. Eliminating the cost of the driver and individual ownership could create a more affordable product since labor is a high-cost category for conventional TNCs (Litman 2015).

Using TNCs as an analog for SAVs, subsidies to incentivize their operation and use in urban areas does not seem to be necessary. Growth in the TNC market has been demand driven. Market forces have worked well. The two market leaders, Uber and Lyft, have experienced exponential growth. As an example, in November 2010, Uber was operating in three cities—San Francisco, Palo Alto, and New York. By June 2013, that number was around 40, and Uber had expanded overseas. In 2014, Uber had operations in 229 cities and 50 countries (Griswold 2014). However, the market-driven growth is not confined to the market leaders. The number of new entrants in the TNC market is increasing. As an example, when Uber and Lyft pulled out of the Austin, Texas, market after a public referendum requiring background checks and fingerprinting for drivers, at least a half dozen start-ups emerged within a month, including FARE, Fasten, Get Me, Wingz, Arcade City, and RideAustin.

However, as TNCs grow, they are unlikely to serve rural, less dense, and some low-income neighborhoods without public subsidy because of the need to turn a profit. To avoid facing the challenge of low demand, TNCs tend to start in places likely to support highest usage, those with a sufficient density of people and uses. There is also a risk that TNCs will siphon away conventional fixed-route transit riders in the most dense and well-traveled corridors, the very places where traditional fixed-route transit makes the most sense. This could not only lead to increased subsidies for traditional public transit, but also to transit agencies reducing levels of

Effectiveness
●○○○○

Efficiency
●●●○○

Political Acceptability
●●○○○

Operational Feasibility
●●●○○

Geographic Impact
Urban, rural

Who
Public transit agencies, cities

Hurdles
Implementation issues (subsidies needed only for special use cases)

service and disenfranchising transit's captive riders.[7] For these reasons, it benefits society if a public subsidy could also be used to target TNC service to first/last-mile connections to transit.

In addition, many policy analysts have argued that TNCs could provide paratransit (or dial-a-ride) service for people with disabilities and the elderly at less cost than that provided by public transit. Brookings analysts found traditional paratransit is the most expensive mode to operate on a per-trip basis, exceeding $23 in 2013 (Kane et al. 2016). Since federal regulations limit the fares transit agencies can collect to double a regular bus ride, very high subsidies are required to close the cost gap. Their analysis indicated that if TNC operations replaced those of public transit, a marginal savings of about $10 per ride would result. With the elimination of labor costs, savings from shifting paratransit trips to SAVs could potentially be even greater.

Externalities Targeted

Research is beginning to indicate that individually owned AVs have the potential to exacerbate congestion and emission problems in urban areas (Fagnant and Kockelman 2015a; MacKenzie et al. 2014; Schoettle and Sivak 2015). Contributing factors include:

- Reduced perceived values of in-vehicle travel time—as former drivers are freed from the task of driving, they may increase trip-making rates and travel distances.
- Increased attractiveness for personal vehicle travel—related to the previous factor, transit's current advantage of allowing users to read, use mobile devices, or engage in other activities could fall away, leading to potential mode shifts away from transit.
- New mobility for those unable to drive—disabled, elderly, unlicensed persons, and perhaps older children would be able to transport themselves via AVs.
- Unoccupied AV travel—AVs could relocate while unoccupied to cheaper parking or to other locations to be used by family members.
- New travel due to increased efficiency—intelligent AV and CV technology and infrastructure could increase effective roadway capacity, thereby contributing to suburban sprawl and longer trips.

Together, these factors may lead to higher trip-making rates, longer trips, and mode shifts away from transit, all of which would lead to increased pollutant emissions and congestion.

[7] Personal interview with Dr. Richard Mudge, July 2016.

SAVs could address these potentially problematic issues through the following ways:

- Value of travel time—a trip taken by SAV may be costlier than a trip taken by a privately owned vehicle on a marginal per-trip basis since the cost of the vehicle would be embedded in the trip price rather than be a single sunk cost at the time of vehicle purchase (Fagnant and Kockelman 2015b).
- Average vehicle occupancy—if ride-sharing is used (pooling two or more unrelated parties in the same vehicle), SAVs could operate as higher-occupancy vehicles. While they may pull from traditional transit forms with higher-occupancy rates, they could also pull from personal vehicles with lower average vehicle occupancies (Zachariah et al. 2014).
- Transit utilization—SAVs could help serve first-mile/last-mile connections for line-haul mass transit systems, increasing the attractiveness of traditional transit systems.
- Unoccupied AV travel—while SAVs may still need to relocate while unoccupied to serve new travelers, preliminary research shows that these trip distances may be much shorter than comparable empty trips taken by privately owned AVs (Schoettle and Sivak 2015; Fagnant and Kockelman 2015b).
- Urban sprawl—SAV systems operate most efficiently in areas with high utilization and trip-making (Fagnant and Kockelman 2014). Assuming SAVs are an attractive travel option, they would likely be implemented in denser urban areas and increase the attractiveness of such areas.

Each of these factors could mitigate added total system VMT, particularly when compared to the potential effects of privately owned AVs. Moreover, SAVs could be designed and operated to match trip purposes, vehicle sizes, and seat availability with travel party size and number of travel parties, leading to even better environmental outcomes. Similarly, SAV operators could adopt electric fleets, which would also have beneficial impacts on emissions.

Applicable Technologies

SAVs require high automation (AV Level 4/5) for their operation.

Implementing Entities

Transit agencies are the most likely implementers of the targeted subsidy strategy for specific SAV use cases. This strategy entails the re-targeting of existing user-side subsidies. Public transit is subsidized by federal, state, and local sources of funding. The percentage of total public transit operating revenues that passengers pay through fares is called the fare box recovery ratio. Most transit systems have fare box recovery ratios between 25 and 35 percent (MacKetchnie

2016). A large part of the gap is covered by state and/or local sources—typically state or city sales taxes. At the federal level, a segment of the federal gasoline tax is used to support the programs of the FTA, including operating subsidies to transit agencies in areas with a population of under 200,000. Another federal role is to fund pilot programs. For example, in 2016, FTA announced the Mobility-On-Demand Sandbox opportunity for public transit agencies and state/local government DOTs to apply for $8 million in funding for mobility-on-demand demonstration projects that more than likely target the specific use cases called out in this report.[8]

Cities have a role in facilitating innovative partnerships with shared mobility providers to qualify for federal funds and to implement proof-of-concept applications.[9] While some cities may not directly regulate TNCs and shared mobility providers, all cities can set service standards that can also affect the specific use cases. For instance, New Orleans is setting a requirement that a certain percent of shared mobility vehicles need to be wheelchair accessible, which could have implications for paratransit service provision.

Many existing user-side subsidy programs for underserved groups and places are managed by public transit agencies; others are managed by cities, sometimes in coordination with local partners (Haarstad 2008). Therefore, local public agencies are well suited to adapt existing programs for SAV use, or alternatively to implement new programs where none exist. The provision of public subsidies for TNCs is a relatively new phenomenon, something that has surfaced in the last 6 months.[10] That said, a disincentive for transit agencies is that funding sources are relatively limited and their capital and operating budgets are often overburdened.[9] Thus, agency willingness to reallocate the limited financial resources means that experimentation and implementation could likely be spotty, as noted in the use case examples provided below.

First-Mile/Last-Mile Connections

These types of connections make it easier for travelers to use light rail or bus rapid transit for the main portion of their trip by facilitating people's travel to and from the transit facility, particularly for those trips that are too distant for walking or bicycling. Transit agencies have begun to view TNCs as an important partner in addressing the first-mile/last-mile problem. For example, the Pinellas Suncoast Transit Authority in Florida began a 6-month trial in 2016 in which it paid half of a United Taxi or Uber ride up to $3 for trips ending at a transit facility (Sacramento Area Council of Governments [SACOG] 2016). Tri-Met has a corporate relationship with Lyft in which potential passengers can access Lyft service through the Tri-Met mobile ticketing app. Lyft recoups its cost through monthly billing to Tri-Met. Tri-Met has control over the passenger price; any cost gaps are covered by reallocating the transit subsidy.[10]

Paratransit Services for Disabled and Elderly

Paratransit services meet the mobility needs of people who are functionally unable to independently use fixed-route transit service. Because of cost efficiencies, local agencies already use private companies to provide paratransit service. Thus, it is a small leap to incentivizing TNCs to expand their offerings to include paratransit service (Shared-Use Mobility Center 2016). For instance, Uber had approached the City of San Francisco, unsuccessfully, about taking over the city's paratransit operations. In the meantime, Uber has launched several relevant products including UberWAV, which allows riders to request wheelchair-accessible vehicles, and UberASSIST, designed to provide additional assistance for members of the senior and disability communities. Orange County Transit Authority has a corporate relationship with Lyft in which it can implement smart dispatch strategies for a Lyft driver or other vehicle for paratransit service depending on the passenger requirements.[10] Massachusetts Bay Transportation Authority, in Boston, solicited proposals from TNCs as alternative providers of paratransit service. In all cases, the cost of a ride would be covered by a payment scheme, such as the customer pays the first $2, the transit agency pays the next $12, and the customer is liable for any amount over that (e.g., special needs, longer trip).

Rural/Low-Density Areas

It is often not efficient or effective for transit agencies to provide bus service in low-density suburban areas or in rural areas. In both cases, public subsidies can be reallocated to enable TNCs to serve the markets. Any such subsidy would be lower per ride than the provision of fixed-route service in low-density areas. For example, Livermore Amador Valley Transit Authority (2016) has planned Wheels on Demand—a partnership with TNCs—to provide service to low-density suburban areas where fixed-route service cannot be supported. It holds no contracts with the TNCs and leaves the decision up to the customer about which service provider to use. This pilot functions as an extension of a traditional user-side subsidy program, which has been used by transit systems nationwide to partner with taxi-cab companies.

Denver Regional Transit District's (RTD's) User-Side Subsidy Taxi Program is a good example of the latter. This program is designed as an alternative to RTD-provided paratransit

[8] Personal interview with Vincent Valdes, FTA, August 2016.

[9] Interview with Seleta Reynolds, Los Angeles Department of Transportation (LADOT) and NACTO, August 2016.

[10] Interview with Emily Castor, Lyft.

services in which the rider pays the first $2, the RTD pays the next $7, and the rider pays any fare over $9 (Burkhardt et al. 2003). For rural area TNC service, the challenge for TNCs is being able to provide a reliable service level.[10] Also in the Denver region, Lyft is operating a fully subsidized operation for RTD to and from its Dry Creek light rail stations to/from locations in Centennial, Colorado. TNCs are more likely to fill the service gap where there is a statewide regulatory framework like California rather than regulations by individual cities. The opportunity cost of turning on service is much lower under uniform statewide regulations. For example, Lyft operates in large swatches of the central valley in California.

Transit Deserts

Transit deserts are areas that lack adequate public transit service for populations that are deemed transit dependent. It is cost inefficient for transit agencies to operate an acceptable level of bus service in transit deserts (Jiao and Dillivan 2013). On the other hand, TNCs can geo-fence the area to provide targeted service and charge for trips according to the subsidy structure or eligibility requirements that the transit agency wants to implement. For example, Gainesville, Florida, has implemented a 6-month pilot program in partnership with Uber and ElderCare to serve low-income senior citizens (Watkins 2015). ElderCare will set up an account with Uber that will be billed whenever a senior citizen in one of the pilot communities requests a ride to either the senior center or to other select destinations. A copay of between $1 and $5 is required, depending on income. Seattle's Smart City proposal established a mechanism for subsidizing income-eligible residents' use of the full spectrum of transportation options including TNCs (Seattle Department of Transportation 2016). LADOT is still trying to figure out how to deal with the equity issues of surge pricing in transit deserts and expects that it may have to put up city money to offset surge pricing.[9]

Legal Authority

The program would run as an extension of a traditional user-side subsidy program.

Geographic Scale

Generally, the strategy would be implemented at the urban and suburban levels of geography, though it could be implemented to serve rural transportation needs.

Applicable Ownership Model: Private, SAV

The strategy targets shared vehicle use.

Other Implementation Challenges

There are no other implementation challenges.

Effect on Implementing Agency

The strategy could have positive budget implications for transit agencies.

Stakeholder Effects

There are five primary stakeholders likely to be concerned with providing user-side subsidies for SAVs. These stakeholders include potential SAV users, SAV operators (which may be TNCs), transit agencies, taxis (as well as non-AV car-sharing services, conventional TNCs, and their drivers), and the general public. If SAV subsidies are implemented, SAV operators and users would directly benefit the most, through increased profits and reduced user fares. Transit agencies could benefit from budget and operating efficiencies. Taxis, non-AV car-sharing services, and non-AV TNCs would be put at a competitive disadvantage. Similarly, professional drivers who work for such firms could see their jobs in jeopardy. The public should see benefits in terms of reduced congestion and emissions and increased mobility and transportation equity, though the general public would also be responsible for funding the subsidies (i.e., sales or fuel taxes).

Winners and Losers

SAV operators and users would directly benefit through increased profits and reduced fares. Transit agencies could benefit from budget and operating efficiencies. Conventional taxis, car-sharing services, and TNCs would face a disadvantage. Individuals who currently lack access to transportation services could be helped by the strategy.

Politically Powerful Stakeholders

There is a significant chance that any effort to enact SAV subsidies will be opposed by negatively impacted firms, professional drivers, and some portions of the public, particularly those helping fund such subsidies but lying outside of the service area. Opposition from some of the public may be minimized if incentives are targeted to the specific use cases previously discussed.

Strategy Disruption

The strategy represents an incremental change; there are examples of similar programs being put in place with TNCs.

Technological Considerations

Assuming Level 4/5 automation is safely achieved, technical viability for SAV systems is not dependent per se upon market penetration (i.e., share of trips taken by SAVs), provided that a minimum demand threshold for economic viability is met. In other words, if demand is low, SAV operators should be able to adjust fleet sizes or area of operation according to the requirements of the specific use case.

Optimal Timing

Optimal timing for SAV-based subsidies is likely prior to the initiation of a new SAV system. SAV use has the potential to substantially ameliorate congestion and emissions externalities and to address specific mobility and equity concerns. The use of subsidies as indefinite commitments may be beneficial in addressing these goals if it serves the purpose of decreasing overall VMT through increased SAV ridership, particularly if rides are shared.

Cost and Benefit Considerations

The amount of funding required for a user subsidy program would likely depend on a number of factors, including the extent of the program and the duration. SAV subsidies may be either temporary in nature (to help establish a new system) or ongoing (to continually boost ridership through lower rider costs). Costs would include those related to both the direct subsidy and the administration, and it is likely that administration costs would represent a greater share if vouchers are given to individuals since the administering agency would be tasked with working with perhaps thousands of individuals rather than just a few SAV providers. However, the user subsidies could be allocated to the SAV providers through a corporate partnership (or monthly billing process).

Potential Funding Sources

Funding would likely stem from one of two broad sources: new taxes or diversion of existing transit funds. Sales tax, fuel tax, VMT tax, property tax, and business tax are all mechanisms that may be used to fund an SAV subsidy program. Such a program may also be included as one component of a larger transportation bond referendum.

Other Costs to Society

Acceptance for something like this might be higher if SAV subsidies could actually result in net transit agency cost reductions (Haarstad 2008).

Benefits of Implementation

Primary societal benefits of SAV system use would likely come in the form of reduced congestion and emissions through lowered VMT (and possibly cleaner vehicles as well), as described at the beginning of this strategy description. Increased access and mobility options are other benefits, particularly for persons with limited transport options, such as those without a car or those unable to drive. In addition, society could benefit if public subsidies for transit capital investments or operations were reduced.

Bottom Line Assessment: Based on what is currently happening with TNCs, it seems unlikely that a strategy that solely encourages SAV alternatives to AVs would be necessary. However, one that incentivizes SAVs to provide first/last-mile service and service for targeted populations could be effective in achieving positive societal outcomes. Hurdles will be in implementation—reallocation of public transit subsidies for SAVs and political opposition from some driver-reliant industries (i.e., taxis and livery services).

Implement Transit Benefits for SAVs

Strategy Overview

Use transit benefits as an economic incentive to encourage individuals to use SAVs.

General Description

Transit benefits are a type of economic incentive provided to individuals to ride transit. They can be provided in one of two ways: as a direct subsidy and as a pre-tax benefit (meaning that the individual can use his or her own earnings to pay for the transit fare, but on a tax-exempt basis). In both cases, the incentive can be used to pay for transit or vanpool fares; in an SAV regime, incentives could be extended to fares for SAVs as well. The private-sector decisions that the strategy seeks to influence are (from Tables 2 and 3 in Chapter 2):

- Consumers use SAVs rather than privately owned AVs to minimize VMT growth.
- Aging adults, youth, and individuals with disabilities (consumers) use Level 4/5 SAVs.
- Producers develop and sell Level 4/5 AVs that are usable by aging adults and individuals with disabilities.

Externalities Targeted

This strategy targets congestion, land development, and pollution through providing incentives to use shared vehicles instead of driving for commute trips. While it does not relate directly to specific CV/AV technologies, the assumption is that a fleet of fully autonomous shared vehicles would constitute an alternative mode and that transit benefits would be expanded to allow employees to pay for these trips. Less directly, SAVs could bring riders to and from transit stations, as opposed to serving entire trips. This might produce less congestion than if riders use individually owned AVs for lengthy trips instead of riding transit.

Applicable Technologies

An SAV fleet would be at SAE Level 4/5.

Implementing Entities

Federal tax law governs how transit benefits can be implemented. Only Congress can determine which commute modes are eligible for benefits (currently, transit, vanpools, and—under a separate program—bicycling), determine which individuals are eligible to participate (only employees of participating employers), and set the upper limit on the tax-free dollar amount (currently $255 per month).

State and local governments can take several approaches to transit benefits. On the more aggressive side, some states have enacted additional tax advantages for participating employers. For example, Washington State allows employers who provide commute trip reduction incentives, including transit benefits, to take a tax credit against other tax liabilities (King County 2016). A few local governments have also begun requiring some employers to offer commuter benefits. According to the Society for Human Resource Management, cities or counties in three metro regions (San Francisco Bay Area, Washington, D.C., and New York) require employers over a certain size to offer commuter benefits to their employees (Lally 2015).[11]

However, it is more typical that regional organizations—such as MPOs or transportation management associations (TMAs), which may be public or private—encourage the use of transit benefits through outreach and information provision. For example, FDOT (n.d.) lists a dozen organizations in the state that provide employer and commuter assistance, which generally includes encouraging employers to adopt transit benefit programs and employees to enroll in them. Where transit agencies have set up specific mechanisms for employers, employers are required to participate in these programs to offer transit benefits. They are not legally allowed to establish their own reimbursement programs. While the majority of transit agencies have such programs, they tend to be most effective in areas where transit provision is high (ICF Consulting and Center for Urban Transportation Research 2005).

Legal Authority

It seems unlikely that Congress would devolve the power to determine which modes would be eligible for transit benefits to the states since federal income tax laws are well established, so states and localities must work within existing laws. Their only power to encourage the use of transit benefits for SAV fleets would be to lobby Congressional representatives to change the law (Miller 2015; League of American Bicyclists n.d.).[12]

Geographic Scale

The strategy would be implemented in a city or region.

Applicable Ownership Model: Private, SAV

By default, the strategy would be implemented in an SAV model.

[11] These are different from mandatory employer-based programs, such as the one required by the South Coast Air Quality Management District, to reduce solo-occupant commuting. The difference is that employers can choose how to meet those mandates—transit benefits are not the only option.

[12] The laws have been changed in the recent past. Congress increased the maximum tax-free limit from $130 to $255 in 2016 (Miller 2015), and allowed employers to begin offering the bicycle commuter benefit in 2009 (League of American Bicyclists n.d.).

Other Implementation Challenges

Employer challenges are fairly minor:

- Making decisions on how to implement transit benefits.
- Establishing an enrollment process.
- Setting up and maintaining an account with the transit agency.
- Changing payroll forms if using a pre-tax program.
- Determining whether to conduct the implementation directly or use a third-party provider.

The main impact on employers is the time required to reach decisions and ongoing administrative time, which would vary with the size of the employer, the number of worksites, the number of employees, and the complexity of the program.

One barrier to more widespread use of transit benefits is that individuals cannot choose to participate in a transit agency program; they can participate only if their employer sets up a program. The determining characteristic is whether an employee receives a W-2 form from an employer. Therefore, persons who are self-employed, or contractors, cannot set aside pre-tax money to pay for transit fares. One potential change to the law would be to allow individuals to participate directly in transit agency programs on a pre-tax basis, without employer involvement.

Effects on Implementing Agency

There are no impacts.

Stakeholder Effects

The stakeholders in transit benefit programs are participating and eligible employers, participating and eligible employees, transit agencies, state and local governments, MPOs, TMAs, and the federal government (Congress in setting the tax law, and the Internal Revenue Service [IRS] in implementing it).

Winners and Losers

Since transit benefit programs in their current form have existed nearly 25 years, there are no particular political concerns about continuing such programs.

One equity concern could arise if transit benefits are linked to individual credit cards (see the next section about a technology system for expanding transit benefits to an SAV fleet). As of 2014, nearly 30 percent of American adults did not have a credit card (Holmes n.d.), a figure that has risen over the past decade.[13] Currently, transit agency cards used for transit benefits are generally not linked to any other payment mode. However, equity concerns could arise if, for example, new technologies required users to link the card to a credit card account to replenish the funds in the event of a purchase that depletes the card balance.[14]

Politically Powerful Stakeholders

Several changes could make transit benefits slightly controversial. Making them mandatory would probably concern employers because it could increase the amount they spend on employee benefits. (However, requiring employers to offer programs is different than requiring employees to use them.) Allowing individuals to participate via pre-tax programs without the intervention of an employer could lead to a small reduction in tax revenues, depending on uptake. However, this would likely be popular because it would help individuals reduce what they pay in transit fares. (The complexity of the program could affect usage and IRS administrative costs, and not all individuals might understand or be motivated by pre-tax savings.) Both of these would have larger impacts if the amount of transit fare that could be provided or set aside as pre-tax was increased.

Strategy Disruption

None of these changes would constitute a radical change, and they would not harm any socially disadvantaged groups. Indeed, the program could be helpful to lower-income persons who are captive riders because it could lower their out-of-pocket cost to ride transit.

Technological Considerations

Transit benefits could be made simpler and less vulnerable to theft or misuse through deploying technological changes to fare media (e.g., automatic downloading of benefits onto a card, card registration such that individuals can reclaim the balance if their card is lost or stolen, integration across multiple transit agencies). Many such technologies are already deployed.

In the case of an SAV fleet, fares could be automatically deducted from a card in a similar fashion to the way that electronic toll collection automatically deducts the fare when a driver passes a toll gantry. A forward-looking transit agency could develop such an application for users to tap the same

[13] It is more difficult to find statistics on debit cards, which come in various forms—both those linked to bank accounts and those that function as prepaid cards.

[14] For example, the toll transponder EZPass can be linked to an accountholder's credit card for automatic replenishment.

card on a bus, a rail car, or an SAV; some validation would be needed to ensure that the rider is tapping the card upon entering and/or exiting the vehicle. A back-end system (such as ride-hailing services use) to debit the card could be deployed; the rider's account with the SAV service would be linked with the account that manages the transit benefit (over time this might be the same account). Such a service could be deployed gradually as SAV services become available; the technology itself would not be on the critical path.

As an example, the Washington Metropolitan Area Transit Authority (WMATA) has a SmarTrip card that functions as the region's transit benefits program—WMATA operates the program, and other transit agencies accept the card as payment. WMATA developed the card initially, and being the region's dominant transit agency, WMATA gradually extended its use to other agencies at their request. The region's agencies meet monthly to sort out the appropriate division of revenue between them.

WMATA's long-term goal is to move toward a mobility as a service (MaaS) orientation, meaning that riders would use a smartphone app to access many modes seamlessly, depending on their location, destination, and real-time availability of various modes (e.g., a traveler might be directed to a train if one is arriving quickly, or to a ride-sourced car if train service has ended for the night). Payments could be processed through the phone. However, WMATA is proceeding slowly with this goal while the technologies that would enable these transactions mature. Equity was not considered a concern since rider surveys show an increasing share of riders with smartphones. However, linking the various modes would require other operational changes. For example, WMATA does not currently allow ride-sourcing vehicles to access its stations to pick up passengers.[15]

In the San Francisco Bay Area, the Clipper Card serves as the region's transit benefits program for more than 20 transit agencies. The Clipper Card was developed and continues to be managed by the Metropolitan Transportation Commission (MTC), the region's MPO, and 1.7 million cards are in use. In its current state, it would be difficult to add new operators to the system, for several reasons. First, adding a new operator requires installing a proprietary fare payment device on all its vehicles. Second, all devices on all existing vehicles need to be programmed with all of the fare rules that apply to each operator. Currently, the system recognizes about 30,000 fare rules,[16] making reprogramming prohibitively expensive.

The limiting factor in using the Clipper Card for non-transit payments is that it has purses on the card only for transit and parking payments. The system operates with a proximity-based card (not a wireless system), meaning that a Clipper Card fare device recognizes immediately whether a rider has sufficient funds on a card for a particular trip. An account-based system needs to communicate with a back-office account.[17] MTC is considering a major upgrade to the system that would introduce more flexibility, including the possibility of additional purses, but any upgrade would probably not take place for at least 5 years. Given the success of the card-based system, MTC would not necessarily seek to replace cards with another fare medium.[18]

Affected by Market Penetration

Changes to transit benefit programs could develop gradually as SAV fleets spread.

Optimal Timing

Timing is not particularly important.

Cost and Benefit Considerations

Since transit benefits are already deployed by most transit agencies, the main cost consideration to expand them to an SAV fleet would be developing the integrated payment system described above. This could vary between agencies depending on the level of sophistication, number of users, and number of AV fleets. It might not be cheaper to develop systems for multiple competing fleets if each insists on its own technology. Past efforts to introduce ticketing systems compatible across multiple operators have ranged widely. For example, the Clipper Card cost over $133 million (Metropolitan Transportation Commission 2016), while the original contract to develop and implement London's Oyster card was over $1.5 billion (Gannon 2006). While figures were not available for WMATA's SmarTrip program, the cost of adding new agencies was not considered prohibitive.[15] There are no other major cost categories; information and outreach services could be expanded relatively easily.

Potential Funding Sources

Funding could come from the fleet operators themselves as an incentive to cooperate with transit operators, or it could

[15] Phone interview with M. Eichler, strategic planning advisor, Metro Office of Planning. Interview conducted by Liisa Ecola, August 2, 2016.

[16] A fare rule is the fare for a specific rider on a specific transit service between an origin and destination. If all riders pay a flat fare for all rides, that equates to one fare rule for that service. If fares vary based on the length of the trip, time of day, or status of the rider (e.g., student and senior discounts), the number of fare rules increases quickly.

[17] The main drawback of an account-based system is first tap risk. This means that a fare device could allow a rider to enter the system with insufficient funds because the transaction is not fast enough to know whether the card has enough funds.

[18] Phone interview with J. Weinstein, principal, Clipper Program, MTC. Interview conducted by Liisa Ecola, August 9, 2016.

be covered in part by local governments or MPOs interested in the possibility of congestion reduction.

Benefits of Implementation

The main benefit would be continued encouragement of both transit use and SAV uptake. It would be difficult to quantify this without specific measures and assumptions.

Bottom Line Assessment: Transit benefits are not by themselves particularly successful in increasing transit use because use depends much more heavily on service provision and user convenience. The strategy could be more effective with an SAV fleet since origins and destinations are less important than they are for traditional transit, but service characteristics could still be important. The key hurdle to implementation is regulatory. Congressional action is required to alter the existing transit benefit program.

Implement a Parking Cash-Out Strategy

Strategy Overview

The strategy uses parking cash-out benefits as an economic incentive to encourage individuals to use SAVs.

General Description

Parking cash-out is an employer-based strategy to discourage drive-alone commuting. An employer who currently provides parking free of charge to its employees (which almost 90 percent of U.S. employers do) instead offers employees the choice between retaining the free space and taking some amount of cash. The private-sector decisions that the strategy seeks to influence are (from Tables 2 and 3 in Chapter 2):

- Consumers use SAVs rather than privately owned AVs to minimize VMT growth.
- Aging adults, youth, and individuals with disabilities (consumers) use Level 4/5 SAVs.
- Producers develop and sell Level 4/5 AVs that are usable by aging adults and individuals with disabilities.

Externalities Targeted

Parking cash-out targets congestion, land development, and pollution through providing incentives to use commute modes other than driving alone.

Applicable Technologies

The strategy does not relate directly to specific CV/AV technologies, but the assumption is that a fleet of shared highly autonomous AVs (Level 4/5) would constitute an alternative mode.

Implementing Entities

Parking cash-out is currently implemented exclusively by employers. No jurisdiction legally prevents an employer from offering the strategy, but it is not particularly popular for two reasons: it is not well known, and many employers would see no financial benefit from discouraging the use of parking. This is because employers who own the parking outright, who obtain parking through a lease and cannot unbundle the parking costs, or who do not have a parking shortage would not see a financial benefit to reducing the number of employees who drive alone to work. Otherwise, there is not much reason to pursue parking cash-out unless there is some type of mandate to reduce drive-alone commuting.

Legal Authority

Parking cash-out payments are not limited by law, and they are taxable, so employees could use them to pay for rides in an SAV fleet.

Geographic Scale

Most metro areas have programs in place to encourage alternatives to solo-occupant commuting, and they could easily add parking cash-out to their list of potential options (many already do).

Applicable Ownership Model: Private, SAV

Parking cash-out is effectively applied in both models as an incentive to reduce drive-alone commuting.

Other Implementation Challenges

Parking cash-out has been adopted in relatively few places. Even in California, where state law has required certain employers of over 50 employees to implement parking cash-out since 1992, the narrow definition of which employers must follow the mandate means that only about 3 percent of the 11 million parking spaces provided for free to employees are covered. The state also does not track participation (Weikel 2015).

Also, the proportion of employers for whom implementing this strategy would be financially beneficial is probably fairly low. Based on a 1994 survey, Shoup and Breinholt (2001) estimated employers provide about 85 million parking spaces to employees, of which 19.5 million (23 percent) are leased and the remainder owned. It was not determined how many of the 19.5 million leased spaces were bundled with the lease payment. If half are, then that suggests that almost 90 percent of employers might realize no financial benefit (that is, they would not save money because they already own the parking, or because they would not be able to save money by giving up leased parking). Finally, to be effective, the strategy requires some type of verification of who is using employee parking; otherwise, employees may take the cash and continue to use the parking.

It might be possible to extend this model somehow to discourage other types of parking, such as at shopping malls or entertainment destinations. In such a model, persons who arrive via SAVs could get a small incentive payment (e.g., $5 off a purchase or admission fee). However, this would require reliable information about how travelers arrived at their destination since self-reported information could be unreliable. Therefore, this strategy would probably remain an employer-based one since employer-provided parking often requires some type of authorized access and is more reliably verified.

Effect on Implementing Entity

There is no impact.

Stakeholder Effects

Based on the assumptions above about implementation, the stakeholders for parking cash-out are employers and employees.

Winners and Losers

Any mandate for employers to provide parking cash-out would likely be unpopular with employers. It might be popular with employees, depending on their alternatives and the amount of payment.

Politically Powerful Stakeholders

There are no politically powerful stakeholders.

Strategy Disruption

If not mandated, this strategy would not be disruptive.

Technological Considerations

There should be no technological hurdles to implementing parking cash-out more widely because the transactions can take place entirely via existing payroll systems.

Affected by Market Penetration

Market penetration is not a concern since parking cash-out can be implemented without any reference to AVs.

Optimal Timing

Timing is not a concern since parking cash-out can be implemented without any reference to AVs.

Cost and Benefit Considerations

The employer's cost depends on its real estate situation; some employers could save money when fewer employees drive to work if they could stop renting expensive parking spaces. Those who own parking or who do not have a shortage would probably require a subsidy or mandate from state or local government to implement the strategy. The overall cost to a local agency that wanted to provide employer subsidies would depend on factors such as the number of employers in the region, the number of employees, the real estate market (this would be far more expensive in a market with high land costs than in one where land is relatively cheap), and the availability of other options. Note that without a mandate to use their parking cash-out money for SAVs, employees could spend the money however they like, including non-transportation purposes.

Potential Funding Sources

The costs for implementing parking cash-out more widely would under present conditions be borne entirely by employers.

If a state or local agency wanted to encourage more employers to implement parking cash-out, it might provide subsidies to relieve the costs to the employer.

Benefits of Implementation

The main benefit, if the strategy is successful, is fewer people driving alone and probably less land devoted to parking (probably because nothing prevents employers from keeping the spaces and using them for non-employee parking; for example, an office building with ground-floor retail could offer parking cash-out to the office employees but make the spaces available to retail customers for a parking fee).

Bottom Line Assessment: While parking cash-out has been fairly successful where adopted, its success also depends on the availability of other commute options. Hurdles are institutional; there is no particular incentive for employers to implement this strategy. However, even making the program mandatory would not necessarily encourage SAV use since employees might opt for the free parking instead.

Implement Location-Efficient Mortgages

Strategy Overview

The strategy is to offer home buyers who are willing to live near transit more advantageous loan terms (i.e., LEMs) as an economic incentive to encourage individuals to use SAVs.

General Description

LEMs are mortgages available to homeowners whose properties are located close to transit stations. The goal is to offer home buyers who are willing to live near transit more advantageous loan terms to encourage the purchase of homes near transit in the hopes that occupants will drive less and use transit more frequently. The private-sector decisions that the strategy seeks to influence are (from Tables 2 and 3 in Chapter 2):

- Consumers use SAVs rather than privately owned AVs to minimize VMT growth.
- Aging adults, youth, and individuals with disabilities (consumers) use Level 4/5 SAVs.
- Producers develop and sell Level 4/5 AVs that are usable by aging adults and individuals with disabilities.

From a lender's point of view, the reasoning behind LEMs is that people who live near transit stations tend to spend less on transportation than homeowners who do not (Holtzclaw 1994; Haas et al. 2008). The proportion of a homeowner's income that can be spent on monthly mortgage payments can be higher given that transportation costs are generally the second most expensive item in a household budget (FHWA n.d.d). Indirectly, LEMs might also encourage the construction of more housing near transit stations. With an SAV fleet, location near a transit station might be less important, but LEMs could be available to persons purchasing homes in denser urban areas.

Externalities Targeted

LEMs target the congestion, land development, and pollution externalities that result from driving through providing incentives to live near transit stations and increase use of transit.

Applicable Technologies

LEMs do not relate directly to specific CV/AV technologies, but assuming they are used to encourage individuals to use SAVs, then they would apply to SAE Level 4/5 technology.

Implementing Entities

State or local government involvement is not required to implement LEMs. However, state and local governments could encourage LEMs by working with mortgage providers to make LEMs available (for example, a local government might provide geo-coded transit maps to enable a mortgage provider to better delineate locations for LEMs), or to promote the mortgages once available. During past pilot programs (discussed below), transit agencies have promoted the use of LEMs through providing transit passes to LEM buyers and making advertising space available (Chatman and Voorhoeve 2010). LEMs themselves would be provided by the same types of entities that provide conventional mortgages: banks, credit unions, and quasi-government entities such as Fannie Mae.

Legal Authority

Lenders could use revised criteria to determine how to apply their underwriting terms to the borrower when the property qualifies as location-efficient.

Geographic Scale

LEMs would most effectively be applied in urban areas.

Applicable Ownership Model: Private, SAV

The strategy could be applied in either privately owned or shared vehicle models.

Other Implementation Challenges

LEMs are not currently available in the United States. Two similar pilot programs ran from the late 1990s to the mid-2000s. The first program was supported by several non-profit organizations and backed by Fannie Mae, and it was available in only four metro areas. The second was a simplified version called the Smart Commute Mortgage, eventually available in several dozen areas. In both cases, the lender used an adjustment factor that increased the amount the prospective buyer was able to borrow (Chatman and Voorhoeve 2010).

These programs faced several implementation challenges and were eventually withdrawn from the market. Consumer demand was low; over the years they existed, only 314 loans were made in 18 markets, and in 12 of those markets, 10 or fewer loans were made (Chatman and Voorhoeve 2010, Table 2). According to an analysis of the loans purchased by Fannie Mae, on average, home buyers borrowed less than they would have been eligible for under conventional loans; it was not entirely clear why. One key reason for the lackluster performance of LEMs may be the relaxation of loan underwriting standards during the early 2000s in general, making it easier for lower-income households to purchase homes. Finally, the revised criteria were not incorporated into Fannie Mae's loan software, making it more challenging for lenders to use them (Chatman and Voorhoeve 2010).

If the goal of LEMs is to encourage the use of an SAV fleet to address access to transit stations, the criteria for making an area available to LEM lending could be based on purchasing a home in a denser neighborhood, rather than within a certain radius of a transit station. This is based on the idea that a more dense neighborhood would be easier to serve with shared vehicles than a less dense one. (Current self-drive shared-vehicle fleets, such as Zipcar, generally serve such neighborhoods rather than less dense suburban ones.)

Effect on Implementing Entity

Lenders would need to develop criteria for which neighborhoods to serve, along with specific transit corridors.

Stakeholder Effects

LEM stakeholders are the lending institutions and prospective homeowners, as well as homeowners with LEMs and other homeowners living near transit stations who did not receive LEMs (perhaps because their lenders did not offer them, or because they did not qualify for other reasons).

Winners and Losers

Any homeowner interested in living near a transit station or in a designated neighborhood could benefit if it means they would have a lower mortgage payment than a conventional mortgage or they could purchase a more expensive home (that is, it would expand the number of homes that they could bid on). However, as the housing crisis of 2008 showed, homeowners may experience a loss in home value or may be steered toward mortgages that prove to be too risky; presumably, an LEM would be subject to the same risk and may tempt a prospective homeowner to purchase more house than he or she can reasonably afford.

While LEMs might not create losers per se, they could have other undesirable effects and raise thorny policy questions.

First, they could create resentment among existing homeowners in a neighborhood if it becomes known that LEM borrowers were able to secure more favorable terms.

Second, it is possible that LEMs might interact with gentrification in ways that make neighborhoods less affordable. For example, if high housing prices elsewhere in a region drive homeowners to consider less-desirable neighborhoods, the availability of LEMs might lead to a run on houses in that neighborhood, driving up prices past the point where current occupants can buy them. Or it may lead to the construction of for-sale over rental housing, which also tends to make desirable neighborhoods less affordable.

Third, LEMs might generally drive up the price of housing near transit stations since more competition for housing (which would occur via LEMs because it would increase the number of borrowers who could afford a given house over the previous non-LEM number) tends to lead to price increases. In many high-cost cities, housing prices in neighborhoods served by transit may have already priced in the location, making them more expensive.

Fourth, LEMs face the challenge of who should be eligible. If an affluent household wishes to purchase a home near a transit station, should the buyer qualify for an LEM, or should LEMs be considered an affordable housing tool available only to less-affluent households?

Fifth, LEMs face the same policy challenge as some affordable housing programs: should the terms be altered when a household's circumstances change? That is, if a home buyer originally commutes via transit but later gets a new job and needs to drive, should he or she remain eligible?

Finally, a related challenge is that it would be difficult to verify how home buyers are commuting. Ensuring that such programs would not be vulnerable to fraud could also pose a challenge. (The pilots described above did not require homeowners to use transit, only to live in close proximity.)

There may be wider effects on the housing market, which may impact low-income households.

Politically Powerful Stakeholders

There are no politically powerful stakeholders.

Strategy Disruption

While this strategy is not disruptive to lenders or borrowers, given that it relies on modifying well-established lending processes, it could be disruptive in other ways, such as contributing to a lack of affordable housing in cities that already have a shortage.

Technological Considerations

LEMs would not require any new technology.

Affected by Market Penetration

LEMs are not affected by market penetration.

Optimal Timing

While they could be rolled out as AVs become more available, the timing would be unlikely to matter to AV penetration.

Cost and Benefit Considerations

LEMs would not create direct costs for state or local agencies.

Potential Funding Sources

There are no potential funding sources.

Other Costs to Society

The potential costs to society are described above: the possibility of gentrification and an increase in housing prices leading to lower housing affordability.

Benefits of Implementation

Local governments could benefit financially from LEMs if they reduce the number of vacant properties or increase housing values since both of those would tend to increase property tax revenues. Lenders could factor any higher costs for LEMs into their fee structure for borrowers.

Bottom Line Assessment: Price is undoubtedly an important component of home buying decisions, but there is no evidence that LEMs make a major difference. The additional increment available to qualified buyers in the pilots was generally in the range of $15,000, which is probably not sufficient in many markets to make a difference in the number of homes affordable to the borrower. Major hurdles to implementation are political. There are a number of stakeholders who might have concerns about such a program.

Implement Land Use Policies and Parking Requirements

Strategy Overview

The strategy is to implement land use policies and parking requirements to support the market penetration of SAVs at transit nodes and other activity centers.

General Description

If AVs are introduced into the vehicle market, they may make driving safer, more convenient, and more widely accessible. SAE Level 4/5 AVs, which do not require a driver to operate the vehicle, could significantly decrease the opportunity cost of long commutes and enable vehicles to travel unoccupied. If AVs lower the non-monetary costs of travel and increase consumer demand for vehicle trips and VMT, the benefits of AVs could exacerbate the negative externalities that are often attributed to the low-density, car-oriented land use patterns that shape the U.S. landscape.

An alternative scenario for the application of AV technology is one in which it is applied to fleets of driverless SAVs that provide on-demand rides to a network of travelers. Unlike a personal vehicle that typically sits idle for most of the day, an SAV could serve successive rides throughout the day and

Effectiveness

●●●◎◎

Efficiency

●●●◎◎

Political Acceptability

●●●◎◎

Operational Feasibility

●●●●◎

Geographic Impact

Urban

Who

Local government agencies, MPOs

Hurdles

Political, objections by private developers and local residents

provide first- and last-mile connections to mass transit. Incentivizing SAV use as a complement to transit would help to ensure that vehicle travel increases are minimized or reduced. Parking demand would decrease and open up land for other development near transit hubs. If state and local agencies aim to harness the benefits of AVs but mitigate the potential land use externalities that can result from increased driving, land use strategies can be implemented to encourage the SAV scenario. Thus, the private-sector decisions that the strategy seeks to influence are (from Tables 2 and 3 in Chapter 2):

- Consumers use SAVs rather than privately owned AVs to minimize VMT growth.
- Aging adults, youth, and individuals with disabilities (consumers) use Level 4/5 SAVs.
- Producers develop and sell Level 4/5 AVs that are usable by aging adults and individuals with disabilities.
- Developers build fewer parking facilities or build parking facilities that can be adapted to other purposes.

Zoning ordinances, development codes, and other land use regulations guide the way that land is used in the United States by managing development that is unsafe or undesirable and incentivizing certain types of development. Land use policies also impact travel behavior and the transportation choices that are accessible to individuals. Local and state agencies can adopt land use strategies that prioritize SAVs. In recent decades, growing concerns about the social, environmental, and economic externalities of car-oriented development patterns have inspired planning movements such as Smart Growth and New Urbanism that set out to create a more controlled, compact form of growth (Smart Growth America 2016; Congress for the New Urbanism 2015). To capture the safety benefits of AVs without increasing trips or VMT, land use strategies of this type could be applied to support and incentivize SAV services to reduce or slow increases in vehicle travel and, when coordinated with transit, increase the use of transit.

This section focuses on two strategies: transit-oriented development (TOD) policies and reduced parking requirements. The objective of these strategies is to minimize the potential for personally owned AVs to exacerbate existing land use externalities that are linked to automobile-oriented land development through land use policies that promote SAV use rather than private AV use.

Strategy 1: Transit-Oriented Development Policies

Local and state agencies can implement TOD policies that encourage and enable the provision and use of SAV services. FTA defines TOD as the creation of "compact, mixed-use communities near transit where people enjoy easy access to jobs and services. Well-done TOD connects transit to desirable places to live, work and visit" (USDOT 2007). TOD is a strategy that has been employed in many communities to not only increase transit ridership but decrease dependence on single-occupancy vehicles and support alternative transportation options. Likewise, TOD policies can be applied to support SAVs.

TOD policies enable developers and property owners to build higher-density projects that consider multimodal accessibility, in contrast to conventional development. Conventional sprawl development is frequently defined by (a) non-contiguous, leapfrog, or scattered development; (b) commercial strip development; or (c) large expanses of low-density or single-use development (Ewing and Hamidi 2015). Zoning generally segregates residential, commercial, and industrial land uses, and roadway design prioritizes travel by automobile, sometimes at the expense of other modes (Parsons Brinckerhoff Quade & Douglas Inc. 1998). In contrast, TOD can be defined by:

- Moderate to higher-density development;
- A mixture of residential, employment, shopping, and civic uses and types;
- Walkable to a major transit station; and
- Oriented principally to transit, pedestrian and bicycle travel from the surrounding area, without excluding automobiles (Smart Growth America 2015).

Zoning—including allowable land uses, building setbacks, and densities—is almost always under the control of local governments and dictates what plans and projects can be developed in that jurisdiction. Conventional zoning tends to separate land uses; restrict density, heights, and lot sizes; and often designate parking minimums. TOD policies include zoning changes, density bonuses, overlay zoning, favorable lending terms, grants and loans, streamlined development reviews, and revised parking standards (Cervero et al. 2004).

A number of cities and local municipalities have demonstrated successful efforts to encourage development at transit hubs and to encourage alternative transportation options in those activity centers. Arlington, Virginia, created a string of mixed-use TOD activity centers by implementing a corridor-wide land use plan that encouraged higher-density redevelopment near transit stations. The effort increased transit commuting considerably, and Arlington has far lower car ownership rates than neighboring counties (Brosnan 2010). The corridor's transit hubs also include designated parking for car-sharing vehicles through partnership arrangements with private car-sharing provider Zipcar. San Jose, California, changed its zoning ordinance to incorporate traffic demand management (TDM) measures and reduce parking requirements for certain land uses and development types that are located near transit. Qualified TDM measures include carpooling, on-site car-share parking, alternative fuel vehicle priority parking, guaranteed ride home, parking cash-out, transit shuttles, and bicycle commuter facilities (Shared-Use Mobility Center 2016). The Los Angeles City Planning Department recently received federal funding to support the development of integrated mobility hubs as part of its TOD plans. The hubs are intended to support extending the accessibility of new rail stations with the integration of multimodal travel options including shared vehicles.

Strategy 2: Reduced Parking Requirements

Local and state agencies can apply reduced parking requirements to encourage SAVs and discourage driving alone. Reduced parking requirements are increasingly being applied in TOD and other development efforts as an alternative to the traditional approach: minimum parking requirements for new development. Typically, city zoning dictates a minimum number of parking spaces required per new unit or commercial square footage developed. Different land uses, zoning districts, and other factors can impact the exact requirement. Most parking requirements are designed to meet peak parking demand and result in parking space that is underused much of the time (Shoup 1999). Changes to parking requirements are frequently an element of TOD projects because the availability of (often free) parking has been shown to encourage private vehicle use and hamper efforts to shift travelers to alternatives.

Parking requirements are being changed in cities to encourage transit and shared mobility. The City of Chicago passed a development ordinance in 2013 that allows higher development density and eliminated or significantly decreased parking minimums around train stations. According to Chicago's Metropolitan Planning Council, the elimination of parking minimums allows for 10 times more transit-adjacent land area available for development (Shared-Use Mobility Center 2015). In Austin, Texas, developments in the urban core can reduce off-street parking if they provide showers (10 percent reduction in parking requirement) or car-sharing spaces (20 space reduction per space). Developments in other areas that are zoned as TOD can take advantage of similar reductions (Kendall 2014). GreenTrip is a certification program of TransForm, a mobility advocacy group in the San Francisco Bay Area. GreenTrip is a traffic reduction and innovative parking certification program that allows developers to reduce parking requirements in exchange for viable shared mobility strategies including locating bike-share and car-share parking on site, decoupling rent and parking costs, and offering free or discounted transit and/or car-share memberships that are linked to each unit at a 40-year time frame (TransForm n.d.). Regulations and programs like this can include SAVs as a complementary measure.

In this research, the focus was limited to parking requirements for new development. However, AVs and SAVs would have implications for on-street parking as well. Pricing on-street parking that is typically free for users is another land use practice that incentivizes private vehicle use (Shoup 1999).

Externalities Targeted

SAV-supportive TOD and reduced parking strategies target the negative land use externalities associated with car-oriented, suburban development. The existing development patterns in the United States have arguably had negative social, equity, and environmental consequences. Personal AVs may continue those effects by allowing travelers to disengage from the driving task and increase the demand for distant land, exacerbating the excessive consumption of land for development.

If fully autonomous AVs are combined with transit and shared mobility, the costs of automobile-oriented land use patterns may be minimized. TOD has been found to increase transit use by 20 to 40 percent near stations, although this varies by project (ARC n.d.). SAVs can provide first/last-mile connections to transit hubs; facilitate ride-sharing and ride-splitting; and contribute to walkable, multimodal environments. Land use policies can enable activity centers and transit hubs that support use of SAVs in order to reduce car ownership levels and decrease VMT growth, two trends that underscore existing land use development patterns. This would indirectly impact other externalities that occur as a result of driving, such as increased congestion and pollution.

Like transit and other shared mobility services, SAVs likely require higher densities to be reliable for consumers and financially viable for providers. SAVs could decrease the demand for parking in TOD areas as well because driverless SAVs can attend to other trips after dropping off passengers or drive and park themselves elsewhere. Areas dedicated to parking could be converted to other transportation infrastructure (such as bike-share parking, accessible design, and public space) or other high-value uses.

Applicable Technologies

SAV-supportive TOD and parking strategies apply to AV Levels 4 and 5 that do not require a driver in the vehicle. A driverless SAV can drop off a passenger and, rather than sitting idly in an adjacent parking space, attend to another traveler. Ford Motor Company posits an SAV scenario in which AV Level 4s operate driverless in a geo-fenced urban area that has been well mapped for AVs. AV Level 5s would be able to operate in a wider environment.

Implementing Entities

Land use policy, including both TOD and parking requirements, is almost always a function of local government agencies. Planning, zoning, and/or development agencies lead implementation of TOD strategies, but the exact structures and responsibilities of each agency may vary in different jurisdictions. Transit and transportation agencies are also involved if they own property near transit hubs or have authority over the type of activity that can occur on or near their property. State transportation and development agencies support TOD and parking policies with statewide plans and programs, technical assistance, and funding.

TOD

A city or town introduces TOD ordinances and supporting regulations through its land use and development code. City governments, redevelopment authorities, regional planning organizations, and transit agencies can be involved. Private developers ultimately design and construct new building, but local zoning and development agencies implement and enforce the policies and regulations that guide that development. In Denver, a citywide TOD strategic plan was developed with multiple city departments, including Community Planning and Development, Department of Public Works, Department of Finance, Office of Economic Development, and Parks and Recreation (City and County of Denver 2016).

State and regional agencies support TOD through funding and partnerships and in some cases have developed statewide development plans to support transit development and TOD. In 2011, California passed a law that allows cities and counties to create incentives for transit priority projects including reduced permit costs, expedited reviews, increased density, and height allowances. The bill specifically linked car-sharing to TOD by requiring developers to provide car-sharing on site or nearby, if available (Shinkle 2012). New Jersey's Department of Transportation developed the Transit Village Initiative that provides incentives to local municipalities that redevelop transit station areas with TOD. New Jersey, Rhode Island, Oregon, and North Carolina have instituted policies to encourage various transportation choices (Renne 2008).

Parking

Parking is typically a local responsibility, implemented through similar channels as TOD. Parking requirements for new development are dictated by city or county zoning, development, and land use codes.

Legal Authority

TOD

Land use zoning is almost always under the control of local governments and dictates what plans and projects can be developed in that jurisdiction. Many cities, communities, and even states have already introduced land use policies and regulations that allow for and enable TOD. In San Francisco, the planning code allows for a zoning administrator to reduce off-street parking requirements for specific projects in areas zoned as neighborhood commercial or residential commercial, pursuant to the approval of an application by the project sponsor (San Francisco Parking Department n.d.). Still, the biggest barrier to SAV-supportive development is the existing codes and regulations that have created suburban, single-use development. Changes to laws and policies to enable alternative development forms are likely to be necessary in many jurisdictions in order to implement TOD. Changes to the existing land use and development codes typically require an administrative process and involve city councils, planning boards, and public hearings (Modes et al. 2009). One additional hurdle could arise if states or cities define transit in a way that does not include SAVs. For example, Minnesota law requires that a transit improvement area support at least one "bus rapid transit, light rail transit, or commuter rail" mode (Shinkle 2012).

Parking

Local zoning or development departments typically mandate parking, and changing parking requirements will incur the same challenges as TOD.

Geographic Scale

The implementation process to change land use and development codes is similar across different geographic settings. However, TOD and changes to parking requirements are most applicable in urban areas. Transit and shared mobility services are more successful in high-density areas that offer a large pool of potential riders. For SAV use to complement transit, there must be an existing transit system available or planned.

TOD

TOD projects can be implemented at a site, area, corridor, or regional scale but are most applicable in urban settings with existing transit infrastructure. Zoning changes or land use designations can be citywide or introduced as special TOD zones. Overlay zones can be placed around transit hubs or other activity centers. Individual projects or sites may be given allowances to deviate from the standard zoning or land use requirements. If agencies stimulate environments that support transit and SAV-accessibility, they may induce more provision and use of these travel options.

The introduction of SAVs may enable TOD-type development in less urban areas without fixed transit hubs. Currently, transit systems function well in high-density urban environments where vehicle ownership is costly or cumbersome. SAVs may offer a more flexible and affordable way to serve low-density areas without requiring high-cost transit infrastructure (Klein 2014).

Parking

Parking requirements would be implemented in the same settings as TOD, often in tandem. In urban areas, SAVs may reduce the need for parking adjacent to destinations. In the long term, this may stimulate infill development since existing parking infrastructure in high-rent areas is no longer needed and can be replaced with other types of development. In contrast, the unbundling of parking in urban areas could lead to parking construction on cheaper, undeveloped land in rural areas, following the same patterns seen with earlier sprawl development.

Applicable Ownership Model: Private, SAV

The strategies are being applied to specifically encourage SAVs rather than AVs.

Other Implementation Challenges

TOD

Local agencies trying to implement TOD face fiscal, organizational, and political barriers, many of which occur with other high-density infill projects. TOD policies are *designed* to overcome existing, engrained automobile-oriented development patterns; this is a barrier in and of itself. Asked to rank barriers to TOD in a survey, public-sector agencies involved in TOD named automobile-oriented land uses as the biggest hurdle. Other barriers to TOD include lack of lender interest, local expertise, market demand, and political support (Cervero et al. 2004). A local agency's role is to provide support that can help developers overcome these challenges. Similarly, agencies can address these issues as they coordinate with car-sharing, ride-sharing, ride-sourcing, and, in the future, SAV operators.

Developers who are needed to finance and build TOD and the lenders who fund them are still risk averse to unconventional development. Although increasing travel costs and changing demographics are driving demand for TOD in many cities, automobile-oriented, suburban development is still seen as a safe investment and has a history of demonstrated returns. Another challenge for agencies trying to implement TOD is that many cities still lack robust transit infrastructure. A TOD development may not realize a shift away from personal automobile use if nearby rail service is infrequent or unreliable.

Parking

Reduced parking requirements that are implemented to support TOD development or other smart growth efforts can face many of the same hurdles as TOD. However, as more communities implement these alternative development strategies, there will be more evidence of successful strategies (Dovey 2015).

Effect on Implementing Entity

Both strategies are already being implemented by local agencies in many jurisdictions. Agencies that implement new TOD strategies may face more complex planning decisions that incorporate overlay zones and more nuanced parking calculations. The introduction of AV technology will introduce new challenges and require more coordination with transportation and other city agencies, as is already experienced with TOD. If SAV services are provided by private companies, more coordination with the private sector will be required. City agencies can continue to prioritize transit, consider multiple modes and coordination between modes, identify new or existing nodes for collection points at activity centers and transit hubs, and start planning for the bigger picture of how these services fit together and fit with SAVs.

Stakeholder Effects

TOD

Stakeholders include property owners, developers, and local residents. Transit agencies are also common partners in TOD projects. Local property owners and residents sometimes express concern that higher-density development will cause local congestion and change neighborhood character. Because TOD is still considered a non-conventional development project, it is often perceived as risky by developers and investors. TOD development can face barriers such as high financial risks, class and racial prejudices, and local concern about gentrification (Cervero et al. 2004).

Many private companies have a stake in the future implementation of AVs, and many of them are considering shared mobility as part of this future. Companies like Uber and Lyft are building a shared mobility industry and even exploring AV applications. Uber has just announced that it will allow customers in downtown Pittsburgh to summon self-driving cars from their phones, which will be supervised by humans in the driver's seat for the time being. GM and Lyft have a long-term strategic partnership that encompasses a vision of SAVs.

Parking

Parking strategies impact similar stakeholders to TOD. Developments that require less parking can be received negatively by local residents who fear that less parking will result in spillover parking on nearby streets. Commuters and community members may oppose efforts to reduce parking requirements. Complementary policies that support car-sharing (or SAVs) could minimize this risk. Developers may be able to reduce some construction costs by decreasing parking needs, increasing housing density, and building smaller units.

Winners and Losers

TOD

TOD policies that enable better access to SAVs and transit would benefit ride-sourcing providers, transit users, and TOD developers. Existing and potential users of transit and shared travel options would benefit from better accessibility and increased choice. If SAV use has positive impacts on decreasing pollution and congestion, then there would be broader social benefits for local residents as well. Taxi drivers and ride-sourcing drivers would suffer since driverless SAVs would reduce or eliminate the need for their positions. TOD development often produces smaller units than may be found in lower-density development. New construction can also be more expensive than existing structures. In some cases, this could raise prices or limit housing supply for larger households and lower-income households.

Parking

The largest benefit of reduced parking requirements is likely to go to developers who can decrease costs of parking construction and dedicate more space to housing. In general, more urban land being developed for other uses may create economic and social opportunities for many individuals. Residents who already choose to use transit and shared mobility may benefit from lower housing costs due to the unbundling of parking from housing costs. However, SAV fleets will still need to be parked during certain times of day, and this could result in negative consequences for rural or urban edge areas that may receive large parking or storage facilities for SAVs. A decrease in the availability of off-street parking could lead to increased competition for on-street parking, impacting residents who want or need cars but do not have off-street parking. Searching for parking has also been noted as a contributor to urban congestion.

Land use that encourages SAVs as a complement to transit and enables mobility for residents without cars could have positive benefits for low-income populations and individuals who rely on transit. However, TOD often occurs on high-priced land and faces other development costs, which can make it hard for affordable housing to be incorporated into such developments (USDOT 2007). The Denver Regional Council of Governments introduced Multimodal Toolkits in 2014, a program targeted at improving non-automobile transportation for low-income residents. A partnership between Boulder Housing Partners (BHP), eGo CarShare, and Boulder B-cycle received a 2-year $100,000 Congestion Management and Air Quality (CMAQ) grant to fund the program. It offers discounted and free transit passes, bike-share memberships, and discounted car-share rentals to low-income residents. The program reportedly led to 78 percent of the initial 280 Boulder Housing Partners residents in the program using at least one alternative mode (Mackie 2014).

Encouraging driverless SAVs may present benefits to some travelers who currently cannot drive, though not necessarily all. SAVs may provide a more reliable travel option for this population that can provide door-to-door service at a cost similar to transit. This may also increase travel options for people in underserved transit areas. The costs of SAV are not yet known, and these services may not be affordable, especially when first introduced. SAVs also have the potential to compete with existing transit options, which could reduce funding for services that currently serve transit-captive riders.

Politically Powerful Stakeholders

Private developers are the party most impacted by changes to land use or development codes. New code or zoning requirements may impose costs or be perceived as a burden, and may be opposed by developers. However, in many cities, parking can be a very expensive element of projects, and many developers are pursuing opportunities afforded by land use codes to reduce parking development. Developers can be a powerful stakeholder at the local level and may seek to influence zoning and planning decisions. While some changes, such as reduced parking requirements, may be advantageous for developers in high-cost cities, in other cases, developers may prefer the freedom to build the amount of parking they expect the market will demand.

Another significant stakeholder group is local residents who may resist the development of dense, transit-oriented projects depending on the location and the impact of the strategy implementation on proximate homeowners. TOD represents a shift away from the status quo in development patterns, and this can often cause concern. Although TOD and similar strategies are gaining popularity in some urban and suburban core areas, they are also met with Not-in-My-Backyard-ism (“NIMBYism”) in many areas. Neighborhood groups have a varying degree of influence over local land use decisions in different cities.

Strategy Disruption

TOD

TOD is a development strategy familiar to most local land use and development agencies in urbanized areas. While land use patterns can take many years to change, TOD strategies have decades of practice but still constitute a relatively small part of our developed environment compared to auto-oriented, suburban development patterns that are supported by existing legal, economic, and political institutions. TOD is also bound by the pace at which construction and housing turnover occurs. It can also be hampered by a lack of transit infrastructure in many U.S. cities.

Parking

Parking requirements are increasingly being reevaluated by planners and policy makers, but changing local regulation will occur incrementally. As with other development policy, it can be difficult to change existing standards. Changing parking requirements are typically one strategy in a TOD project or smart growth initiative in which several strategies are combined to encourage changes in the overall travel patterns of local residents.

Technological Considerations

TOD

Land use policies to encourage transit and other alternative travel options are being applied to existing shared mobility services already; SAVs would offer an additional option for these policies.

Parking

Parking requirements exist to regulate the existing fleet of vehicles, and parking reductions are being implemented regardless of AV technology. This strategy assumes that AV technology will be available to both personal vehicle manufacturers and shared mobility providers.

Affected by the Percent Market Penetration

TOD

Agencies can plan for SAVs to be incorporated into TOD strategies since existing shared mobility services are starting to be incorporated today. Even with relatively low SAV market penetration rates, land use policies that encourage shared mobility and SAVs may increase the potential profitability for private shared mobility providers to purchase and use AVs.

Parking

The strategy focuses on encouraging shared use mobility that incorporates AV technology as that technology becomes available. Significant reductions in parking demand would only be viable if there was a significant shift to SAV use and decline in personally owned vehicle use.

Optimal Timing

Both strategies have been implemented (to support transit and other shared travel options) in cities across the United States, and the impacts of AV technology on existing development are increasingly under consideration by planners. Local and state planners can begin to evaluate how SAVs would fit into existing or planned TOD efforts immediately. TOD and parking strategies can begin before AVs are even on the market because these strategies could incentivize shared mobility providers and AV manufacturers to develop vehicles for the

SAV market. If SAVs are introduced, there may be an evolutionary period before a significant shift in travel habits or vehicle ownership would occur.

Cost and Benefit Considerations

TOD

Local agencies would be responsible for introducing a new TOD overlay zone or redrafting sections of the zoning and development codes for their jurisdiction. The main cost would be staff time dedicated to this effort but could involve outside consultants and a significant planning process if it is a major overhaul. For smaller changes, agencies that implement land use or zoning changes will not experience costs that are significantly different from those incurred by other zoning changes. On the other end of the spectrum, Kansas City completely revised the city zoning code over 9 years, at a cost of $457,000 plus agency staff time (Spencer-Fane LLP 2010). If public opposition is significant, more effort may be required to explain the changes and engage with the community.

TOD projects can range in form, size, and cost. Agencies will have to invest far more if a TOD project requires the construction of transit infrastructure, although those costs may be borne in part by transit agencies and FTA. Redevelopment at existing transit hubs or focusing on lower-cost transit infrastructure such as bus and bus rapid transit will be less costly upfront. Several states include bus transit, which is cheaper to build, as an eligible TOD mode (Shinkle 2012). Overall, TOD policies that integrate SAVs would not be significantly different from existing TOD efforts in terms of agency cost.

Parking

Agencies that change parking requirements for development properties will experience similar costs as TOD in terms of the required effort of zoning and planning staff. The effort is not likely to be significantly different than for previous zoning ordinances. A public agency that owns or generates revenue from public parking may experience lost revenue if parking demand is severely decreased by the use of SAVs, as would be expected with driverless SAVs. Local governments may need to enact permit parking programs if building less off-street parking results in more demand for residential on-street parking. Many governments charge residents for on-street parking permits.

Potential Funding Sources

TOD

Changing local zoning and development codes will not require significant outside funding, but implementing TOD projects may. State and local agencies can implement TOD projects using funding from state and federal sources. Grants and funding for TOD exist, as do broader sources of funding for transit projects or urban redevelopment. TOD projects can also be joint development opportunities in which transit agencies or municipalities partner with private developers who build on or around transit stations (Cervero et al. 2004). Developers and property owners ultimately finance most TOD, as with other land development, so most projects will require agency collaboration with private partners. SAVs may require additional partnerships with private service providers.

At least 22 states have statutes that support TOD in some way (Shinkle 2012). In some cases, this simply includes defining TOD, but several states support TOD implementation with funding, incentives, and technical support. Examples include Maryland Transit Administration's TOD funding program, California's Transit Village Development Planning Act, and the New Jersey Transit Village Initiative. Oregon passed a law (Senate Bill 763) to allow tax abatements for higher-density housing near rail stations.

FTA is authorized under MAP-21 to provide financing for comprehensive planning for TOD that facilitates multimodal connectivity and increases private-sector participation. This program was continued in the 2015 FAST Act and distributed about $20 million to communities in 2015 (FTA n.d.). FTA created a Center for Transit-Oriented Development that provides standards, guidance, and technical support for agencies engaging in TOD efforts. TOD plans and capital projects may be eligible for federal funding as well (FHWA 2016). Federal environmental programs, including CMAQ, can also be used to support TOD and smart growth projects (FHWA 2014). The Los Angeles/Long Beach Integrated Mobility Hub project was funded with over $8 million from FTA's Job Access and Reverse Commute Program (City of Los Angeles 2010).

Parking

Like TOD, reduced parking requirements would not introduce large costs for agencies that implement changes to parking regulations. Changes to local parking requirements would not require outside funding. Changes to parking requirements are often part of TOD projects, and the funding sources noted for TOD above would be applicable to parking as well.

Other Costs to Society

TOD

The costs of implementing TOD policies and parking requirements to support TOD and SAVs are uncertain and mainly indirect. As noted earlier, local agencies are equipped to change land use and zoning; administratively, the costs would not be significantly increased. However, the implication that conventional land use patterns would shift with this type of planning would impose some costs on neighboring residents and society more broadly. The upfront costs of TOD can be higher than conventional development efforts due to potential development fees; higher construction costs for mid-rise, multistory structures; and, in infill cases, site clearance or environmental remediation (Cervero et al. 2004). This is especially true if the development includes high capital and operating cost transportation infrastructure such as rail.

Societal impacts include the potential for increased costs of personal vehicle travel, upfront costs to fund transit infrastructure, and quality-of-life effects. TOD may lead to increases in cost or travel time for personal vehicle travel because this type of development would prioritize transit and shared vehicle mobility more than in the past. Transit infrastructure, in particular rail projects, is costly to build and maintain. Many individuals maintain a legitimate preference for personal vehicle travel and suburban development patterns. There are tangible local environmental costs to living in urban environments, such as noise and air pollution.

Parking

The outcomes of reduced parking requirements may increase costs for personal vehicle owners and drivers, who pay more or travel longer to access parking. Parking facility owners and operators may lose revenue if there are far fewer cars to be parked.

Benefits of Implementation

TOD

TOD aims to increase transit ridership and provide economic development opportunities for cities and public agencies. TOD can reduce public infrastructure investments relative to low-density development on undeveloped, distant land and public service costs to serve those areas. TODs have also demonstrated positive impacts on property values (National League of Cities, Sustainable Cities Institute 2013). These effects lead to secondary effects including reduced VMT, congestion, land consumption, road and infrastructure expenditures, and parking costs (Cervero et al. 2004). The Sacramento MPO, SACOG, projects that a regional smart growth plan could decrease infrastructure costs by over $9 billion, decrease CO_2 emissions by 14 percent, increase public transit use by 300 percent, and increase the number of residents who walk or bike by 6 to 13 percent between 2000 and 2050 (Choi 2010). However, not all TOD projects lead to all of these outcomes, and the individual context of a project must be considered carefully by local agencies. In combination with transit, it is possible that SAV use could reduce individual transportation costs, increase transit use, and decrease VMT. It is not yet clear whether SAVs will be affordable or how individual travel behavior will be impacted by the introduction of this travel option.

Broadly, the benefits of compact TOD can be measured in terms of the reduction of negative impacts on agricultural and environmentally sensitive land (Shinkle 2012). Burchell et al. (2002) projected that between 2000 and 2025, 18.8 million acres of land will be converted to build 26.5 million new housing units and 26.5 billion sq ft of nonresidential space in the United States. This is a conversion rate of 0.6 acres per residential unit and 0.2 acres per 1,000 sq ft of nonresidential space. The majority of land that would be converted is agricultural and environmentally fragile land. The authors suggest that nearly one-quarter of this land development could be avoided under a controlled, compact growth scenario. Landis (1995) found that nearly 50 percent of farmland acreage and 100 percent of wetland areas near San Francisco could be saved under a compact growth scenario (Shinkle 2012).

While still relatively new, shared mobility services may also serve to increase transit use and increase multimodal travel options. Car-sharing has been found to lower individual transportation costs, vehicle ownership, VMT, and greenhouse gas emissions (Shaheen and Cohen 2013; Martin and Shaheen 2010), but generally in higher-density areas and for persons whose vehicle use was already below the American average. Evidence on the societal benefits of shared ride services, such as Uber and Lyft, is limited. One study showed that ride-sourced trips were more likely to replace taxi and transit trips than personal vehicle trips (Rayle et al. 2016). However, efforts to increase the occupancy in ride-sourced vehicles through ride-splitting could lead to lower VMT if the density of riders is high and vehicles do not have to travel far out of their way to pick up additional passengers.

Parking

Areas dedicated to parking could be converted to other transportation infrastructure (such as bike-share parking and sidewalks) or other uses, providing opportunities for property owners and developers to capitalize on available property. Cities would benefit from the increase in tax revenue from higher-value development. Land area, particularly in high-value urban areas, presents a significant value to developers, property owners, and residents. Parking can also significantly increase costs for property developers (Litman, n.d.; Shoup 1999). A study of urban Sacramento found that 24 percent of developed land was occupied by roadway and 12 percent by parking (Akbari et al. 2003). Parking area occupies an estimated average of 31 percent of central business districts in cities internationally (Manville and Shoup 2005). Litman (n.d.) estimated that the annual cost of parking facilities ranged from about $400 per acre (in suburban surface lots) to more than $2,000 per acre (in central business districts). A study of TOD properties in Santa Clara County, California, estimated that the unused parking spaces (built to conventional local parking requirements) represented over $37 million in opportunity cost (San Jose State University and Santa Clara Valley Transportation Authority 2010).

Bottom Line Assessment: Land use strategies allow, incentivize, or mandate development features, but they do not ensure that developers will provide them, or that the realized design will function as envisioned. The likelihood that such policies will generate a large shift to SAV use must be compared to existing efforts to promote shared mobility. However, these examples are still quite limited, though they show signs of success where they do exist. Hurdles are political, with potential objections from private developers and local residents.

Apply Road Use Pricing

Strategy Overview

The strategy would employ direct pricing of AV and CV systems for the use of roadway infrastructure. Pricing would be applied to achieve specific objectives related to the impacts—both positive and negative—of AV and CV systems.

Effectiveness
● ● ● ● ◎

Efficiency
● ● ● ● ●

Political Acceptability
● ◎ ◎ ◎ ◎

Operational Feasibility
● ● ● ◎ ◎

Geographic Impact
Urban, suburban, rural

Who
All state and local agencies

Hurdles
Public and political opposition

General Description

This strategy would employ direct pricing on the use of roadway infrastructure. The most economically efficient form of pricing, that which truly internalizes the costs of driving, would be marginal cost pricing that takes into account any number of transportation costs borne by society including congestion, pollution, noise, and oil dependency (among others). In the context of this report, pricing would be applied in order to achieve specific objectives related to externalities associated with AV and CV systems: limiting increases in overall travel demand, limiting distance traveled for housing, discouraging parking in urban centers, and promoting SAV usage. The private-sector decisions that the strategy seeks to influence are (from Tables 2 and 3 in Chapter 2):

- Consumers use SAVs rather than privately owned AVs to minimize VMT growth.
- Consumers of AVs minimize VMT growth, though the technology decreases travel cost and enables mobility among some who cannot otherwise drive.
- Consumers of AVs do not drive farther for housing, even though the technology decreases travel cost.
- Aging adults, youth, and individuals with disabilities (consumers) use Level 4/5 SAVs.

Pricing in this context could take any number of forms, including but not limited to those described below.

Road User Charges

Road user charges (RUCs) are fees levied over a broad area (be it a state, region, or city) that are assessed based on distance traveled (among other potential factors). The charge may be collected through any number of assessment and administration systems including those based on odometer readings, in-vehicle diagnostic-based devices, data from mobile phones or navigation devices, or in-vehicle telematics systems. Fees may also be levied on specific classes of vehicles. For example, while there is only one RUC system currently implemented in the United States for passenger vehicles, several states have mileage and weight-based fee systems targeted to heavy commercial vehicles. Furthermore, as vehicles get more fuel efficient, there may be a need to levy state or national RUCs on electric vehicles. RUCs may also be collected on behalf of transportation agencies by private-sector entities including the providers of in-vehicle services, shared-vehicle service providers, and (in the future) the providers of SAV services. Within an AV and CV context, an RUC might be deployed in order to stimulate or depress the purchase and utilization of these vehicles. If a state or local agency concludes that AVs will lead to overall increases in travel volume or longer commutes, a general RUC on all vehicles or an RUC targeted just to AVs will work to reduce travel demand by affixing a fee to all travel, incentivizing less travel or shorter trips. However, if an agency desires to promote the wider utilization of AV and CV systems, it might deploy an RUC over all vehicles with reduced rates for AVs and CVs, or it may simply levy an RUC on all vehicles that do not support AV and CV functions. The incentives under this regime are oriented around raising costs for non-equipped vehicles and increasing demand for AV and CV systems. An RUC may also be deployed to encourage or discourage vehicle ownership and associated vehicle utilization models. For example, if a government agency wishes to discourage ownership of AVs and encourage the use of SAV systems, then it might levy an RUC on all travel by personally owned AVs but not levy the same charge on any vehicles used as part of a vehicle sharing service. Conversely, if an agency wishes to discourage the use of SAVs, then it may levy the RUC on all shared vehicles services but not personally owned vehicles. An RUC may also be deployed not with the specific objective of discouraging or encouraging a particular behavior but, rather, with the objective of simply offsetting perceived negative impacts of certain behaviors. For example, it is possible that AV systems will result in loss of jobs within industries that rely on professional drivers. This includes the shipping, courier, and taxi industries but may include many more. To offset this loss of jobs, an agency might deploy a general RUC on AVs but would have to dedicate revenues from that RUC to programs aimed at helping the employed within the professional driver industry.

Toll Roads, Tolled Bridges, and/or Tunnels and Managed Lanes

Pricing in the United States is most commonly deployed on specific roadways, lanes, or other infrastructure such as bridges and tunnels. For the purposes of this report, a toll road refers to a roadway facility where all lanes are tolled and there are no parallel free lanes. Similarly, tolled bridges and tunnels are facilities that are available for use only with the payment of a toll. For the purposes of this report, priced lanes include those facilities that feature a lane or multiple lanes that are priced but also feature free parallel lanes. These are generally referred to as managed lanes (MLs) since access is limited (in this case managed) to certain classes of vehicles (such as HOVs) or those paying a toll. It is common for priced facilities, and in particular MLs, to offer various types of incentives to certain vehicle classes. The most common take the forms of transit and HOV discounts, where vehicles with two or more passengers are allowed to use the facility for free in order to increase the vehicle occupancy and person throughput. Agencies may also provide free or reduced access to low-emitting vehicles in order to achieve environmental goals. These discounting mechanisms could also be used to achieve various objectives for AV and CV systems. If a state or local agency wishes to promote the use of AV and CV systems, it may provide discounts to those types of vehicles on priced facilities. These discounts may be coupled with occupancy-related discounts in order to incentivize the wider use of SAVs.

Cordon Pricing

Cordon pricing systems involve establishing a cordon around a particular area, such as a central business district, and charging vehicles for crossing that cordon and, in some cases, charging for mileage accrued within the cordoned area. There are no cordon pricing systems in the United States, but there are mature systems in Singapore, London, and Stockholm, with more basic systems in a few other European cities. If an agency in the United States desired to promote the use of AV systems within a central business district or other discreet location, it might establish a cordon and charge vehicles without AV technology to enter and travel within the cordon. Discounted travel within the cordon area could also be provided to SAV systems. However, if the overall objective is to simply limit vehicular travel into a certain area, then a basic cordon charge for all vehicle classes will be sufficient.

Parking Pricing

Parking pricing involves setting the price for surface parking based on the number of available spaces to maintain a certain threshold occupancy rate. As the total number of available spaces decreases, the price of parking increases. If a local agency desired to limit parking in urban centers and promote the use of AV Level 5 systems, it could simply implement a parking pricing system with graduated fees based on available spaces. This would provide an incentive to use modes that do not require the driver to park, such as SAV systems, during periods of heavy parking demand.

Externalities Targeted

Pricing can be applied in a manner that directly addresses congestion and the costs associated with congestion. This is accomplished by setting price to fluctuate based on congestion levels, volume, or demand. Congestion pricing is commonly applied in the utility industry, where the price for electricity and water services increases during periods of highest demand in order to encourage conservation. Furthermore, private transportation services also levy forms of congestion pricing. TNCs routinely apply what is known as surge pricing where service rates are higher during periods of higher demand. From the perspective of governmental transportation agencies, pricing for congestion is accomplished through either variable or dynamic pricing of facilities or for general travel. In a variable pricing environment, price is set based on a schedule, with price for access being higher during periods of the day when volume is anticipated to be higher. In a dynamic pricing regime, price is set based on actual, observed volumes. Pricing based on congestion helps to internalize the cost of congestion to the driver and may reduce congestion by either incentivizing people to drive during different times of day or use non-priced modes such as carpooling or transit that can reduce vehicular volumes. All of the pricing mechanisms discussed in this report can be structured to account for congestion.

Pricing for the purposes of reducing congestion also can help to address air pollution by increasing traffic flows and reducing time spent idling in traffic. Pricing can also provide an incentive to use lower-emitting modes (in terms of emissions per passenger) such as transit and carpooling, and provide an incentive to use less-polluting vehicles. Agencies accomplish this by offering discounted or free access to preferred vehicle classes such as transit, carpools, and low-emission vehicles such as electric and hybrid cars. Furthermore, pricing may be structured in order to further internalize actual pollution costs. This is generally done by charging a higher access price for heavier and/or older vehicles. Such fees are commonly levied on heavy commercial vehicles in European countries as a means of both collecting revenues from commercial vehicle operators and encouraging those operators to continually shift to newer, lower polluting technologies. All of the pricing systems discussed in the report can be structured to account for pollution.

Pricing could potentially be deployed in order to affect land development. In theory, local agencies could apply pricing on select corridors in order to discourage development (or at least shift commuting patterns within) the areas served by those corridors. However, this is not a common practice because priced facilities are often reliant on a certain volume of traffic to generate funding for project financing. There is no precedent in the United States for the deployment of road pricing to discourage land development since pricing is most often applied in anticipation of development and resultant traffic volumes, not as a deterrent. An agency could implement a cordon pricing system in order to address congestion within a localized area such as a central business district. In this case, land development may be impacted within the charged zone based on the policy objectives of the system. A cordon pricing system, if effective at limiting personal vehicle traffic into the charge area, could result in the reallocation of land use away from parking facilities and to other land uses such as walking and biking facilities or transit facilities.

Pricing is currently applied to achieve general mobility objectives by providing discounted or free access to privileged vehicle classes and user groups. For example, many ML facilities provide discounted or reduced tolls for HOV, low-emitting vehicles, and/or transit vehicles. Transit access, in particular, is valuable in terms of promoting mobility for lower-income drivers and those without access to a personal vehicle. Furthermore, some pricing applications attempt to address equity concerns by providing free (or reduced cost) tolling transponders to lower-income drivers and providing toll credits when alternate modes, such as transit and carpooling, are used. Similar incentives could be provided to groups for whom mobility is an issue. For example, free or discounted toll tags and toll rates could be provided to users of AVs that have a disability in order to provide additional mobility options. Similar discounts could be used in order to provide privileged access to priced facilities by SAVs or vehicles with safety-related CV equipment.

Applicable Technologies

Pricing applications are currently implemented in numerous forms throughout the United States. They can be applied regardless of the CV/AV technology. However, the penetration of CV/AV technologies within the general vehicle fleet could make the implementation of pricing easier since these vehicles are likely to be equipped with technologies that allow charges to be levied and collected without the need for aftermarket components such as tolling transponders and toll tags.

Implementing Entities

A statewide pricing system, such as an RUC or statewide tolled road network, would have to be initiated by a state legislature. State legislation would have to designate the appropriate state agencies to implement, operate, and administer the system. Responsible agencies could include state departments of transportation, departments of motor vehicles, or state comptroller's offices, but the private sector and local agencies could also play a significant role in the levying and collection of the fee itself.

State and local agencies have the authority to implement facility-specific tolling (general toll roads and MLs), parking pricing, and cordon tolling. However, if pricing is to be applied on a facility that receives federal funding, authority to price lanes on that facility must first be granted by FHWA. The agencies most likely to be responsible for implementing facility-based pricing are local agencies including MPOs, local/regional toll authorities, transit providers, local governmental councils, and private consortia.

Legal Authority

There are currently no federal limitations on the ability of a state to levy an RUC. States and local agencies are limited in their ability to levy statewide charges only by their own specific state legislation. The collection of a statewide-level RUC would need to be done through the passage of state legislation that enables a designated state entity to operate and administer the charging system. So far only one state, Oregon, has passed legislation authorizing a road user fee system on personal vehicles. However, the system is limited in scope since only 5,000 initial participants are authorized. There is currently no federal legislation limiting the implementation of an RUC by a state.

In certain cases, local and state agencies must first conduct environmental assessments to determine the impact of pricing if it is to be levied on a facility. This is particularly true in areas that are classified as non-attainment by the Environmental Protection Agency for certain air pollutants. Such non-attainment areas are required to meet various air quality objectives as a prerequisite for federal planning funds, which are administered through the regional MPO. Non-attainment areas desiring to implement a pricing system must show how that system will impact air quality and show how equity and access issues will be addressed. This is generally accomplished through the traditional urban planning and development process.

In many cases, a state legislature must first authorize municipalities to collect tolls, meaning that many local and regional pricing mechanisms might first require action by the state legislature in order to levy tolls on infrastructure. There are currently 35 U.S. states and territories that have at least one tolled highway, bridge, or tunnel (International Bridge Tunnel and Turnpike Association 2015).

States are limited by the federal government in terms of their ability to implement tolling and pricing on federal aid highways. Under Section 166 of Title 23, existing HOV lanes can be converted to collect tolls if the local MPO endorses the conversion and subsequent use and number of tolls on the converted lanes. Project sponsors must also demonstrate that "conditions on the facility are not already degraded and that the presence of paying vehicles will not cause conditions on facility to become degraded." Section 166 also requires that, in the event a previously free federal aid facility is to feature a new pricing component, then the facility must provide the same number of free lanes as existed prior to the imposition of tolling. Furthermore, operating agencies are subject to annual reporting requirements on the converted lanes and must bring the facility into compliance (either by increasing HOV occupancy requirements, increasing tolls, increasing capacity, or eliminating access to paying motorists) if conditions degrade. All tolls on new federal aid highway lanes must incorporate a variable pricing component and use electronic toll collection to manage travel demand. Section 166 also established other requirements that must be met by the implementing agency in terms of operating tolled lanes on federal aid highways. Toll revenue usage for converted HOV lanes is dictated by Section 129 of Title 23, which imposes a requirement for annual audits to be conducted and transmitted to USDOT. The Secretary of Transportation is then authorized to, based on these audits, make determinations as to whether all requirements stipulated under Section 166 are being met (FHWA n.d.c).

Geographic Scale

Statewide RUCs will cover both urban and rural areas within a state. Equity issues are likely to be more pronounced in rural areas with more low-income residents because they are likely to perceive the system as unfair given that they have to travel farther for work and basic amenities relative to their urban counterparts. However, Oregon's most recent RUC pilot found that while rural drivers do indeed drive farther on a trip-by-trip basis, they also make fewer trips, meaning that their total mileage is comparable to urban drivers, and they may, in fact, pay less under an RUC relative to urban drivers (D'Artagnan Consulting LLP 2013).

Facility pricing is most likely to be applied in urban areas on facilities with sufficient volume to generate a viable funding stream. However, toll roads have been implemented in rural areas as a means of providing a bypass. In both rural and urban areas, income equity issues are often raised, as are issues about accessibility. Accessibility issues may be more prominent in rural areas where residents have few travel options relative to their urban counterparts.

Cordon pricing is most likely to be implemented in urban areas and, specifically, dense urban cores and central business districts. There is generally not sufficient travel demand and associated traffic volume to necessitate a cordon pricing system in rural areas.

Parking pricing is most likely to be implemented in urban areas where parking may be limited. Rural areas and small town centers generally do not have sufficient traffic volume and associated demand on pricing to warrant the imposition of a parking pricing system.

Applicable Ownership Model: Private, SAV

Pricing can be effective under any ownership model. However, depending on the specific application, the SAV model may lower potential administrative and operating costs. This is because the SAV model reduces the potential number of collection points for the charge. Numerous people can make numerous trips under this model with the charges being accrued to and collected from one vehicle. These costs, once collected from the owner of the vehicle, can then be passed on to the vehicle's various users by the service provider as opposed to the implementing entity. The total number of accounts that must be maintained is reduced. Pricing may also be more effectively enforced under the SAV model, assuming that vehicles are equipped to assess and levy charges. Drivers will likely have the cost of any tolls (be it a statewide RUC, facility toll, or parking fee) levied on the bill they pay for the overall service. All costs associated with a particular trip can be included in one bill paid for the overall service as opposed to having to pay tolls separately. The private sector has already shown that it can implement controversial congestion pricing systems. For example, many TNCs employ a pricing regimen known as surge pricing, which increases the cost associated with providing mobility services in proportion to demand of those services. When more people need to use the service, the price goes up. This is essentially the same economic pricing principle underlying congestion priced toll facilities in the United States, where the price for access to the tolled facility or lanes increases in response to the number of vehicles using the facility/lane.

Other Implementation Challenges

The levying of any pricing system within an area where there are no existing systems will require the development of pricing infrastructure (such as tolling gantries) and administrative systems and an increase in staffing in order to operate and administer the system. Agencies may alternately contract with the private sector to fulfill these needs. A statewide RUC could require either a significant increase in personnel, data processing, and storage and management or a greater reliance on the private sector.

Effect on Implementing Entity

The implementation of a new pricing system will increase agency responsibility for operating and administering the system. A new pricing system may also result in the generation of new revenues for use by the implementing agency.

Stakeholder Effects

Drivers (including commercial vehicle users) are a stakeholder in that they use the facilities being priced and will be asked to pay a fee for that use. They will be negatively impacted in that they will be paying more for transportation services but may also benefit from those services as well. The owners of the facilities (state and local agencies) being priced are stakeholders in that they will have additional revenue streams available for providing transportation services but will have greater responsibility for the operation and administration of those facilities. OEMs and aftermarket device manufacturers are stakeholders. OEMs may find that, if pricing is levied on specific vehicle classes such as AVs, the incentive of drivers to purchase those vehicles will be reduced. Aftermarket developers may realize new business opportunities by providing the components necessary for the assessment and collection of fees. Back-office entities, which may include a governmental agency (such as a DOT or state DMV) or private contractor, are stakeholders in that they will be responsible for maintaining administrative data on facility users and, in some cases, conducting collections and other enforcement activities.

State and local elected officials are a stakeholder group in that they will be responsible, in many cases, for authorizing the implementation of these pricing systems and will be accountable to the public for performance of the pricing system in meeting its stated objectives.

Business owners in the vicinity of the pricing system are also stakeholders in that there is the potential for their businesses to be impacted by the imposition of a pricing regime. Toll facilities may lead to drivers bypassing certain businesses, while cordon pricing systems could reduce vehicular traffic into priced areas. Depending on the scale of the pricing application, the general public could also be considered a stakeholder regardless of whether they use the priced roadway or drive within the priced area. Pricing increases the costs of shipping goods and providing services, meaning that costs associated with shipping and associated services could be passed on to consumers regardless of whether they are drivers.

Winners and Losers

The general public is likely to benefit from enhanced transportation services made possible by a pricing system. Higher-income drivers, who can afford to access priced facilities to a much greater extent, are likely to be beneficiaries of any pricing system. Users of alternate modes like biking are likely to benefit from a cordon pricing system. Environmental stakeholders are likely to benefit. Winners will depend on use of revenue.

Transportation pricing, regardless of the specific mechanism, can generate equity issues based solely on the fact that it imposes new costs on travelers. These costs are likely to make up a greater percentage of the cost of living for lower-income drivers relative to middle- and upper-income drivers, who can more easily bear the cost.

If pricing is applied in a manner that provides incentives for AV and CV adoption, there could also be income equity issues. In the near term, it is likely that AV and CV systems will only be present on newer and higher-end vehicles, meaning that low-income drivers are less likely to purchase them and benefit from the pricing incentives.

Politically Powerful Stakeholders

The trucking and general shipping industries are likely to oppose tolling of major roadways and corridors, particularly if fees are set based on vehicular weight and emissions class to achieve environmental-related goals.

General public opposition to pricing can lead to political opposition by elected officials. One of the most common reasons for the failure to implement pricing systems is political opposition stemming from public opposition.

Strategy Disruption

Pricing can be moderately disruptive. It is a different way of paying and will take an adjustment. AV technology itself is very disruptive, and pricing is not going to seem that disruptive. This could actually make pricing implementation on a wider scale more feasible.

Technological Considerations

Pricing could potentially drive the deployment of CV systems if it is implemented such that internal CV system technologies are used to assess and collect fees. This would reduce the need to purchase toll transponders or tags.

If AV and CV systems are able to communicate with transportation systems without the need for roadside infrastructure, such as through cellular transmission networks, then the need for state and local agencies to rely on roadside tolling infrastructure such as overhead gantries would be reduced.

Affected by Market Penetration

Pricing systems in general are already feasible and implemented throughout the United States. Their viability will not be hindered by a lack of AV or CV market penetration.

Statewide RUC systems are currently being implemented in Oregon and actively explored through pilot programs in California and Washington. The technology and back-office systems have developed significantly since Oregon concluded its first pilot in 2007. Successive pilots have noted the need for technology improvement, but technology limitations have not been identified as a restraining factor in RUC development. As such, the technical viability of RUC development is not hindered by the percent market penetration of equipped vehicles. However, RUC systems would likely be easier to implement within a CV/AV context, particularly with significant market penetration of equipped vehicles. This is due to the large amount of data likely to be stored onboard the vehicle that could potentially be used for estimating miles traveled. Furthermore, AV penetration could lower costs associated with administering and managing data because a significant portion of the data required for fee estimation would be collected and maintained by the private sector.

All other pricing systems have seen some form of implementation, although cordon charging systems have only been successfully deployed in Europe and Singapore. The deployment of these systems will not be dependent on the penetration of equipped vehicles in the auto market. However, pricing systems dependent on DSRC technologies could be easier to implement from a vehicle equipping standpoint. CVs using DSRC technology would likely not need to purchase tolling tags, which would enable wider usage of those facilities and reduce implementation costs.

Optimal Timing

Pricing is already being implemented in a number of forms to address public policy concerns outside of those associated with AV and CV deployment, most notably system management and revenue generation. As such, there is no optimal timing for this strategy intervention. Furthermore, it is unlikely that large-scale statewide RUC systems, facility-based tolling, or parking pricing would be implemented directly in response to AV- and CV-related externalities. However, the operational policies of a pricing system might be adjusted in order to address AV- and CV-related externalities. This need will only manifest itself when AV and CV systems achieve certain market penetration levels to trigger public concern and associated action by elected officials.

Cost and Benefit Considerations

State Charging Systems

There is only one state road user charging system in operation, and it has not been in operation long enough to generate estimated costs associated with operations and maintenance. However, rough road user charging system costs have been developed based on previous pilots of the concept. A National Cooperative Highway Research Program (NCHRP) report estimated that fees based on VMT would yield the following costs: $4,042 per lane mile, $6.26 per 1,000 VMT, $75.16 per vehicle, and $6.95 per transaction, with total costs equaling 6.6 percent of total revenue (Balducci et al. 2011).

Cordon Pricing Systems

NCHRP estimated that a domestic cordon pricing system might cost an estimated 38.7 percent of total revenue based on the international experience of other systems, such as those in Stockholm and London.

Tolling Systems

Operational costs for an electronic toll facility can range between 12 percent and 20 percent of annual toll revenues, or between $0.23 to 0.62 per toll transaction. Maintenance costs can range from 1 percent to 16 percent of annual toll revenue. Cost for a given facility will depend on the size of the facility, type of facility (road, tunnel, bridge), percent of electronic toll transactions, division of responsibilities between contractor(s) and agency, number of violators and cost to collect from violators, availability of automated electronic toll collection customer account access via Internet and telephone, variations in facility bond covenants, and variations in accounting practices (IBI Group 2007).

Managed Lane Systems

The costs associated with deploying tolling and ML systems depend on the nature of the project. Deployment in dense urban areas with little available right of way can increase costs, for example. The 2015 Urban Partnership Agreement invested significant funding in several U.S. cities in order to implement pricing systems on MLs. The level of investment in tolling systems for each city was as follows: Atlanta ($52 million), Los Angeles ($106 million), Miami ($43 million), Minneapolis ($267 million), and San Francisco (40 million) (Zimmerman et al. 2015).

Potential Funding Sources

Traditional transportation funding sources, such as fuel taxes or general revenue funds, could be tapped to implement these systems.

Revenues from the pricing itself are likely to be a viable funding source for pricing system development. Toll roads and priced facilities are increasingly financed using a mixture of bonding authority and credit, which is typically backed by anticipated future toll revenues. Thus, it is possible to implement these systems without the need to use traditional funding sources.

Benefits of Implementation

The U.S. Bureau of Transportation Statistics (BTS, n.d.) classifies costs and benefits within transportation in general and for specific incentives (such as pricing) under several categories. BTS notes that the major reason for incentivizing some modes (such as, potentially, AV and CV systems) is that they are "perceived as providing social benefits in addition to the benefits provided to passengers using these modes." Benefits can take the form of societal costs in general (environmental pollution and excessive energy use), congestion costs, and efficiency costs (in terms of accurately pricing the marginal costs of transportation usage). Benefits accrue to society based on making improvements to these key areas of cost, which has the effect of increasing total social welfare by improving air quality, reducing energy consumption, reducing congestion, and efficiently using transportation systems.

Costs Compared to Benefits

The relative weight of costs and benefits from pricing varies significantly based on the project type and use of funding. The costs imposed on society from an RUC might be significant in terms of revenues generated, but significant benefits can accrue if these revenues are used to enhance the transportation system. From the perspective of an individual driver, a priced lane, cordon, or parking charge might be a significant one-time cost, but the driver may benefit from expedited (or congestion free) travel or the guarantee of an available parking space.

Bottom Line Assessment: Pricing could be effective in achieving specific objectives related to minimizing the impacts of driving. However, road use charges are among the most unpopular of pricing applications in society. Thus, hurdles to implementation will be public and political opposition.

Implement a No-Fault Insurance Approach

Strategy Overview

Restructure liability regimes to accelerate market penetration of AVs by implementing a no-fault insurance approach.

General Description

If autonomous and connected technology reduces the perceived responsibility of the individual driver, a no-fault approach to assigning financial responsibility for crashes may appear more attractive. Currently the law in about 12 states, the no-fault system allows crash victims to recover damages from their own auto insurers after a crash instead of having to seek recovery from another driver. It might retain the model of having the individual car owner be fiscally responsible for crashes and preserving the vast existing crash economy, of insurers and other parties, without having to make potentially difficult determinations about responsibility between drivers, automobile makers, etc. This may make it less likely that manufacturers would face the increased liability costs that may slow the introduction of the technology. The private-sector decisions that this strategy influences are (from Tables 2 and 3 in Chapter 2):

- Producers develop and sell safe AVs.
- Producers develop and sell Level 4/5 AVs that are usable by aging adults and individuals with disabilities.

There are at least two versions of the no-fault approach that might be used. First, a national no-fault program could create a means by which victims would be compensated similar to the National Childhood Vaccine Injury Act, which was passed to limit liability for drug companies and create a no-fault compensation system for those injured by vaccines. This is the most attractive and comprehensive version of a no-fault approach. However, it is outside the scope of the current report, which focuses on state and local efforts.

Alternatively, a state legislature could pass a no-fault regime that is applicable to the particular state.

Current U.S. no-fault auto statutes (which are all state based) have an injury threshold; if a crash causes an injury of sufficient seriousness (usually measured in a dollar amount), then the no-fault restrictions are lifted and the plaintiff can sue whomever (including another driver or a manufacturer). For good and for bad, the existence of the threshold has preserved many of the advantages (access to justice) and disadvantages (transaction costs) of the conventional tort system. If a goal of the no-fault strategy were to reduce manufacturer liability, then a no-fault law would have to either be without a threshold or explicitly exempt manufacturers from lawsuits. This would be unlike all existing and past U.S. no-fault laws.

Externalities Targeted

There is some concern that fear of civil liability will deter the efficient development and adoption of this technology because of the perception that these technologies are inconsistent with the conventional attribution of fault in automobile crashes and the concern that the liability system inefficiently burdens new technology. The negative externality comes from this liability "tax" on new technologies. However, the conventional fault-based system of crash liability is likely to be able to adjudicate the responsibility for such crashes with a larger proportion of the responsibility falling on the auto manufacturers.

The case for no-fault automobile insurance depends on how important it is to (1) clarify liability and (2) reduce manufacturer liability. At this point it is not clear whether these goals are worthwhile. No-fault insurance would likely clarify liability and, depending on the statutory language, reduce or eliminate manufacturer liability. If one believes that the tort system creates externalities, reducing tort liability would reduce externalities. However, no-fault automobile insurance in the United States has had the unintended consequence of substantially increasing insurance costs. It is possible that the same would be true for a new no-fault approach, though there may be ways to control this.

For this externality to affect AV/CV adoption, it must uniquely apply to new technologies. If tort judgments are too high across-the-board, this may result in suboptimal outcomes, but it will not especially slow the adoption of AV/CV technology. If a state passed a no-fault law that prevented suits against manufacturers, this impact, assuming it exists, would be reduced.

No-fault could actually slow adoption of AV/CV technology rather than accelerate it. If AV/CVs are much less likely to be at fault, then their insurance costs are likely to be comparatively lower under a conventional fault-based system. In that case, instituting a no-fault system may actually reduce incentives to adopt AV/CV technology because purchasers would not recoup the full benefits of crash reduction if most of the avoided crashes are ones in which the operator would have been found at fault. No-fault approaches may also reduce incentives for safety. If a vehicle operator is no longer fully responsible for the crashes that they cause because victims will recover from their own insurers, they may have reduced incentive for safety. Since safety is expected to be one of the key comparative advantages of AV/CVs, it is possible that this effect may slow adoption.

Applicable Technologies

This strategy would apply to all technologies and passenger vehicles. It would probably not apply to shared vehicle operations, commercial trucking, or transit because they typically use different kinds of insurance and are regulated by different statutes.

Implementing Entities

The state legislature would implement this strategy by passing a law that would govern insurance in the state.

Legal Authority

The legislature most likely has legal authority to enact a no-fault statute. However, if the statute precluded lawsuits against manufacturers, plaintiffs may challenge it as violating state constitutional rights on access to courts and jurisprudential doctrines on the separation of powers. It is difficult to predict whether those challenges would ultimately succeed, but the litigation would likely delay the effective date of the enactment.

Geographic Scale

This strategy would be implemented at the state level.

Applicable Ownership Model: Private, SAV

It is applicable to an individual ownership model of cars.

Other Implementation Challenges

States without experience in implementing no-fault insurance systems may experience some implementing challenges as the relevant agencies, policy makers, and courts learn about this approach. Consumers, courts, lawyers, insurers, and claims adjusters would also have to learn about the new approach, the limits on suits, the process of claiming from one's own insurance company, the size of the injury thresholds that allow circumvention of the limits on lawsuits, and the secondary effects. There are also sometimes interactions with victims' health insurance and determinations as to whether the auto insurer or the health insurer is ultimately responsible for the cost of medical care.

Effect on Implementing Entity

The legislature passing the statute would not be particularly impacted. The state insurance commission would have to issue new rules.

Stakeholder Effects

Auto insurers, auto manufacturers, consumer groups, plaintiffs' attorneys, and transportation network operators (e.g., Lyft and Uber) would all be relevant stakeholders. The extent to which these stakeholders would be affected by the strategy depends on many variables including the details of the statute. While initially auto insurers supported no-fault approaches, current opinion in the insurance industry is mixed. Historically, consumer groups' views on no-fault insurance also varied.

Winners and Losers

Different auto insurers are likely to oppose or support the passage of individual state no-fault statutes depending on their perceived comparative advantage in those states. If no-fault statutes included a provision that exempts manufacturers from liability, this would obviously benefit the manufacturers. Plaintiffs' attorneys would almost certainly oppose this strategy because it would reduce access to the courts and prevent some lawsuits against otherwise culpable motorists and manufacturers.

Historically, most forms of automobile insurance have been very expensive in impoverished urban neighborhoods due to a variety of factors. Whether no-fault policies would be more expensive would depend on the rating factors allowed.

Politically Powerful Stakeholders

In the past, trial lawyers have opposed no-fault approaches to auto insurance. They have generally succeeded in ensuring that any no-fault legislation includes injury thresholds so that seriously injured victims are permitted to sue other parties in tort. Insurance companies are also powerful stakeholders, but their position on a no-fault approach to auto insurance depends on the specific company. Trial lawyers' opposition is likely to be a substantial barrier to enactment.

Strategy Disruption

The strategy is substantially disruptive to the existing automobile insurance system in states that do not already have a no-fault system. If liability protection was extended to automobile manufacturers, this would be a disruptive change even in states that currently have no-fault automobile insurance systems. States without experience in no-fault systems may encounter challenges as the relevant agencies, policy makers, and courts learn about this approach. Consumers, courts, lawyers, insurers, and claims adjusters would also have to learn about the new approach.

Technological Considerations

There are no technological considerations.

Affected by Market Penetration

The strategy is not affected by market penetration.

Optimal Timing

It is not especially time sensitive.

Cost and Benefit Considerations

Training costs would be necessary to teach courts, lawyers, consumers, and state insurance agencies how no-fault automobile insurance works. It is difficult to estimate the magnitude of such costs.

Potential Funding Sources

General tax revenues would be the most likely source, but the costs to the state are not likely to be particularly high.

Other Costs to Society

Based on past experience with no-fault automobile insurance approaches in the United States, consumer automobile insurance costs are likely to rise.

Benefits of Implementation

The possible advantages of the no-fault approach are that it would clarify liability and protect manufacturers from liability. However, it is unclear whether this protection for manufacturers would benefit society.

Bottom Line Assessment: State-level no-fault automobile insurance would likely accomplish goals of clarifying assignment of liability and, depending on the statutory language, reducing or eliminating manufacturer liability. The political feasibility of implementing such an approach in certain states is uncertain due to the potential opposition from powerful stakeholder groups.

Effectiveness
●●●●◎

Efficiency
●●●●●

Political Acceptability
●●●◎◎

Operational Feasibility
●●●●●

Geographic Impact
State

Who
State legislatures and state insurance agencies

Hurdles
Popularity with general public; enforcement of insurance minimums

Require Motorists to Carry More Insurance

Strategy Overview

This strategy involves restructuring liability regimes to accelerate market penetration of AVs by requiring motorists to carry more insurance.

General Description

States could raise mandatory insurance minimums to cover a higher proportion of the expected harms associated with a serious motor vehicle crash. In many states, motorists are only required to carry $30,000 or less worth of liability insurance. With the value of a statistical life for USDOT being more than $9 million, this leaves a vast gap between the harms that are regularly inflicted by drivers and the amount available for recovery. This gap discourages the purchase of safer CV/AVs because it has the effect of subsidizing more dangerous vehicles. The private-sector decisions the strategy attempts to influence are (from Tables 2 and 3 in Chapter 2):

- Producers develop and sell interoperable V2V or V2I mobility and environment applications.
- Producers develop and sell safe AVs.
- Producers develop and sell Level 4/5 AVs that are usable by adults and individuals with disabilities.

Externalities Targeted

Many motorists are either not insured at all or underinsured. Because they lack sufficient assets, they are essentially judgment proof: they are impossible to sue because they do not have sufficient assets to pay a judgment against them. Because it is possible to impose substantial harms on others as the result of driving a motor vehicle, this failure to carry adequate insurance imposes a substantial negative externality on other motorists and pedestrians. Other motorists and pedestrians can be harmed with relative impunity. This acts as a *de facto* subsidy to dangerous vehicles and motoring behavior. Since CV/AV technologies are expected to be substantially safer than conventional vehicles, this externality subsidizes existing vehicles and reduces the economic incentives for adoption of safer technology. One strategy then is to require motorists to carry more insurance.

Applicable Technologies

This strategy would encourage the adoption of technology that results in safer vehicles. To the extent that CV/AVs are safer than those driven by humans, it will encourage their adoption.

Implementing Entities

This could occur on either a state or federal level. Since insurance and driver requirements have historically been regulated at the state level, the remainder of this section addresses this possibility.

Legal Authority

State legislatures have the legal authority to enact or change such laws. However, enforcement of even existing insurance requirements has historically been a problem, particularly in some jurisdictions. Increasing the insurance minimums is likely to exacerbate that problem and lead to more noncompliance. While most states require proof of insurance as a condition for registration of the vehicle and obtaining a valid license plate, enforcement of this requirement is haphazard. In Pennsylvania, for example, one is required to submit proof of insurance in order to receive a registration sticker of about 1 in. by 1.5 in. that is then attached to one's license plate. While it would be theoretically possible for police to observe an expired registration sticker, it would be difficult. In Philadelphia, these stickers are sometimes stolen from parked cars and then resold. Determining the best method to enforce existing and increased insurance requirements was outside the scope of this research but needs to be acknowledged as an important obstacle to this strategy. There are various technological solutions, for example, requiring every vehicle (including existing vehicles) to carry a transponder that transmits real-time proof of insurance, but these have their own disadvantages.

Geographic Scale

The geographical scale is national.

Applicable Ownership Model: Private, SAV

Increased insurance requirements would affect private owners of vehicles. MaaS models would typically use other kinds of insurance.

Other Implementation Challenges

There are no other implementation challenges.

Effect on Implementing Entity

There would be no impacts to the implementing entity.

Stakeholder Effects

The web of stakeholders is complex and includes consumer advocates who may be alarmed about mandatory increased purchase requirements and insurance companies who may support these requirements. Many individual consumers are likely to oppose the increased costs associated with higher mandatory insurance requirements. It is difficult to anticipate how intense this opposition is likely to be and whether it would be possible to explain the advantages of this approach. Trial lawyers are likely to support this change.

Winners and Losers

Victims of car crashes and the lawyers who represent them are likely to benefit from this strategy. Increased insurance requirements would also raise equity issues. In most jurisdictions, automobile insurance is priced according to locality, with urban jurisdictions being the most expensive, as a function of the claims history (including both likelihood of crash and jury verdicts). This results in very high auto insurance premiums for many of those least able to pay them. This, in turn, leads to widespread failure to obtain insurance, which can lead to a vicious cycle of increased insurance rates.

Politically Powerful Stakeholders

Insurers and trial lawyers have both traditionally been politically powerful groups who are likely to support this change. Automakers may oppose it because it will make it more expensive to operate a vehicle.

Strategy Disruption

This change would be fairly incremental rather than radical. If it occurred at the state level, it would not fundamentally alter existing laws or relationships.

It is possible that federal legislation could also accomplish the same thing. This would have the advantage of accomplishing the goals of reducing this negative externality by passing a single piece of legislation and would reduce the patchwork quality of existing laws. There is some precedent for attempting insurance changes on a federal level. In the late 1990s, there was a bill introduced in Congress to enact a national no-fault automobile insurance. However, this bill did not pass. States have historically regulated all forms of insurance, so a federal bill would represent a radical change in the status quo.

Technological Considerations

The strategy impacts technology development because it would increase the financial advantages of technologies that reduce crashes.

Affected by Market Penetration

The technical viability is not affected by the market penetration unless the new insurance requirements are only applied to new vehicles.

Optimal Timing

Optimal timing is as soon as possible. The strategy could be implemented immediately.

Cost and Benefit Considerations

The direct cost to implement the strategy to the state would be fairly small; it involves passing a bill. The increased enforcement costs could be substantial, though they may be partly offset by fines. It is difficult to estimate the potential benefits, but they include (a) increased resources to those seriously injured or killed by automobile crashes, (b) elimination of the existing public subsidy for dangerous vehicles and drivers, and (c) increased incentives to purchase safer automobiles. While the benefits of this strategy exceed the costs, it is difficult to measure their magnitude. They will depend in part on the price elasticity of consumers with respect to new technology. If consumers are highly price elastic, then relatively small changes in the costs of using existing vehicles will cause consumers to purchase new, safer technology. If consumers are not price elastic, then raising the existing costs of vehicles will not lead to a substitution of safer vehicles and transportation modes.

Potential Funding Sources

Costs of implementation will be relatively low, so no new funding source is likely to be necessary. In the long run, reduced public crash costs are likely to pay for whatever short-term public costs are entailed.

Other Costs to Society

There are no other costs to society.

Benefits of Implementation

The benefit to society of implementation would be substantial.

Bottom Line Assessment: The strategy is very likely to produce a net-positive socially beneficial outcome because it will eliminate the existing subsidy for unsafe vehicles and drivers. Without enforcement, the strategy may have unintended consequences, namely the increased incidence of consumers not purchasing any insurance. Hurdles include the effective enforcement of insurance minimums and the likely unpopularity of higher mandatory insurance requirements among the general public.

Subsidize CVs

Strategy Overview

This strategy seeks to encourage the adoption and market penetration of CV technology by providing subsidies for CV equipment.

General Description

The objectives of this strategy are to accelerate the market penetration of CV technologies for both new and aftermarket vehicles. This strategy is particularly effective when the

Effectiveness

●●●●○

Efficiency

●●●●○

Political Acceptability

●○○○○

Operational Feasibility

●●●○○

Geographic Impact

Urban, suburban, rural

Who

Any state and local agencies

Hurdles

Political feasibility: allocation of funds with unknown return on investment primary barrier for widespread adoption of a technology or service is the relatively high entry price, for either producers or consumers. By providing a subsidy for CV technology, the effective price to produce and/or consume the technology is lowered, making it a more attractive and affordable option for a much wider market. The private-sector decisions targeted include (in Tables 2 and 3 in Chapter 2):

- Producers develop and sell interoperable V2V or V2I mobility and environment applications.
- Consumers purchase vehicles with V2V and V2I capabilities.
- Consumers purchase and use aftermarket V2V safety applications.

Externalities Targeted

By encouraging the adoption of CV technologies, traffic crashes (number and severity), congestion, pollution, and land development may be reduced, and mobility may be increased. These effects would all be positive, meaning the stakeholders of the externality experience an improvement. However, the externality of economic disruption to driving professions, which is already considered a negative externality, would be further negatively affected by this strategy.

Applicable Technologies

This strategy primarily applies to all of the CV technologies. With the NHTSA NPRM, the needed role of incentives is for existing vehicles that are not required to be equipped under the NHTSA mandate. This is a valid role for public policy since older vehicles will not receive safety benefits, nor will DSRC-equipped vehicles be able to realize their safety benefit unless the other vehicle is also equipped.

Implementing Entities

The implementation of subsidies for CV technology could come from various sources, including federal government, state governments, and local agencies. For example, the Energy Policy Act of 2005 directly influenced the sales of hybrid (gas-electric) vehicles between 3 percent and 20 percent, depending on the model (Jenn et al. 2013). A similar Congressional allocation would likely be required in the case of CV technologies, which has already begun with the recent CV pilot deployment of SmartCities programs and the 2015 FAST Act.

Legal Authority

These activities have firmly established the legal authority for the federal government to directly fund CV research, development, and deployment and have been created alongside the efforts of NHTSA, which plans to mandate the inclusion of CV technologies in new vehicles in the very near future. Vehicle OEMs have the legal authority to subsidize any technology they choose, assuming there are no legal or regulatory barriers.

Geographic Scale

Subsidies can be implemented on a nationwide scale; however, particularly in the case of CV technology, the initial implementation will likely be focused on urban environments.

Applicable Ownership Model: Private, SAV

This strategy can likely be effectively applied within both a shared- and a private-ownership model, although the market focus for these two models is very different.

Other Implementation Challenges

Potential challenges for implementing this strategy primarily involve the availability of funds, particularly in the case of state governments and CV technology where the funds must be congressionally allocated. Further, implementation of this strategy, in the case of CV technology, would benefit from leadership from USDOT but would ultimately need to be executed at the state and local level by agencies that plan to deploy CV technology on their roadways.

Stakeholder Effects

The stakeholders for the strategy of providing subsidies for the adoption and deployment of CV technologies spans a wide range, including individual consumers (Center for Automotive Research 2012), vehicle OEMs and their suppliers, MPOs, cities, state DOTs, and USDOT.

Winners and Losers

Each of these stakeholders plays a specific role in the adoption and use of these technologies. Currently, CV technology deployment is following a push model. The push model is driven by the regulatory framework for vehicle technologies, including supporting infrastructure technologies, since it applies to safety primarily and other benefits secondarily, such as mobility and the environment. The USDOT CV program has been in development for about 20 years, bogged down by standards activities related to CV hardware, software, and communication protocols, as well as a lack of consumer interest or demand for the technology. The rapid development of the smartphone, however, has leapfrogged the problem of connectivity between vehicles and infrastructure; still, this technology operates on a private service model, rather than a public service model, so the USDOT CV program continues to develop along its course.

Subsidizing CV technology, if it leads to wider and more rapid adoption, would ultimately benefit producers and consumers of the technology, as well as all levels of government; however, some groups would be negatively affected. Long-haul truckers would also be affected by the deployment of these technologies since a number of trucks could be self-driven as part of a platoon, convoy, or road train. This technology also affects the military, which is always looking to find ways to minimize human deaths. CV technology has been under development for the U.S. military for decades, and many of its systems are now essentially fully automated. However, vehicle crashes still kill many soldiers every year, and, in a combat zone, manned vehicles are desirable targets. Removing the human occupants from these vehicles is the best way to ensure zero deaths.

The strategy of implementing subsidies for CV technology would likely benefit stakeholders across socioeconomic classes because it may provide opportunities for greater mobility within society and create economic sectors that do not yet exist.

Politically Powerful Stakeholders

No stakeholders have more political power than others.

Strategy Disruption

This strategy could prove to be very disruptive because it would lower the economic barrier for entry of CV technology. However, the disruption will likely affect many industries and economic sectors that are not directly involved with the technology, which should be considered in policy making. Some refer to the crash economy as the economic activity that is associated with vehicles crashing. This includes EMS and hospitals, vehicle repair shops, vehicle OEMs (to replace lost vehicles), banking, and insurance. These economic sectors would need to adjust rapidly to an environment where vehicle crashes are severely reduced or eliminated.

Technological Considerations

This strategy would greatly impact the development of the technology by lowering the economic barriers for entry; however, subsidies would likely not affect the use of the technology.

Affected by Market Penetration

The viability of CV technologies is significantly improved with increasing market penetration, in part because each technology is improved by the other.

Optimal Timing

The timing and duration for implementing a subsidy for vehicle technology adoption can vary greatly depending on a number of factors (Liu and Greene 2012; Yamashita et al. 2014). However, the subsidy will follow a pattern where the subsidy is rapidly implemented at its greatest level of funding and then quickly tapers off to zero.

Cost and Benefit Considerations

The specific time duration and dollar amounts are affected by the competing factors that are working against the technology being subsidized and the consumer demand response. USDOT has already invested hundreds of millions of dollars in the development and pilot deployment of CV technology and may further subsidize vehicle OEMs in the initial years after onboard CV technology is mandated. The cost to implement a strategy of CV technology subsidies may be significant. The federal government has already spent hundreds of millions of dollars on pilot programs and other forms of market subsidization. State DOTs and local municipalities will also incur costs—in the form of technology deployment and maintenance—that they would not necessarily have incurred without the subsidy lowering the economic barrier to entry.

Potential Funding Sources

The federal government would use congressionally allocated funds to execute a program of CV technology subsidies, and vehicle OEMs would use funds derived from their revenue.

Other Costs to Society

CV technology represents a disruptive event for a wide portion of the economy. The implementation of a subsidy to essentially accelerate this disruption could have catastrophic effects on these areas of the economy.

Benefits of Implementation

Conversely, the benefits to society in the form of increased mobility and reduced crashes, injuries, deaths, land development, and pollution would be substantial, and the overall balance would be worth the negative implications.

Bottom Line Assessment: A subsidy strategy for CV technologies will provide a specific price signal that will encourage the adoption of the technologies. With the issuance of the NHTSA NPRM, the subsidy may only be needed for retrofits. However, subsidizing this technology will, by design, accelerate that adoption, which will be disruptive even for many unrelated segments of the economy. Subsidies will likely require authorization and legislation at their respective levels that create barriers to implementation.

Invest in CV Infrastructure

Strategy Overview

This strategy aims to provide investment in CV infrastructure to encourage the development and adoption of AV and CV technologies.

General Description

CV infrastructure primarily refers to DSRC radio equipment but can also refer to the supporting infrastructure needed for deployment, such as backhaul communications, CV data analytics, CV-equipped traffic signal controllers, etc. The objectives of this strategy are to provide support within the infrastructure that encourages development and deployment of these technologies. Investment in the infrastructure necessary to support a connected transportation system will likely influence the following private-sector decisions (from Tables 2 and 3 in Chapter 2):

- Producers develop and sell interoperable V2V and V2I mobility and environment applications.
- Consumers purchase vehicles with V2V and V2I capabilities.

CV infrastructure investment also directly benefits the DOT stakeholders who will be the recipients of the wealth of data created by a CV-enabled transportation system. FHWA has developed a draft V2I Deployment Guidance document which provides guidance to state and local DOTs.[19]

Externalities Targeted

The strategy of CV infrastructure investment would primarily target the externalities of congestion, pollution, land development, and mobility, and would have little or no impact on the externalities of traffic crashes or economic disruption to driving professionals.

Applicable Technologies

This strategy applies to all of the CV technologies previously discussed, although AVs that are also CVs will certainly benefit from the expanded situational awareness provided by a connected infrastructure.

Implementing Entities

The implementation of investing in CV infrastructure would come from both federal and state government agencies; however, the funding of infrastructure in the United States has severely suffered over the last 30 years, with a total funding gap for roads, bridges, and transit of $846 billion (2010 dollars) for the planning time frame of 2013 to 2020 (McNichol 2016). However, CV infrastructure funding may come from a different source, such as the traditional sources for roads and bridges. Significant USDOT funding has already been allocated toward the development and deployment of CV technologies, including the recent CV pilot deployment, SmartCities, and other programs, and much of this funding has been supplemented by matching funds from state DOT agencies and technology OEMs (FHWA n.d.a). These programs focus on both the vehicle and the infrastructure components of a CV transportation system. The 2015 FAST Act also specifically identifies investment for the infrastructure required for ITSs, which include AV and CV technologies (FHWA n.d.a).

Legal Authority

These activities have firmly established the legal authority for the federal government to directly fund CV infrastructure projects, and, according to the Government Accountability Office, $570 million was spent on CV technology projects between 2003 and 2014 (Wise 2015).

[19] See 2015 FHWA Vehicle to Infrastructure Deployment Guidance and Products http://www.its.dot.gov/meetings/pdf/V2I_DeploymentGuidanceDraftv9.pdf

Geographic Scale

Infrastructure investment for CV technologies can be implemented on a nationwide scale; however, initial implementation will likely be focused on urban environments.

Applicable Ownership Model: Private, SAV

This technology operates on a private service model, rather than a public service model, but it is yet to be seen how V2I will mature.

Other Implementation Challenges

Developing a good measure of the return on investment (ROI) in CV investment is a challenge. Many generalized statements are made about the vast data and applications that will be available. In what locations is the deployment of CVs most likely to provide a positive return (sharp curves, signalized intersections, corridors with unique data needs that can only be filled by CVs)?

Data issues are a related implementation challenge, specifically to clarify what data will be available (or available for free) from CVs. The assumption is that DSRC data (basic safety message 1 and 2) will be freely accessible to state and local agencies and other stakeholders. The availability of such data could be used in part to offset the infrastructure investment—which is perhaps the largest challenge.

Potential challenges for implementing this strategy primarily involve the availability of funds for the CV infrastructure investment. However, other challenges exist in including the CV infrastructure component into existing and planned CV technology model deployments and test beds. A heavier focus has been placed recently on CV technology installed within vehicles and has only recently begun to shift toward the infrastructure component. Implementation of this strategy would be overseen by the DOT; however, the DOT would need to collaborate with a number of administrations and offices, such as NHTSA, FHWA, USDOT ITSs Joint Program, state DOTs, and local agencies that plan to deploy CV technology on their roadways.

An example of a collaboration opportunity is the AASHTO SPaT Challenge, being led by AASHTO and the V2I Deployment Coalition. A Signal Phase and Timing (SPaT) message communicates traffic signal information between a traffic signal controller and a mobile or onboard device. The challenge to state DOTs is to equip roughly 20 signalized intersections in each of the 50 states with DSRC infrastructure to broadcast SPaT information by January 2020, and maintain operations for at least 10 years. The rationale is to encourage broad V2I deployment. While a dedicated funding source is not available, the V2I Deployment Coalition and AASHTO are providing the resources of their volunteer members and funded technical support to develop resources to be used as reference materials as the infrastructure owners and operators deploy SPaT broadcasts (AASHTO, 2016).

States and cities are taking a hard look at their investment options and opportunities for CV/AV technologies, and are taking into account the expected market penetration of these technologies for their 5-year and longer-term planning horizons. Many state and local agencies are, and have been for several years, allocating funds for research and development projects for CV/AV technologies.

Stakeholder Effects

The stakeholders for the strategy of investing in CV infrastructure primarily include state and federal DOTs and local municipalities since they will bear the direct cost of the strategy and gain the most immediate benefit by tapping into the wealth of data streaming from CVs. Secondarily, individual consumers will benefit as CV infrastructure becomes available, through the increased situational awareness CV infrastructure technology can provide.

Winners and Losers

Investment in CV infrastructure will not necessarily benefit all aspects of society and the benefit largely depends on what type of infrastructure is funded. CV infrastructure on the highway system obviously benefits those individuals traveling in individual vehicles, whereas CV infrastructure to facilitate public transit movement efficiency and reliability would primarily benefit users of public transit.

Politically Powerful Stakeholders

USDOT is a powerful agency in some ways, but it is often not at the top of the list for attention/funding from Congress and so may have little sway over the political decision-making process. State and local agencies have been more successful in raising funds for projects with local impact.

Strategy Disruption

This strategy is not necessarily disruptive. An increase in funding for CV infrastructure would not necessarily translate into an increase in demand for CV technology development. NHTSA can mandate in-vehicle DSRC devices be included in new vehicles without the need for existing or future CV infrastructure, and many OEMs are already pursuing vehicle-to-infrastructure functionality in their vehicles using cellular and satellite communication methods. The rapid development of the smartphone has also leapfrogged the problem of connectivity between vehicles (their occupants) and infrastructure.

Technological Considerations

This strategy would greatly impact the development of CV infrastructure technology and traffic management software integration, and would provide an expanded avenue for participation of CVs within an overall integrated traffic system.

Affected Market Penetration

The technical viability of CV infrastructure is directly tied to CV market penetration levels; however, the utility of CV infrastructure could be realized with even low levels of CV market penetration. Technical viability of CV infrastructure is also affected by the development of competing technologies, such as the use of cellular and satellite communication methods to circumvent the need for installed infrastructure. The DSRC-based CV infrastructure that NHTSA has been pursuing may become simply a tool that local DOTs use to gather macro-level data on transportation systems, and not be actually relevant to individual CVs.

Optimal Timing

The timing of CV infrastructure funding should be, essentially, now, to begin to demonstrate utility for CVs as they start to come into the transportation system. In particular, operational CV infrastructure would provide local DOTs leverage and an advantage in partnering with vehicle OEMs as they begin to roll out the technology in their vehicles.

Cost Considerations

Implementing a strategy of CV infrastructure funding will cost USDOT and local DOTs hundreds of millions of dollars, some of which has already been spent or allocated for near-term spending. One of the biggest unknowns for state DOTs is the expected costs of this technology in terms of maintenance, which can often greatly exceed the original cost of the technology. This concern is made worse because this technology is essentially unproven and still in flux, even at the standards development level.

Potential Funding Sources

State governments could use congressionally allocated funds to execute a program of CV infrastructure funding, with likely significant matching funds from USDOT.

Benefits of Implementation

The benefits of increased CV infrastructure funding are in theory wide ranging, although this greatly depends on what type of CV infrastructure is put in place, who it serves, and whether other technologies circumvent it.

Bottom Line Assessment: CV infrastructure funding is marginally likely to affect the overall development of CV technologies since it is still unclear whether the benefits of increased funding for CV infrastructure will be greater than the costs. Hurdles include funding availability and the associated fact that investing agencies will want concrete evidence of ROI.

Grant AVs and CVs Priority Access to Dedicated Lanes

Strategy Overview

This strategy grants AVs and CVs priority access to dedicated lanes to promote market development.

General Description

This strategy involves granting priority access to AVs and CVs in dedicated lanes on any number of roadway types, including freeways and local streets, accounting for the different operating characteristics of AVs and CVs. Longer trips served by freeways could support the ability of AVs and CVs to travel at close spacing and/or to form fast-moving, densely spaced platoons. For special urban districts, exclusive lanes for SAV could fit a service model rather than a private-ownership

Effectiveness ●●●◎◎
Efficiency ●●●●◎
Political Acceptability ●●◎◎◎
Operational Feasibility ●●◎◎◎
Geographic Impact Urban
Who State and local road operators
Hurdles Political, operational

model, and could support reduction of VMT in the district, depending on the shared-ride requirements imposed. The private-sector decisions the strategy aims to influence are (from Tables 2 and 3 in Chapter 2):

- Consumers purchase safe AVs.
- Consumers purchase vehicles with V2V and V2I capabilities.
- Consumers purchase and use aftermarket V2V safety applications.

Externalities Targeted

The potential for fast and safe travel on long-distance dedicated lanes for AV or CV systems would naturally encourage the purchase and use of AVs and CVs. The improvement in traffic flow and throughput improves social welfare through reduced congestion, reduced travel times, and reduced vehicle operating costs. As long as there are sufficient AVs or CVs to fill the exclusive lane, then the benefits would exceed the costs. This is because a dedicated lane could move many more vehicles much faster, thus relieving some congestion on the other lanes. The additional throughput on dedicated lanes also tends to lessen the congestion on the general purpose lanes. Therefore, all travelers would benefit from this strategy. For commercial vehicles, platoons in dedicated lanes could provide fuel savings, which reduces emissions. If the use of this strategy is to increase market penetration of equipped vehicles, the effectiveness will depend heavily on road operators' willingness to dedicate lanes to AVs and CVs. If the use of this strategy is to reduce VMT in a restricted district or area (like an urban center), the effectiveness will depend on how well the supply of SAV matches the demand.

Applicable Technologies

Higher level AVs and CVs with V2V capability will have the ability to form vehicle platoons that could benefit from exclusive lanes.

Implementing Entities

The most common form of dedicated lanes is MLs, which vary considerably in size, allowed uses, and ownership. The most prevalent are HOV lanes, which allow vehicles with a higher number of occupants (e.g., 2+, 3+) to travel on the lane for free. These are most often owned and operated by a state DOT since they are usually part of an interstate or state highway. Some are owned and operated by local transit agencies (FHWA n.d.b).

Allowing closely spaced AVs and CVs would likely require the owners of the lanes to work with FHWA to ensure minimum standards are met, such as 45 mph speed in the lanes for 90 percent of the peak period. Lane owners would also likely have to work with state legislatures in the case where a lane is dedicated to AVs versus CVs. A dedicated lane for driver-operated CVs would need different regulations than an AV lane. The best candidates for either would be those lanes with many travelers using the lane for long trips.

Legal Authority

Allowing closely spaced operation of AVs (Levels 3, 4, and 5) or CVs (V2V) on MLs, or any roadway, will require enabling legislation. For example, TTI investigated what current legislation may delay or deter commercial truck platooning. The researchers found a large number of regulations that might have some impact on truck platooning, but few that would seriously deter the concept. One reason was that NHTSA does not recommend that states regulate Level 2 automation, which is the level of platooning. One of the few regulations found that does directly deter platooning refers to minimum allowed following distance. A good example of restrictive legislation comes from the Texas Transportation Code Section 545.062:

> Sec. 545.062. FOLLOWING DISTANCE. (a) An operator shall, if following another vehicle, maintain an assured clear distance between the two vehicles so that, considering the speed of the vehicles, traffic, and the conditions of the highway, the operator can safely stop without colliding with the preceding vehicle or veering into another vehicle, object, or person on or near the highway.
>
> (b) An operator of a truck or of a motor vehicle drawing another vehicle who is on a roadway outside a business or residential district and who is following another truck or motor vehicle drawing another vehicle shall, if conditions permit, leave sufficient space between the vehicles so that a vehicle passing the operator can safely enter and occupy the space. This subsection does not prohibit a truck or a motor vehicle drawing another vehicle from passing another vehicle.

This would need to be adjusted to allow efficient platooning in the case of trucks.

Geographic Scale

Dedicated lanes are located throughout the country, generally in urban areas where there are sufficient numbers of carpools and transit riders to justify the use of the lane.

Applicable Ownership Model: Private, SAV

The strategy can be effectively applied in either a private-ownership or an SAV model.

Other Implementation Challenges

Additionally, many of the current MLs were constructed using bond financing and/or public-private partnerships, backstopped by toll revenue. Therefore, the financial documents (bond covenants) may need to be modified to allow this new user group, especially if the preferential treatment includes a toll discount, which would impact the revenue stream of the lanes. For urban district conversion of lanes exclusively for SAV or urban freight delivery, implementation challenges arise when restricting use to one travel mode within areas already experiencing high demand and addressing the logistics of displaced road users and local residents who do not own AVs and CVs. For minimal cost, the potential societal benefits are very large. However, deployment will require the right situation. For managed lanes, it will require long-distance trip patterns; for urban districts, it will require the right market conditions for SAV.

Effect on Implementing Entity

Prioritizing AVs and CVs in dedicated lanes will require little to no change in governing structure since it is an extension of current ML practice. The financial aspects of addressing the bond covenant issues would need to be addressed by the implementing entities.

Stakeholder Effects

Stakeholders include the owners, operators, users, and financers of MLs, and any displaced users of converted lanes.

Winners and Losers

The impact is likely to be positive (in revenue, vehicle throughput, and congestion reduction) or the facility would not adopt the preferential treatment. All income groups and disadvantaged groups stand to benefit from this change, although higher-income groups would likely see more benefit from tolled MLs since they use them more often. This strategy could be considered an incremental change since it is increasing the throughput of a small number of lanes on specific freeway facilities.

As noted above, priority access for privately owned AVs/CVs would provide the most advantages to those able to afford these vehicles. SAV models are likely to be at a more competitive price point and create more equal benefits since a wider cross-section of the public would be more likely to access an express lane or priority parking.

Politically Powerful Stakeholders

The displaced users of converted lanes could represent a potential politically powerful stakeholder group. If this group is vocal enough about its concerns, it could attract the attention of policy makers. There are cases of ML projects that have been stopped because of public objection. Among the various options for priority lane designation, political acceptability will be lowest for the conversion of a general use lane to a dedicated use lane.

Strategy Disruption

The amount of disruption varies directly with the market penetration of AVs and CVs. If there is a small percentage and only a few platoons, the disruption would be minimal. If there is a large percentage, then platoons may comprise the entire ML system, which would disrupt current users of the lane. It could also significantly reduce the amount of space for general purpose lanes, and it could represent increased costs for construction.

Technological Considerations

The policy does not impact technology deployment of the AVs or CVs themselves. There may be some technological impacts on MLs.

Affected by Market Penetration

The strategy requires a critical mass of CV/AV vehicles participating to achieve benefits. The exact percentage is difficult to predict and will be site specific. For example, if the freeway has four general purpose lanes and one ML in each direction, and most equipped vehicles use the MLs, then all it would take is a 20 percent market penetration rate to potentially fill the ML with platoons of AVs and CVs. Conversely, consider a freeway with three general purpose lanes and two MLs where many of the AVs and CVs do not want to use the MLs. It would require a much higher market penetration rate to reach the critical mass of AVs and CVs in the MLs where the platooning benefits are realized. Although these scenarios differ considerably, the one constant is to incentivize the AVs and CVs to use the MLs.

Several researchers have used simulation models to estimate the impact of these platoons, often referred to as cooperative adaptive cruise control. The results included a couple that showed increased congestion due to drivers being uncomfortable with small gaps between cars (Shladover et al. 2012; Davis 2004). However, most showed congestion could be reduced even at market penetration rates as low as 10 to 20 percent. One example of platooning AVs and CVs on MLs on I-95 in

Florida showed a need for 20 percent market penetration on the MLs to achieve limited benefits and 60 percent to greatly reduce congestion (Qom and Hadi 2016). These market penetration rates for cooperative adaptive cruise control are frequently predicted to occur within the next decade. Conversely, Reich (2013) compared the potential benefits of this strategy to those of using electronic toll collection. Based on that analogy, Reich predicted a need for 55 to 65 percent market penetration, which he predicted to occur in the 2040 decade.

Optimal Timing

If the objective is to incentivize market adoption, optimal timing would be in the near term. For lane dedication that involves displaced users, the political challenges will likely dictate the timing.

Cost and Benefit Considerations

For preferential treatment of AVs and CVs, the majority of the costs are built into the vehicles themselves. As long as those vehicles can platoon, then allowing them to do so on MLs will require minimal costs on the part of the ML owner/operator. The costs of this change to the MLs might be similar to when an HOV lane converts to a high-occupancy toll (HOT) lane as a new user group (platooning vehicles) is added to the lane. This might include additional signage, announcing the program, educating the public, and likely some tolling system software modifications.

Potential Funding Sources

As with most current MLs, funding will likely come from bond financing and/or public-private partnerships, backstopped by toll revenue.

Benefits of Implementation

Other than the costs noted above, the rest of the impacts will likely be benefits. These will be dominated by savings in travel time and improved travel time reliability. Based on the speed of the platoon and the reduced aerodynamic drag on the platooned vehicles, it is possible emissions could increase or decrease.

Bottom Line Assessment: For minimal cost, the societal benefits of granting privileged access are very large. However, implementation will require the right situation. If the intent is to increase market penetration of equipped vehicles, effectiveness will depend on road operators' willingness to dedicate lanes to AVs and CVs. If the intent is to reduce VMT in a restricted district or area (like an urban center), effectiveness will depend on how well the supply of SAVs matches demand.

Grant Signal Priority to CVs

Strategy Overview

The strategy grants CVs, including transit and commercial vehicles, signal prioritization to accelerate market penetration.

General Description

Traffic signal priority for CVs involves sophisticated signal timing algorithms that estimate the arrival of platoons of CVs and coordinate the signal timing to increase throughput by providing these platoons green light priority. This would be a more complex version of transit signal priority. The goal would be to decrease the total delay at the traffic signal for all vehicles, but particularly CVs, as a way to stimulate consumer action toward market penetration. The specific private-sector decisions targeted are (from Tables 2 and 3 in Chapter 2):

- Consumers purchase vehicles with V2V and V2I capabilities.
- Consumers purchase and use aftermarket V2V safety applications.

Externalities Targeted

The call for priority could come from any number of platoons at any time approaching from all directions. Conversely,

Effectiveness

●○○○○

Efficiency

●●○○○

Political Acceptability

●●○○○

Operational Feasibility

●●●●○

Geographic Impact

Urban, suburban

Who

State and local transportation agencies that operate traffic signals

Hurdles

Political

during periods with very little traffic, the traffic signal may be able to provide green for any approaching CV, saving time, fuel, and operating costs for those AVs and CVs, and mitigating congestion and emissions externalities.

Applicable Technologies

All levels of connectivity and automation could benefit from this as long as there was connectivity in the infrastructure. This policy would require a high percentage of CV vehicles in the traffic stream in order to reduce overall delay.

Implementing Entities

Providing CVs priority treatment at signalized intersections would be led by the state and local agency in charge of the city traffic signal system.

Legal Authority

There are no expected legal barriers since state and local agencies have the authority to operate traffic signals. There are many such agencies that currently grant some priority treatment to transit. CV priority would be a more complex version of this.

Geographic Scale

This strategy would be focused on urban and suburban applications, where signal priority makes a difference in the traffic flow.

Applicable Ownership Model: Private, SAV

With sufficient numbers of CVs, the policy could work well in both a private-ownership and an SAV model.

Other Implementation Challenges

The overall impact would depend a great deal on the market penetration of CVs. If they represent a small portion of the traffic, then granting those individual vehicle calls for green might increase overall delay and create the case where many non-CVs are negatively impacted. Additionally, during periods of peak congestion and saturated flows, it is likely that priority treatment would not improve traffic flow and would provide a negligible benefit to the CV owner.

Effect on Implementing Entity

As an extension of the current practice of granting transit signal priority, the strategy would have little impact on the implementing entity. The strategy is somewhat more complex than transit signal priority since there is a limited number of calls for green time by transit vehicles at any given intersection. New algorithms overseeing the priority treatment for CVs would be needed.

Stakeholder Effects

Stakeholders include the owners and operators of the traffic signals plus all travelers on the roadway network.

Winners and Losers

The impact is likely to be positive (reduced traffic congestion and delay) or the signal system would not adopt the preferential treatment.

All income groups and disadvantaged groups stand to benefit from this change, although higher-income groups would likely see more benefit since they are more likely to afford a CV.

Politically Powerful Stakeholders

There are no politically powerful stakeholders.

Strategy Disruption

This strategy could be considered an incremental change since it is increasing the throughput of intersections by adjusting signal timing.

Technological Considerations

The strategy does not impact technology deployment of the CVs themselves. There may be some technological impacts on traffic signal systems.

Affected by Market Penetration

As noted, the strategy requires a critical mass of CV vehicles participating to achieve benefits.

Optimal Timing

Traffic signal priority requires a traffic signal to be able to receive a signal request message from the platoon and act on it by giving priority to the platoon. Most traffic signal controllers installed in the last 15 to 20 years have this ability. The ability of platoons to send this signal has not been developed, nor have algorithms that guide when the signal will grant priority.

Cost and Benefit Considerations

For traffic signals, there will be some cost of software improvements so that the traffic signal controller can minimize total traffic delay based on the calls for priority.

Potential Funding Sources

Funding would come from current operating budgets.

Other Costs to Society

The strategy should result in a reduced delay for CVs but could increase delay for traditional vehicles. It could also negatively impact transit travelers since they currently are the only travelers who receive priority treatment. Traffic signal controllers can only grant priority every so often in order to not be detrimental to the flow of traffic. Therefore, it would likely reduce transit's ability to receive priority once some CVs were also receiving priority.

Benefits of Implementation

The estimates of benefits depend on the market penetration of CVs in the traffic stream. Generally, implementing the strategy should result in travel time savings, fuel savings, and reduced operating costs.

Bottom Line Assessment: It is unlikely that this policy will be the driving force to increase market penetration of AVs and CVs since the travel time benefits will be minimal. It may also have the negative outcome of reduced priority treatment for transit.

Effectiveness

● ◎ ◎ ◎ ◎

Efficiency

● ● ● ◎ ◎

Political Acceptability

● ● ◎ ◎ ◎

Operational Feasibility

● ● ● ● ◎

Geographic Impact

Urban

Who

Local government

Hurdles

Effectiveness

Grant Parking Access to AVs and CVs

Strategy Overview

This policy strategy grants AVs and CVs priority parking access to accelerate the market development.

General Description

This strategy would provide preferential parking spots to AVs. The private-sector decisions to be influenced include:

- Consumers purchase safe AVs.
- Consumers purchase vehicles with V2V and V2I capabilities.
- Consumers purchase and use aftermarket V2V safety applications.

However, analysis shows that there is unlikely to be a need for preferential parking for AVs. Once the traveler leaves the AV, the vehicle can be parked in the least preferred locations such as the top floor of a garage or back areas. Further, AVs can use much smaller parking spots, and vehicles can be stacked since the vehicle can park itself and there is no need for a driver to be in the car and no need for the doors to open. Due to these impacts, parking costs could feasibly be reduced for AVs, freeing up high-value spaces for traditional vehicles. As AVs are introduced into a city environment, limited parking spaces for AVs may be provided at key transportation hubs so that travelers have easy and quick access. However, as SAVs take hold, the goal would be for these vehicles to constantly be in motion to capitalize on a revenue stream.

For CVs (V2I or V2V), there would not be a societal benefit to providing them preferential parking, but alerting the vehicle to available parking spots would benefit society through reduced VMT from parking searches. The alerts could come from the infrastructure or from other vehicles that sense open spaces during their travel. This is similar to some smartphone apps that provide this information to travelers in some cities today (such as ParkMe [http://www.ParkMe.com]).

Externalities Targeted

The strategy targets congestion and emissions externalities. Theoretically, parking priority for AVs and CVs would be an incentive to consumers to purchase personal AVs or use SAVs, thereby increasing the numbers of AVs and CVs and realizing their safety, congestion, and environmental benefits.

Applicable Technologies

This strategy relates to AVs (SAE Levels 3–5) and to CVs (V2V and V2I).

Implementing Entities

State and local entities have authority over on-street parking on public roads and parking garages owned and managed by these agencies. However, the majority of parking that would be impacted by priority parking for CV/AVs would lie with private property owners. For example, the reduced space needs for AVs and possible reduced parking needs of a MaaS model would reduce the parking footprint. Therefore, private developers anticipate converting parking into a higher-valued use such as retail. Additionally, AVs will create more demand for curb space for pick-up/drop-off. Forward-looking developers today would provide large valet areas in the anticipation of converting them to curb access areas for AVs.

Legal Authority

As noted above, state and local entities have authority over on-street parking on public roads and parking garages owned and managed by these agencies.

Geographic Scale

The strategy would apply primarily to urban areas.

Applicable Ownership Model: Private, SAV

For private ownership, all persons benefit from AV parking. AV owners have convenient curb access but the AV is parked remotely, freeing up desirable parking for non-AVs. In an SAV model, equity is more likely to be distributed to a broader cross-section of travelers since AVs used in SAV fleets would have equal access to curbside space.

Other Implementation Challenges

Providing priority access to parking for CV/AVs will impact public agency codes for parking requirements and access. For example, new development or redevelopment could be impacted because extensive use of AVs will likely reduce the space needed for parking. This space (formerly used for parking) can be freed for high-value use. This is primarily an urban issue. For on-street parking, use of AVs would alter access to businesses and property. Priority curb space for AVs (private or SAV models) might be desirable in some instances. In other cases, AV use could free parking spaces for conventional vehicles since AVs can drop off passengers and be parked remotely. A single drop-off point could service many AVs. For SAVs, preferential curb access would facilitate their use because good access would increase convenience.

Many parking facilities are owned and operated by municipalities, airports, and transit stations. Parking fees are a significant revenue source for these organizations. There is no benefit to priority access for AVs; however, in the event that SAVs reduce the demand for parking, the revenue streams may be negatively impacted.

Stakeholder Effects

For AV preferential parking, stakeholders include the owners and operators of the parking facilities plus all travelers on the roadway network.

Winners and Losers

The impact is likely to be positive (reduced traffic congestion due to reduced parking search times and increased parking spots due to smaller space needs to park an AV).

All income groups and disadvantaged groups stand to benefit from this change. Under SAV fleet deployment, it is likely that these benefits are more widely dispersed.

Strategy Disruption

This strategy could be considered an incremental change since it is simply adjusting who is allowed to park in certain spaces.

Technological Considerations

The policy does not impact technology deployment of the AVs or CVs themselves. There may be some technological impacts on parking facilities.

Affected by Market Penetration

The strategy requires a critical mass of CV/AV vehicles participating to achieve benefits. The exact percentage is difficult to predict and will be site specific.

Optimal Timing

The strategy is not time sensitive.

Cost and Benefit Considerations

The direct cost to implement is unlikely to be high since priority access to parking for CV/AVs is a policy change. The cost would be in analyzing the options and public involvement to institute a change in parking codes.

Benefits of Implementation

The benefits would be negligible.

Bottom Line Assessment: Priority parking will have zero effect on the market penetration of AVs and CVs. The ability of an AV to park itself will likely be more of a market incentive. If implemented, the strategy would reduce some parking availability for non-AVs, which would incur opposition from the general public.

Implement New Contractual Mechanisms with Private-Sector Providers

Strategy Overview

The strategy aims to establish new contractual mechanisms with private-sector providers, including shared data arrangements, to incentivize the development of a viable marketplace for AV and CV technologies.

Effectiveness

●●○○○

Efficiency

●●●●○

Political Acceptability

●●○○○

Operational Feasibility

●●○○○

Geographic Impact

Urban

Who

Transportation agencies in urban areas: state DOTs, cities, toll authorities, public transit agencies

Hurdles

Viable business models, legal and governance, political acceptability

General Description

The objective of this strategy is to accelerate the market penetration of AV and CV technologies for both new and aftermarket vehicles, as well as the associated infrastructure needed to enable the technologies to flourish, such as:

- DSRC RSE or other communications equipment.
- Associated backhaul connectivity equipment to operations centers.
- Enhanced signage or road markings for AV sensors.

This strategy is a regulatory/planning instrument and is designed to create the appropriate ecosystem that will enable a marketplace to develop and could lead to innovation. The private-sector decisions it seeks to influence are (from Tables 2 and 3 in Chapter 2):

- Producers develop and sell interoperable V2V or V2I mobility and environment applications, and consumers purchase vehicles with these applications.
- Producers develop and sell safe AVs, and consumers buy them.
- Producers develop and sell connected AVs that harmonize traffic flow, and consumers purchase them.

Externalities Targeted

By encouraging the adoption of AV and CV technologies, traffic crashes (number and severity), congestion, pollution, and land development may be reduced, and mobility may be increased. These effects would all be positive, meaning the stakeholders of the externality experience an improvement. However, the externality of economic disruption to driving professions, which is already considered a negative externality, would be further negatively affected by this strategy.

Applicable Technologies

This strategy applies to both CV and AV technologies; however, only AV Levels 4 and 5 would be affected because lower levels of AV technologies are already widely adopted under the technology umbrella of ADAS, which includes functions such as automatic braking, adaptive cruise control, lane keep assist, and others. Implementing a P3 would be particularly useful in the stimulation of CV technologies because they are not being driven by the same consumer demand model as AV technologies.

Implementation Considerations

The implementation of a P3 for CV/AV technology can be undertaken by any government agency and would be particularly effective at the state and local levels, with state DOTs and regional MPOs driving the planning process overall and maintaining control over the project while shifting some of the cost and risk to private enterprises. Recently, state and local transportation agencies in Hawaii, New York, and Massachusetts announced P3s for various transportation development projects related to rail lines and station upgrades. In the case of New York, USDOT also partnered with local port authorities on the P3 arrangement with Amtrak and private investment interests.

This activity may be undertaken by a transportation agency by directly creating a marketplace for the exchange of services or goods, or by partnering with private-sector entities in P3s. In the case of a P3, the private entity essentially enters into a long-term development and service contract with a government entity and may be involved in aspects of design, build, operation, and ownership of the system and its assets (Button 2016). P3s can reduce development risk for complex projects such as the installation of CV/AV infrastructure, provide a more cost-effective and timely delivery, and leverage traditionally limited public-sector resources while maintaining overall control over the project (Meyer 2012). One example of a P3 would be a state DOT contracting with a private firm to design, build, and manage a toll road. Part of the agreement could involve the firm reinvesting some of the eventual toll revenue to integrate and deploy CV infrastructure. The firm could advertise this infrastructure investment as providing enhanced safety and mobility for those road users. The data generated by CVs using the managed roadway could then serve as another revenue stream.

Legal Authority

There are no specific legal barriers for state and local agencies to implement P3s. A suitable legal framework must be established to facilitate the arrangement, and this can vary widely among states. The goal of establishing a legal framework is to allow the public entity to take advantage of the benefits realized from a P3 project while protecting the public interest (FHWA n.d.a).

Geographic Scale

P3s can be implemented on a nationwide scale. Particularly in the case of CV technology, the initial implementation will likely be focused on urban environments where a greater density of users will be available to take advantage of CV infrastructure.

Applicable Ownership Model: Private, SAV

This strategy can likely be effectively applied within both a shared and a private vehicle ownership model, although the market focuses for these two models are very different.

Other Implementation Challenges

One of the challenges with P3s is the perception that they are a more expensive form of project delivery. Through careful and thorough financial analysis of the project costs and benefits, specifically a value-for-money estimate, P3s can often be shown to be the better project delivery mechanism (Meyer 2012). Decision makers evaluating a P3 arrangement for the delivery, operation, and maintenance of a CV/AV infrastructure project must also ensure that the project is financially viable and determine whether they have the necessary resources available for a successful contract negotiation and project lifecycle management.

In the case of CV infrastructure, this will require public agencies and private investors to identify viable sources of revenue that may be realized (Wang and Liu 2015), or other sources of value such as the large amount of detailed data that will be generated from CVs. These data could be very valuable to local transportation agencies in providing better insight into the efficiency of the transportation system and the impact of planning, operations, or maintenance activities.

Effect on Implementing Entity

The implementing agency needs to have knowledge of effective P3 contractual arrangements: what works and what does not work. Thus, the agency may need to augment current staff or hire consultants.

Stakeholder Effects

The primary stakeholders for implementing and operating a P3 for the adoption and deployment of CV and AV technologies are the state and local transportation agencies and the private investment organizations. A P3 might have a number of individual stakeholders that represent the public or private interest. Detailed and thorough negotiations are often required so that all stakeholders understand and agree to their roles and responsibilities in making the P3 a success. However, there is also a fine line between ensuring due diligence in the contracting and negotiating processes and creating undue barriers that can deter private-sector interest in the project.

Winners and Losers

Public entities that enter into P3 arrangements for CV/AV technologies stand to gain invaluable access to near-real-time data from their traffic system, where the vehicles themselves essentially act as traffic system probes. The field of data analytics and its arsenal of big-data tools, including other fields such as artificial intelligence and machine learning, can then be applied to this rich, dynamic data set. This will in turn aid state and local transportation organizations with activities such as maintenance scheduling, current operations management, and future infrastructure investment planning. Similarly, private-sector stakeholders stand to benefit from P3 arrangements in many ways depending on the nature of the specific project. Implementation of a P3 arrangement is by definition an effort to maximize the public interest in some sense.

In the case of CV/AV technology, the immediate benefits would of course be realized by those who can afford the technology, and so there is some chance for social inequity, although secondary benefits may also be realized by a broader population. However, if the P3 projects are implemented—for example, for mass transit—the immediate beneficiaries of the project will not necessarily be only those who can individually afford the CV/AV technology.

Politically Powerful Stakeholders

There are no politically powerful stakeholders.

Strategy Disruption

CV/AV technologies, as discussed previously, represent a disruptive event for a wide portion of the economy, and the implementation of P3 arrangements could accelerate this disruption. However, P3 projects are typically multiyear or multi-decade in timespan, so the impact of any single P3 project would likely not be as drastic.

Technological Considerations

The strategy of using P3s could impact the development of CV/AV technology and its use by providing direct and immediate financial incentives for the development and deployment of a specific technology or set of technologies within specific environments. The public-sector stakeholders have a specific public benefit in mind for the P3 project, and the private-sector stakeholders have specific short-term and long-term revenue targets for the technologies. The P3 provides a mechanism where these interests can join forces in the development and deployment of specific technologies, but this is at the exclusion of other technologies and services.

Affected by Market Penetration

The viability of CV/AV technologies and services is tightly coupled to market penetration, and a P3 project must take into account the current and expected market penetration levels for any CV/AV technology under consideration.

Optimal Timing

The timing for a P3 implementation depends on the specific technologies, services being used, and specific purpose of the project. Early P3 projects may be beneficial in developing the market for CV/AV technologies that might not develop on their own for some time, and, with the development of the market, additional CV/AV market penetration may be encouraged. Later P3 projects may be primarily beneficial in expanding an existing CV/AV market.

Cost and Benefit Considerations

The cost to implement a P3 is completely dependent on the scope of the project but is generally a much higher cost (and risk) than either public- or private-sector stakeholders are able to bear alone.

Potential Funding Sources

In a P3 arrangement, both public and private sources of funding are used, including legislatively allocated public funds and municipal bonds for the public sector.

Benefits of Implementation to Society

P3 projects would begin to benefit society as they are implemented in the form of reduced crashes, injuries, deaths, land development, and pollution, as well as increased mobility.

Bottom Line Assessment: P3 arrangements have a long history of creating net-positive benefits to society, so this strategy for AV/CV technologies would likely have similar outcomes. However, P3s are generally perceived as a more expensive mechanism to realize those benefits, so identifying a suitable revenue stream (i.e., monetizing available data) to support the marketplace for AV and CV technology is a necessary precursor.

CHAPTER 5

Conclusions and Recommendations

This study examined the societal impacts of AVs and CVs—both beneficial and detrimental—and identified policy and planning strategies at the state and local levels that could internalize these impacts in market decisions made by individuals and organizations. Traditionally, public agencies intervene in market activities when there are goods or services that may not be efficiently or equitably provided by the market. In such instances, public and private interests do not align. The deployment of AV/CV technologies will have effects on producers and consumers in the market, on public agencies themselves, and on third parties who are not involved in the market of buying and selling AVs and CVs. It is the role of public agencies to consider the interests of all these groups and, in cases where those interests do not align, to intervene in the market to maximize potential benefits and minimize negative consequences.

Public agencies have many mechanisms with which to align public and private interests, including economic, regulatory, and planning actions. This research identified 18 strategies that represent common types implemented by state and local governments. The viability of each was assessed by the following criteria: effectiveness and efficiency in achieving the desired outcome; implementation considerations; stakeholder, equity, and political considerations; technological developments; and cost and benefit considerations. The feasibility of achieving the desired outcomes was deemed more likely with some strategies than others, but all are presented for consideration. The particular circumstances of one state, region, or locale over another may influence the overall viability of a particular strategy. The important goal is to create desirable outcomes for society. The first is safety. The second relates to enhanced mobility. A third relates to mitigating pollution and congestion. The fourth relates to market barriers that could deter and delay introduction of these technologies.

Summaries of Policy and Planning Strategies

The following strategies are presented organized by the desired outcome.

- Outcome: to mitigate safety risks through testing, training, and public education.
  - Enact legislation to legalize AV testing: Legislation will provide a necessary policy framework to allow AV testing on public roads. Testing is a critical path step for mitigating safety risks.
  - Enact legislation to stimulate CV or AV testing: Legislation will provide a necessary policy framework to stimulate others to test AVs and CVs on public roads. Testing is a critical path step for mitigating safety risks. Direct funding may be needed to stimulate CV testing.
  - Modify driver training standards and curricula: Driver training standards and curricula will be essential to safe operation of AVs and CVs.
  - Increase public awareness of benefits and risks: AV and CV technologies have the potential to bring immense societal benefits but also pose new risks, both of which need to be made known to the general public to ensure market acceptance as well as safe operation.
- Outcome: to encourage SAV use.
  - Subsidize SAV use: A strategy that incentivizes SAVs to provide first/last-mile service and service for targeted populations could be effective in achieving positive societal outcomes.
  - Implement transit benefits for SAVs: This economic incentive could be more effective with an SAV fleet than traditional transit because of the flexibility in origins and destinations served, but service characteristics would still be important.
  - Implement a parking cash-out strategy: While parking cash-out has been fairly successful where adopted,

its success depends on the availability of commute alternatives.
- Implement LEMs: Price is undoubtedly an important component of home buying decisions, but there is no evidence that LEMs make a major difference.
- Implement land use policies and parking requirements: The likelihood that such policies will generate a large shift to SAV use must be compared to existing efforts to promote shared mobility. These examples show signs of success where they do exist.
- Apply road use pricing: Road use charges have been effective in achieving specific objectives related to minimizing the negative impacts of driving, but they are very unpopular.

- Outcome: to address liability issues that may impact market development.
  - Implement a no-fault insurance approach: A state-level no-fault automobile insurance approach would likely accomplish goals of clarifying assignment of liability and, depending on the statutory language, reducing or eliminating manufacturer liability.
  - Require motorists to carry more insurance: Raising mandatory insurance minimums would very likely produce a net-positive socially beneficial outcome. Without enforcement, the strategy may increase the incidence of consumers not purchasing *any* insurance.
- Outcome: to enhance safety, congestion, and air quality benefits by influencing market demand.
  - Subsidize CVs: If NHTSA requires DSRC/CV equipment on new vehicles, then the incentives would be used to retrofit existing vehicles.
  - Invest in CV infrastructure: It is unclear whether the benefits of increased funding for CV infrastructure will be greater than the costs. Evidence of ROI is needed.
  - Grant AVs and CVs priority access to dedicated lanes: For minimal cost, the societal benefits of fast and safe travel on dedicated lanes for AVs and CVs are very large. However, implementation will require the right situation.
  - Grant signal priority to CVs: It is unlikely that this policy will be the driving force to increase market penetration because the travel time benefits will be minimal.
  - Grant parking access to AVs and CVs: Priority parking likely will have zero effect on the market penetration of AVs and CVs.
  - Implement new contractual mechanisms with private-sector providers: P3 arrangements have a long history of creating net-positive benefits to society, so this strategy would likely have similar outcomes.

The strategies provided through this research offer considerations for state and local agencies using the best information available at the time. Technology direction may change, consumers may not adopt certain products, and any number of global economic or environmental drivers could alter the policy course. Even within such uncertainty, it is incumbent upon state and local agencies to use available policy and planning strategies to nudge private-sector choices regarding AVs and CVs toward outcomes that would benefit society, thus aligning public- and private-sector interests in the technologies. Ultimately, transportation planning and policy making for AVs and CVs will be informed through a cycle of learning and leveraging early-adopter agencies that support testing, evaluation, research, and continuous knowledge creation.

Suggestions for Further Research

The assessments conducted in this research were high-level viability reviews. Several of the strategies warrant more in-depth study to tease out key issues.

- Enact legislation to stimulate AV or CV testing.
  - Among states that have already passed legislation, what persuaded lawmakers to spend their political capital and energy to pass it? What was the driving factor and/or economic productivity advancement?
  - Who wins and who loses at the local or state level? How can the winners be persuaded to be supportive? How can losers be addressed?
  - What are the motivators for the private sector to select one location over another?
  - Why is funding of CV testing for V2I a good public investment? What is the ROI?
- Subsidize SAV use.
  - Under what conditions would transit properties want to subsidize SAV use? How much subsidy is needed?
  - With a large investment in rolling stock, how would transit gradually move into a combined bus/SAV fleet?
  - For which future public transport scenarios should cities be preparing, and how will this affect congestion and safety?
- Implement new contractual mechanisms with private service providers.
  - What do public agencies have in the AV/CV realm that is of value to private service providers?
  - What data will be available from CVs, how can the data be monetized, and by whom?
  - What types of P3 arrangements can be created to provide public agencies with the data they need for operation of public roadways?

- Invest in CV infrastructure.
  - What is the ROI for public agency investment in CV infrastructure?
  - In what applications is CV infrastructure most likely to provide a positive return?
- Subsidize CVs.
  - What level of incentive (price) is needed to motivate the auto owner?
  - What is the estimated level of public good that comes from retrofit and that would justify government subsidy?
- Implement land use policies and parking requirements.
  - What is a new policy framework for parking and its evolution in terms of AVs?
  - What is the financial impact of reduced parking demand?
- Grant AVs and CVs priority access to dedicated lanes.
  - What levels of AVs are prioritized? Are CVs or SAVs prioritized? In a simultaneous arrival situation, which of the technologies have ultimate priority access?
  - What level of incentives (if lanes are priced) are effective in managing their use or discouraging their use?

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A P P E N D I X

Viability Assessments

ENACT LEGISLATION TO LEGALIZE AV TESTING

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	N/A	Quite a few states have proclaimed the legality of AVs, but few have attracted private companies. Even if a private company came and tested its AVs in a given locality, it does not follow that this testing will improve or accelerate the adoption of AVs in that locality. *The Patchwork of Regulations.* A frequent concern raised from the AV industry is that many states will all enact a conflicting patchwork of regulations on AVs, which—the industry fears—would slow AV implementation. This negative, unintended consequence could be realized if many states go beyond legalizing and/or funding testing and enact custom sets of regulations governing vehicle operation.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	2	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	3	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	N/A	Based on current experiences, state and local governments enacting pronouncements of AVs' legality or a willingness to test CV/AV systems have had limited success. As a public good, absent funding for CV systems, testing is unlikely.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	2	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	5	There is no funding associated with this policy; it is limited to public proclamations and is unlikely to result in increased burdens on low-income or other socially disadvantaged groups. Since the strategies do not generally increase costs or create burdens, this does not apply. Since the strategy does not increase costs and is unlikely to create societal benefits, it is unlikely to create an inequitable distribution of societal benefits.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	NA	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	5	

Criteria	Consideration	Likert Rating	Rationale
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	2	Unless a state passes many additional regulations, simply legalizing or supporting testing is unlikely to result in pushback from stakeholders.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	5	Because the policy does not require funding and is unlikely to harm stakeholders, the public is likely to accept the strategy.
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	The policy does not harm stakeholders, but there is funding associated with it.
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	3	Since regulatory structures required by law require agencies to take actions, it is disruptive.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	3	Legalization may require new structures.
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	3	Legalization would incur additional expenses if a regulatory framework were required.
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	4	Legalization may require additional skills to implement regulations.
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	5	Legalization would not require new infrastructure.
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	3	Legalization would not create any challenges.

ENACT LEGISLATION TO STIMULATE CV OR AV TESTING THROUGH DIRECT FUNDING

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	3	This strategy would provide a Pigouvian subsidy to state and local governments for a good (V2I) that provides a public benefit. The subsidy makes the agencies more likely to adopt the systems, which directly internalizes the positive externality associated with V2I. *The Patchwork of Regulations.* A frequent concern raised from the AV industry is that many states will all enact a conflicting patchwork of regulations on AVs, which—the industry fears—would slow AV implementation. This negative, unintended consequence could be realized if many states go beyond legalizing and/or funding testing and enact custom sets of regulations governing vehicle operation.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	N/A	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	3	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	3	The strategy involves creating a Pigouvian subsidy on a good with positive externalities, and the funding would go to the entities to test the goods. This would incentivize the entities to adopt the good (V2I) with socially beneficial outcomes, internalizing the external costs. The public agencies testing CV systems would gain experience implementing and operating CV infrastructure and systems. Such institutional knowledge and experience could increase the likelihood of future adoptions and deployments.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	3	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	5	There is little funding associated with this policy; it is limited to testing systems and, as such, is unlikely to result in increased burdens on low-income or other socially disadvantaged groups. Since the strategies do not generally increase costs or create burdens, this does not apply. The policy involves testing only, the CV system provides benefits to all equipped vehicles, and since the equipment is expected to be mandated by NHTSA, equity issues are not a concern.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	N/A	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	5	

Criteria	Consideration	Likert Rating	Rationale
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	2	Funding is commonly a contentious subject in legislative bodies, and any policy that requires it will likely meet some level of resistance.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	Despite the funding concerns, the strategy is unlikely to harm any stakeholders, is technically oriented, and is unlikely to attract much public attention or pushback.
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	2	The policy does not harm stakeholders, but there is funding required to test CV systems.
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	3	The amount of disruption will depend on the agency's background, although in general there should be little disruption for an agency to test CV systems. Agencies with experience testing and evaluating new technologies, a preexisting research and development division, or those able to contract out the testing and evaluation process would face little disruption.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	3	Agencies testing CV systems may require some interagency coordination and cooperation. For example, a state DOT might need to contract with a municipal government agency to test CV systems, which might require additional coordination with local utilities, law enforcement, etc.
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	3	Testing costs for CVs will vary, but in comparison to the costs associated with many transportation infrastructure projects, the costs would be minimal.
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill- and knowledge-ready to implement*	3	The agencies overseeing, and especially conducting, testing will likely require some new skills and training to conduct the testing and evaluate the results.
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	3	At a minimum, testing a CV system would require the agency to modify existing backhaul, modify traffic signal controllers, and install new DSRC radios—all of which would require modifying the infrastructure.
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	3	Testing CV systems would likely present some challenges to the agency across all these areas.

MODIFY DRIVER TRAINING STANDARDS AND CURRICULA

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	N/A	The desired policy outcome is correct and safe use of CV and AV technologies by drivers. Changing driver/operator licensing and training requirements to reflect the changing driver capabilities and skills needed to operate vehicles with CV and AV technologies has a reasonable chance of encouraging this outcome, but the results are likely to be complicated by the wide range of technologies in the vehicle fleet.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	3	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	3	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	N/A	The strategy is likely to contribute to improved roadway safety and greater mobility for some groups of road users. There is also potential for less-desirable side effects such as loss of employment in some driving-related job sectors.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	3	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	5	While low-income groups are not likely to bear the costs of implemented changes to driver licensing, they may not be able to take advantage of those changes to improve personal mobility due to the likely cost of more-advanced vehicle technologies (including associated costs such as re-training).
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	5	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	2	
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	2	Determining and implementing changes to existing training materials and licensing requirements may be met with resistance by the personnel responsible for actually conducting driver education and by those who conduct on-road tests. New testing procedures to accommodate input/involvement from CV/AV technologies may be resisted by driving examiners and trainers.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	

Criteria	Consideration	Likert Rating	Rationale
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	1	Altering driver training and licensing requirements for AV Level 3 vehicles will require significant restructuring of driver training and of licensing requirements and testing. AV Level 4/5 vehicles could lead eventually to the elimination of driver training, examining, and licensing as it currently exists.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	5	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	2	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	1	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	N/A	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	1	

INCREASE PUBLIC AWARENESS OF BENEFITS AND RISKS

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	N/A	Public outreach and education by itself is not an economic strategy, but it can include information about an economic strategy. It can also contain or impart information that will make it easier (or harder) to achieve policy objectives. This will depend on how the message is received and whether or not it renders a response, positive or negative, by the receiver.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	2	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	5	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	N/A	Public outreach, education, and communication can have a positive society benefit, as evidenced in driver safety campaigns, health education campaigns, anti-litter campaigns, and a plethora of other local initiatives. The effectiveness of the campaign and the ability to achieve a positive societal outcome will be determined by acceptance of the message, the credibility of the messenger, and the perception of the receiver about the necessity and validity of the message. Additionally, if the public education campaign can spur capital investment, it may accelerate the development and implementation of CV infrastructure. Likewise, if the public perceives a benefit of AV technology, they may more readily accept and purchase AVs, increasing market penetration.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	5	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	5	Successful outreach, education, and communication appeal to a broad spectrum of people. Assuming an effort is made to be inclusive in messaging (e.g., messages in multiple languages, messages targeted and appropriate for specific audiences) and that messages extoll the benefits of CV/AV technologies, public education can increase equity among society. As noted earlier, there is a proportion of society that is transportation disadvantaged. These technologies offer a way to overcome those disadvantages. Education and communication should focus on
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	3	

Criteria	Consideration	Likert Rating	Rationale
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	5	how to access these technologies. Investment decisions should be made equitably, as required by numerous federal and state statutes.
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	4	Certainly politically powerful stakeholders have the opportunity to influence public education efforts either by causing the efforts to be withheld or by actively promoting them. It seems unlikely that CV/AV technology implementation would get to the point of public education and information campaigns if there were powerful opposition. However, an unlikely opponent could emerge after education and outreach efforts have begun. That is why it is a public engagement best practice to conduct a thorough stakeholder and audience analysis at the beginning of a process. This will identify any potential opponents and allow them to proactively be contacted and have their concerns addressed. Public acceptance of the outreach will depend on the credibility of the message, the messenger, and the perceived need for the information. Again, decision makers will have likely already accepted the programs and policies surrounding this technology by the time a public education campaign is advanced. Public support for these technologies will also influence decision making for investment and ease of implementation through rulemaking and legislation or adoption of policies that promote or hinder advancement.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	4	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	5	Public outreach, education, and communication programs will not be disruptive to the implementing agency(ies). This is something they do on a daily basis. Because this concept is new and has the ability to be transformative, it is likely that an implementer or associated agency will want to go above and beyond its standard messaging protocols. This may require cooperative relationships with other agencies and the private sector. It will be important to ensure that the education and messages reach all audiences. It is also likely that implementers will want to use new and/or different technology to communicate. The
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	5	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	2	

Criteria	Consideration	Likert Rating	Rationale
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	4	responsible workforce should be knowledgeable and possess the skill sets to be as innovative as the technology. Special attention should be paid to the transportation disadvantaged that stand to benefit from these technologies. This will likely need an increase in manpower to identify their groups, tailor messages appropriate to them, and ensure that delivery of the messages is conducted in such a way as to be trusted and valued by the receiver. These efforts could increase the costs associated with public outreach and education.
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	5	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	3	

SUBSIDIZE SHARED AV USE

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	2	Based on what is currently happening with TNCs, it seems likely that the strategy is not needed to encourage SAV alternatives to AVs. Growth in the TNC market has been market-driven, and the market has worked well; however, it could be used to encourage SAV fleets to provide first/last-mile service and service for targeted populations. Most policies have some unintended consequences. These are not reasons to not implement the policy but may reduce its benefit. For example, the policy may end up further cannibalizing ridership from traditional public transit, requiring ever-larger public subsidies to provide such service. As another example, it may entice taxi and livery services to re-brand themselves as TNCs to get around all fare regulation.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	N/A	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	2	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	3	Reallocating a portion of the subsidies that currently support public transit for specific SAV uses—first-mile/last-mile service, paratransit service, transit deserts, and rural areas—would have the outcome of mitigating congestion and emissions because it could bolster or maintain ridership on traditional public transit, as well as in serving special populations (low income, disabled, elderly, and rural) because it would enhance mobility and improve transportation equity. Society could benefit if public subsidies for transit capital investments or operations were reduced.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	3	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	3	SAVs should lower the cost of conventional paratransit, ride-sourcing, or taxi companies. Thus, there should be lower costs to use them for all potential users. The strategy has been developed to improve transportation equity, not diminish it.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	3	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	3	

Criteria	Consideration	Likert Rating	Rationale
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	2	The taxi or livery industries may oppose the strategy for the same reasons that they currently oppose TNCs. It is uncertain what impact SAVs will have on these industries. Will they morph into SAVs or somehow remain distinct? It is likely that some politicians will oppose the strategy in that they might oppose public subsidies for transit in general, or alternatively seek to protect jobs that they see as threatened by SAVs.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	2	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	3	At the time of implementation, the implementing agencies (public transit agencies or cities) would already have implementing analog programs pertaining to TNCs. Thus, the extension to SAVs should not be disruptive. This is a reallocating or re-targeting of a portion of public subsidies to SAVs. There should be no additional cost to implement, assuming an external agreement is already in place, and net agency savings may be possible if some paratransit are able to be served on a cheaper per-trip basis.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	3	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	4	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	4	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	5	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	3	

IMPLEMENT TRANSIT BENEFITS

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	3	Transit benefits are not by themselves particularly successful in increasing transit use because use depends much more heavily on service provision and user convenience. It could be more effective with an SAV fleet since origins and destinations are less important, but service characteristics could still be important (How quickly does a vehicle come? How much longer does it take than other modes?). The differential between the cost of an SAV ride and the amount available for pre-tax could also be important. If a one-way ride that includes both transit and an SAV costs $10 (meaning that a commute would cost $440 per month), and a rider can obtain the current $255 from an employer, this might not induce a person to ride since it would still mean $185 out of pocket, which might be more expensive than driving. Currently, the transit benefits law allows the ceiling to rise with inflation, but Congress could change this.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	N/A	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	4	Currently, the main unintended consequence from transit benefits is fraud. A GAO investigation easily identified employees who were selling their benefits, although the law clearly states they are for the use of the employer only. However, if people are using them to commute via transit (or SAV fleet), the main unintended consequence is to the employer, who is subsidizing the commute of a non-employee. This would not be a major overall negative since it would still provide an incentive for somebody to use transit or SAV fleets.
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	2	While transit benefits are not particularly costly to implement, they also do not tend to encourage a very large uptake in transit use. They tend to be used by persons for whom transit already serves their origins and destinations with relatively convenient service. They could well be more effective in terms of an SAV fleet, in which any origins and destinations can be served. However, without knowing the cost of such a service, it is difficult to say what fraction of riders' costs could be covered by this incentive. The time differential between solo
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	3	

Criteria	Consideration	Likert Rating	Rationale
			driving and riding in an SAV might also affect their use; if an SAV functioned like a shared-ride taxi service, picking up riders at multiple origins and dropping them off at multiple destinations, the additional time could be a detriment to adoption for all commute trips. (Some of this additional time could be offset by the ability to use the time in vehicle for other purposes, but riders might have other trips for which speed is important and would therefore prefer to travel alone.) Transit benefits can result in a positive outcome if they encourage more people to use SAV fleets by reducing the out-of-pocket cost to commuters. The likelihood would probably increase as the difference between the level of subsidy and the out-of-pocket cost decreased; that is, if it were fairly inexpensive to switch to using an SAV fleet from driving, some people might switch. This policy would likely be net positive regardless, although the total benefit might be relatively small.
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	5	Transit benefits lower the overall cost of riding transit, so it should be positive for low-income groups. There are no financial costs to drivers to participate in a transit benefit program, regardless of whether the program is employer subsidized or pre-tax. Thus, it should not create any additional inequity. This assessment might not be accurate if SAV riders are advantaged over transit riders in some way. Much will depend on the actual cost of an SAV ride vis-à-vis a transit ride, and the actual amount of the transit benefit.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	5	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	5	
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	4	Generally, this is not particularly politically controversial. However, employers might object to mandatory programs, particularly subsidy programs. SAV operators might object to working with transit agencies and vice versa; while the current track record is fairly good on
	How likely is the general public to	5	

Criteria	Consideration	Likert Rating	Rationale
	accept this strategy? *1=extremely unlikely, 5=extremely likely*		this score, over time the groups might become antagonistic if they view each other as competitors for the same riders. Transit benefits should be an easy sell to the public; they already exist and just need to be extended. While Congressional action would be required to allow the use of transit benefits for SAV fleets, since currently they are not an eligible expenditure, this would not be controversial, just time consuming and unpredictable (a member would have to sponsor a bill, it might be tied up with other, more controversial legislation, and so forth).
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	4	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	5	Transit benefits are already in place, so they require adjustments rather than a new strategy. In terms of governance, agreements in individual regions between transit agencies and SAV operators would be needed. Developing a multiagency technology for fare payment can cost hundreds of millions of dollars. However, it could cost considerably less if there were smaller and fewer systems to integrate within a region. Conversely, it could also cost less if one technology were adopted very widely (such as EZPass for electronic toll collection) due to economies of scale. Various agencies might bear these costs. Extending transit benefits should not require new skills from transit agencies in terms of implementation, but it does require developing new payment and accounting mechanisms, and SAV operators must ensure that their customers are paying the appropriate fare. No new physical infrastructure is required. There are two main challenges: developing the payment mechanism and changing the existing legislation to expand use to SAV fleets (and possibly increasing the upper limit).
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	4	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	3	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	3	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	5	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	4	

IMPLEMENT A PARKING CASH-OUT STRATEGY

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	2	While parking cash-out has been fairly successful where adopted, its success also depends on the availability of other commute options. However, even making the program mandatory would not necessarily encourage SAV use since employees might opt for free parking instead. For unintended consequences, the main concern would likely be fraud. Employees could receive the benefit and continue driving to work if, for example, the employer did not adequately enforce parking restrictions. The main consequence would be to employers, not society overall, but unlike illegal sales of transit benefits, there would be no incentive to use SAVs.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	N/A	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	4	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	3	Parking cash-out has tended to be somewhat effective in terms of encouraging mode switching since drivers can opt for multiple modes. Presuming the costs are not high, this is likely more efficient than transit benefits since it can appeal to a larger group of users.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	2	While parking cash-out can result in a net-positive outcome, in that it takes single-occupant vehicles off the road, those former drivers may or may not use SAVs. Also, because this has been used by so few employers, given that many employers would see no benefit, it is likely that any positive impacts would be fairly small. The magnitude of the change will vary by employer—in the best-known evaluation of the effects of parking cash-out at eight employers, the change in the percent share of employees driving alone decreased from 3 to 22 percent.
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	4	In theory, this should not increase costs or burdens because employees should be making their own decision. However, in practice it is possible that people who accept parking cash-out do not understand the cost of other commuting options. Thus, there is a slight risk here of disadvantaging some groups.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality?	4	While there are no financial costs to drivers

Criteria	Consideration	Likert Rating	Rationale
	1=extremely likely, 5=extremely unlikely		who participate in a parking cash-out program, it is possible that participants may pay more for alternate options than their parking cash-out is worth. In theory, people could compare their cash-out amount to their out-of-pocket cost for alternate modes and accept cash-out only if it saves them money, but the cost of the alternate mode might increase over time while the cash-out amount might not. Thus, widespread use could create a group of people who would prefer to drive to work but who are no longer able to.
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	4	
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	5	Absent a mandate, this is entirely an employer and employee decision, so it seems unlikely that powerful stakeholders, the general public, or decision makers would have strong objections.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	5	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	5	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	5	This is not disruptive for employers to implement, and no new governance structure is required. Local organizations that already encourage TDM measures can easily add this to their outreach materials, so costs to public agencies should be minimal; the cost would be a local decision. However, if they wanted to encourage adoption, they might provide subsidies to employers. The direct costs to implement parking cash-out would be borne by employers, who would pay employees to give up parking. Whether they would recoup these costs through giving up parking spaces depends on how much they pay for the spaces (lease costs for rented spaces, whether they are bundled with the lease, and maintenance and operations costs for spaces that are owned). Indirect costs could be borne by real estate owners or developers, if
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	5	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	4	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	1	

Criteria	Consideration	Likert Rating	Rationale
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	4	employers give up parking spaces that they cannot re-lease to others or use as short-term paid parking. The main challenge is that employers may not see the benefit of adopting this policy. Some minor changes to physical infrastructure would be required if employers have to reconfigure their parking facilities.
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	4	

IMPLEMENT LOCATION-EFFICIENT MORTGAGES

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	1	Price is undoubtedly an important component of home buying decisions, but there is no evidence that LEMs make a major difference. When home buyers did take out larger loans than they otherwise might have, the additional increment available to qualified buyers was generally in the range of $15,000, which is probably not sufficient in many markets to make a difference in the number of homes affordable to the borrower. In expensive or gentrifying cities, widespread use of LEMs could have an impact on housing prices overall, or in particular neighborhoods, in ways that are difficult to predict. As Chatman and Voorhoeve (2010) noted, in a constrained housing market with permanent LEM lending, "one would expect a one-time windfall for landowners and a permanent increase in the price of housing in targeted areas" (p. 377).
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	NA	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	2	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	1	Since the pilot LEM programs did not require borrowers to prove they were using transit, it is impossible to say if the program even achieves its goal of encouraging transit use. It would be politically difficult to force home buyers not to own vehicles or drive, not to mention nearly impossible to enforce. Given the past difficulties with implementation and the prospect for unintended consequences to housing prices, LEMs do not seem likely to result in a net-positive outcome.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	1	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	2	For several reasons, LEMs could disadvantage lower-income groups. First, they could encourage people to purchase larger and less affordable homes. This can leave homeowners vulnerable to the type of house price declines and reductions in wealth that occurred in the 2008 recession, which was triggered by a collapse in the subprime mortgage market. Second, they could lead to higher housing prices in areas near transit, which would likely induce price increases in other areas as well. Finally, it is unlikely that lower-income homebuyers can outbid more-affluent buyers for individual houses, given the relatively modest increase in purchasing power. Although in theory an LEM should lower overall housing and transportation costs for those homeowners with an LEM, in practice there may be reasons why they experience higher costs than with a conventional mortgage. Much would depend on both the terms of the LEM and the individual circumstances. For example,
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	3	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	3	

Criteria	Consideration	Likert Rating	Rationale
			the homeowner may have a larger mortgage payment than with a conventional mortgage if they purchase a larger house but spend the same amount on transportation than they would have (e.g., the homeowner might have been willing to take transit even if he/she bought a house outside the LEM zone). Or, the homeowner's commute pattern might change, resulting in higher commuting costs. These would of course be costs borne voluntarily, but they would still constitute financial costs.
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	3	Generally, it is difficult to imagine home buyers opposing a strategy that, at least in theory, could increase their borrowing power. Opposition could arise from three groups. First, if designed to make homeownership more affordable to lower-income groups, LEMs could trigger the types of opposition often seen in response to other affordable housing programs, which can take the form of concerns about declines in property values. Second, if the programs make housing less affordable (by spurring housing price increases or a loss of affordable housing), opposition could arise from affordable housing advocates. Finally, lenders might oppose mandates to offer LEMs. When first introduced, press coverage tended to be positive. If not mandated, it should not be particularly controversial to either the general public or decision makers.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	4	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	3	The pilots were found to be somewhat disruptive to lenders. The original LEM pilot wascomplicated by the complex formulas that determined the additional amount of the loan, which varies not only with the borrowers' characteristics but by neighborhood. Of course, this could be simplified, as in the second pilot, but in this case the formulas were not integrated into existing Fannie Mae software, making it harder for national and more-standardized lenders to change their underwriting formulas (Chatman and Voorhoeve 2010). However, no new governance structures are required. In terms of direct costs, LEMs should not incur any costs to state or local governments and, as noted above, might even increase property tax revenues. However, costs to lenders may increase because they need to incorporate adjustments to the formulas by which they
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	5	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	5	

Criteria	Consideration	Likert Rating	Rationale
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	2	determine the amount a prospective home buyer can borrow. Home buyers may pay higher fees if they borrow larger amounts of money than they otherwise would, given that some fees are based on the loan amount or house price. Lenders may need to train employees on accurately using modified loan formulas. If LEMs prove popular, there may be demands for new infrastructure in the form of stations and additional housing (to the extent housing is considered infrastructure). Overall, these programs have proven difficult to implement under existing conditions. Adoption of CV/AV technology would not change these conditions. In addition, the potential benefits are unproven, and the potential for negative consequences is a concern.
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	2	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	2	

IMPLEMENT LAND USE POLICIES—TOD

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	N/A	TOD is not an economic strategy but a planning tool that can help to create a built environment that may incentivize developers and mobility providers to provide and incorporate SAVs with transit. Land use strategies allow, incentivize, or mandate development features but they do not ensure that developers will provide them, or that the realized design will function as envisioned. For example, an allowance for higher-density development adjacent to transit does not ensure that residents will want or be able to use transit to commute. Existing examples of TOD reveal mixed success that is highly dependent on the individual project's attributes and context. As seen with conventional land use, the outcomes have economic, environmental, and social impacts. TOD would likely have consequences beyond transportation impacts. Some of these may be positive, such as increasing land values, and some may be negative, such as increasing costs for driving and parking. The likelihood that TOD will generate a large shift to SAV use must be compared to existing efforts to promote shared mobility. However, these examples are still quite limited, though they show signs of success where they do exist (for instance, car-sharing). There is a risk that encouraging SAV use could generate more trips and more VMT. This would not achieve the objective to decrease excessive land use consumption.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	2	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	3	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	N/A	TOD can have a positive social benefit by increasing travel options, supporting transit use, decreasing congestion, and creating active social and economic hubs. The effects of TOD and the likelihood to achieve a positive societal outcome will be determined by the implementation at a particular site or neighborhood and the actions of the individuals who live or use the space. For example, a TOD that most riders access by driving will not have the environmental benefits of a station that is generally accessed on foot. Furthermore, although the potential for benefits is high, existing TOD efforts have not dramatically altered car-focused, suburban land use patterns. If the public perceives a greater benefit of SAVs, they may be more likely to accept and use SAVs, increasing demand for the service and development that supports it. However, the limited extent of current TOD projects in the United States suggests that land use strategies alone are not enough to change travel behavior.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	3	

Criteria	Consideration	Likert Rating	Rationale
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	3	Using TOD to support SAVs can improve access to transit and activity centers, creating the potential to provide broad economic and environmental benefits. It allows some residents to live without a vehicle, which can provide monetary savings. Low-income residents are often disproportionately affected by air and noise pollution, which may be mitigated by increased transit use. However, some TOD has been criticized for failing to provide low-income or affordable housing and serving mainly higher-income individuals. Some projects may also displace current residents. Historical land use patterns supported automobile owners and suburban residents while underfunding infrastructure for transit and shifting public investment away from urban areas, so a shift toward TOD development may be seen as a tool to counteract this existing imbalance.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	2	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	4	
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	3	Developers are the party most impacted by changes to development code. New code or zoning requirements may impose costs or be perceived as a burden, and may be opposed by developers. However, TOD is being implemented by developers across many U.S. cities. The public is likely to have mixed acceptance levels, depending on the location and the impact of the strategy on homeowners. Neighbors of TOD may have concerns about increased local congestion and changes to neighborhood character. The likelihood of acceptance is low based on current evidence that suburban, car-oriented development is still preferred by the majority of Americans. TOD represents a shift away from the status quo in development patterns, and this can be a barrier. Although TOD and similar strategies are gaining popularity in some urban and suburban core areas, they are also met with NIMBYism in many areas. TOD is gaining support from federal, state, and local planning and transportation programs that may contribute to wider acceptance in the long term.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	2	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	4	

Criteria	Consideration	Likert Rating	Rationale
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	4	TOD strategies have been implemented in many cities for years, and there is an existing institutional, technical, and financial foundation that can be used to guide future efforts to incorporate SAV into these strategies. However, they are not common in all municipalities and often require changes to legal statutes and regulations, which can pose a burden on local agencies. Increasing support from state and federal programs may mitigate these burdens. TOD development can also require collaboration between multiple agencies (e.g., transit agencies, planning departments, zoning departments, and developers) and, with SAV fleets, the addition of more private partners as well. Overall, the operational challenges are larger in communities that do not have experience with TOD, but a growing body of knowledge can support implementation.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	3	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	3	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	4	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	4	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	4	

IMPLEMENT LAND USE POLICIES—REDUCED PARKING REQUIREMENTS

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	N/A	Reduced parking requirements are associated with decreasing the costs of development for TOD and smart growth projects. This can provide a strong incentive for developers and property owners to develop land that encourages shared mobility and enables SAV use. However, the likelihood of generating a large shift toward SAVs must be compared to existing efforts to promote shared mobility, which are still quite limited, though they show signs of success where they do exist. There is a risk that encouraging SAVs would generate more VMT and replace transit trips instead of complement them.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	4	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	3	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	N/A	Parking requirements can increase the costs of development, pushing projects to undeveloped areas and overbuilding parking in high-value, urban areas. With reductions, developers should be able to build other facilities and more housing. Currently, parking is often provided for free, acting as an incentive to increase personal vehicle trip-making. Limited or costly parking correlates with decreased vehicle use, suggesting that this strategy may be an effective policy strategy in shifting demand from personal vehicles to shared vehicles. It should be implemented along with other TOD policies.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	4	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	3	Reduced parking requirements may reduce the supply of parking for low-income travelers, but that would be most likely offset by the potential for increasing alternative travel options that are already used more by disadvantaged groups. SAVs as a mobility option may not be cheaper on a per-trip basis, but they can provide a safety net for regular transit users. There is also a possibility that if SAVs are successful, they will draw funding away from mass transit. If SAV service is not affordable to low-income individuals, their mobility will be negatively impacted.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	2	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	4	

Criteria	Consideration	Likert Rating	Rationale
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	2	Developers and property owners who benefit from parking revenue or existing development patterns may oppose a shift away from existing parking policy. However, in many cities parking can be a very expensive element of projects, and many developers are pursuing opportunities afforded by land use codes to reduce parking development. Car manufacturers may also oppose incentives for transit and SAVs, but companies such as Ford and GM are already investigating SAVs and AVs for future investments. Policy makers in many areas have to face proponents of conventional development patterns who disapprove of investing in high-density, urban development. This could present a challenge to changing existing laws, and parking in particular can inspire strong opposition from neighborhood groups.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	4	A challenge to implementing reduced parking requirements is the process of changing local regulations. However, implementing the strategy would not be expensive; changes to development codes are made regularly, and local agencies can adjust procedures as necessary. Cities and towns are changing parking requirements in many areas and provide a growing body of knowledge on the process. Reduced parking requirements mainly apply to new construction, but if SAV use increases, there may also be a need to retrofit existing property. This would require adapting infrastructure; developers may be eager to do so on high-value development opportunities.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	3	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	4	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	4	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	3	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	3	

APPLY ROAD USE PRICING—STATE-LEVEL ROAD USER CHARGES

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	5	Pricing represents one of the best policy actions for internalizing the external costs associated with transportation. The policy levies a charge directly on travel within a very large area and can be structured to account for any potential travel cost over a very large area. As such, it is among the best pricing options for fully internalizing the costs of travel. An unintended consequence of an RUC is that travel could be reduced as drivers attempt to minimize their exposure to the charge.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	N/A	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	3	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	5	As a direct economic instrument, pricing is very efficient at recovering the costs of externalities because those costs can be directly incorporated into the charge itself. Furthermore, because pricing can be structured to incorporate and account for any number of factors (congestion, pollution, etc.), it is more likely to result in a net-positive beneficial income because it can achieve numerous transportation policy objectives.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	4	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	2	Pricing is likely to illicit equity concerns from lower-income drivers who would see a larger percentage of their income dedicated to travel expenses relative to middle- and upper-income drivers. However, pricing systems can be structured in any number of ways to address these concerns. Within the context of a statewide pricing system, it is likely that discounts could be offered to low-income drivers. Road users (in this case, drivers) are the ones who bear the burden of the RUC. They are primarily responsible for the externalities being internalized, so impacts to other groups are minimized. Furthermore, the benefits of an enhanced transportation system due to the increases in transportation revenue are likely to result in a fair distribution of impacts across society.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	4	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	3	

Criteria	Consideration	Likert Rating	Rationale
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	2	RUCs are among the most unpopular of pricing applications. Drivers in general do not support paying more for transportation, and RUCs are viewed as being particularly onerous because the public is not accustomed to knowing exactly what it is paying for transportation in the form of fuel taxes. Furthermore, the trucking industry views RUCs as being burdensome given the number of transportation-related fees and taxes that are already paid by the industry. Drivers and the trucking industry are likely to apply intense pressure to public officials opposing road user fees, meaning that decision makers are unlikely to immediately support such mechanisms.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	1	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	1	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	2	RUCs are new in the United States, and there are a number of questions about how they would be deployed. Regardless, they would represent a significant increase in administrative capability since the current fuel tax regime collects taxes from only a few points (fuel distributors) as opposed to collecting from all drivers/vehicles. New accounting systems will need to be developed, and it is possible that new technologies would need to be developed for the metering of road usage and collection of associated charges. There is a strong potential for these aspects of system implementation and operation to be handled by the private sector, but even then, public agencies will need to ensure that private-sector vendors are meeting their obligations.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	2	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	3	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	3	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	4	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	2	

APPLY ROAD USE PRICING—FACILITY PRICING

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	4	Pricing in general represents one of the best policy actions for internalizing the external costs associated with transportation. However, facility pricing is less effective than RUCs only because it is limited in its scope to certain facilities. It is effective at internalizing costs for users of the priced facility, not all road users. Price, though, may still be based on any number of factors and internalize any number of costs associated with use of a particular facility. There is a likelihood with facility pricing that drivers will divert to non-tolled roads as a means of reducing their financial exposure to the new charges.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	N/A	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	2	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	4	As a direct economic instrument, pricing is very efficient at recovering the costs of externalities since those costs can be directly incorporated into the charge itself. However, facility-specific pricing is only effective at improving efficiencies within the priced infrastructure, not among all users. A net-positive outcome will depend on the particulars of the project and the goals and objectives behind the pricing regime. Pricing based on wider-scale societal factors, such as environmental goals, may yield wider benefits to society. Pricing systems with facility-specific objectives, such as revenue generation in support of financing, may yield narrower benefits.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	3	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	4	Facility pricing will illicit equity concerns from lower-income drivers who would see a larger percentage of their income dedicated to travel expenses relative to middle- and upper-income drivers. However, pricing systems can be structured in any number of ways to address these concerns. Within the context of a statewide pricing system, it is likely that discounts could be offered to low-income drivers. Furthermore, with facility-specific pricing, there are likely to be non-priced alternatives that those wishing to avoid the charge may use. Unlike an RUC, facility-specific pricing generally only requires the users of a specific facility to pay. Improved traffic flows resulting from pricing may benefit adjacent general purpose lane users.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	4	
	How likely is the strategy to result in an unfair distribution of benefits across society?	3	

Criteria	Consideration	Likert Rating	Rationale
	1=extremely likely, 5=extremely unlikely		Furthermore, reduced congestion may lead to improvements in air quality, which benefit society as a whole.
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	2	Pricing is generally opposed by the public since it results in additional travel costs. However, facility-specific pricing is more acceptable because it is limited to the users of the priced facility, not all drivers. Furthermore, the public and political acceptability increases when free alternatives are provided, or when discounts for certain vehicle classes and users (such as transit users and carpoolers) are offered.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	2	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	4	The operational challenges associated with facility-specific pricing will depend on the particular agencies' past experiences with pricing. Implementing new pricing systems in areas with an established experience in pricing will be relatively straightforward, even though there will likely need to be capital investments in technology and infrastructure and back-office systems. These costs will be more significant for agencies with no experience in pricing, and significant investment may be required in order to establish necessary institutional and workforce capabilities.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	4	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	2	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	4	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	2	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	3	

APPLY ROAD USE PRICING—CORDON PRICING

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	3	Pricing in general represents one of the best policy actions for internalizing the external costs associated with transportation. Cordon pricing systems can be structured to account for any number of externalities, but they only internalize the costs associated with travel into particular areas. Cordon pricing could impact business within the charged zone by reducing vehicular traffic into the area.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	N/A	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	2	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	3	As a direct economic instrument, pricing is very efficient at recovering the costs of externalities since those costs can be directly incorporated into the charge itself. However, cordon pricing is only effective at improving efficiencies within the priced area. Efficiency gains are improved if the pricing structure includes a distance-based element (for all travel within the cordon) as opposed to a fee for simply passing the cordon line.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	3	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	3	Cordon pricing may illicit equity concerns from travelers who have no other modal option for entering the cordon area. Equity may be improved by providing additional modal options and providing monetary incentives for the use of those modes.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	3	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	3	

Criteria	Consideration	Likert Rating	Rationale
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	1	Pricing is generally opposed by the public since it results in additional travel costs. However, cordon pricing is more acceptable because it is limited to the road users in a specific area, not all drivers. Furthermore, the public and political acceptability increases when free alternatives are provided, or when discounts for certain vehicle classes and users (such as transit users and carpoolers) are offered. However, businesses within the cordon are likely to oppose the system because it makes travel into the area costlier, which may reduce revenues. These interests may be more concentrated and organized than general public stakeholder groups, meaning that pressure can be more specifically applied to elected officials. This increases the political difficulty of implementing cordon pricing systems.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	2	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	2	Cordon pricing systems have never been implemented in the United States, meaning that any agency implementing them will be faced with new implementation challenges in terms of operating, administering, and enforcing the system. However, agencies with a history of pricing might find these challenges easier to overcome than agencies with no experience in pricing, who may require significant investment to establish the necessary institutional and workforce skills and capabilities.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	3	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	2	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	2	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	2	

Criteria	Consideration	Likert Rating	Rationale
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	2	

APPLY ROAD USE PRICING—PARKING PRICING

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	2	Pricing in general represents one of the best policy actions for internalizing the external costs associated with transportation. Parking pricing systems can be structured to account for any number of externalities, but they only internalize the costs associated with parking, not overall travel. Parking pricing could impact area business by raising the costs associated with parking.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	NA	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	3	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	2	Parking pricing only results in improved efficiency for parking operations. Benefits are likely to accrue only in the specific areas where the strategy is applied, not among the general public.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	3	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	3	Parking pricing may illicit equity concerns from travelers who have no other modal options and cannot avoid parking their car in the charged area. Equity may be improved by providing additional modal options and providing monetary incentives for the use of those modes.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	3	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	3	

Criteria	Consideration	Likert Rating	Rationale
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	3	Pricing is generally opposed by the public since it results in additional travel costs. However, parking pricing is more acceptable because it is limited to parking in specific areas as opposed to general travel or travel on major roadways. Public and political acceptability increases when modal alternatives are provided or when discounts for certain vehicle classes and users are offered. Businesses within the priced area are likely to oppose the system because it makes accessing area businesses with a personal vehicle costlier, which may reduce revenues. These interests may be more concentrated and organized than general public stakeholder groups, meaning that pressure can be more specifically applied to elected officials. This increases the political difficulty of implementing a pricing system, but the overall number of affected stakeholders is likely to be lower than other pricing mechanisms.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	4	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	2	If an agency is looking to implement a parking pricing system, it is likely that it already has parking facilities it is managing. Pricing represents a new operating component, but it is smaller in scale relative to other pricing systems. It is likely that significant capital investments in new technology and infrastructure will be required.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	3	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	3	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	2	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	2	

Criteria	Consideration	Likert Rating	Rationale
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	3	

IMPLEMENT A NO-FAULT INSURANCE APPROACH

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	1	State-level no-fault automobile insurance would likely accomplish goals of clarifying assignment of liability and, depending on the statutory language, reducing or eliminating manufacturer liability. If one believes that the tort system creates externalities, reducing tort liability would reduce externalities. No-fault automobile insurance in the United States had the unintended consequence of increasing costs. It is possible that the same would be true for a new no-fault approach, though there may be ways to control this.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	4	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	2	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	1	The likelihood of the strategy producing a net-positive socially beneficial outcome depends on how important it is to (a) clarify liability, and (b) reduce manufacturer liability. At this point, it is not clear how socially important those goals are.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	2	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	2	Historically, state no-fault automobile insurance has increased auto insurance costs. This may harm the urban poor for whom auto insurance costs are particularly high. Eliminating a right to sue either another motorist or an auto manufacturer may increase the perception of inequity.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	NA	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	3	
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	2	Plaintiffs' lawyers and consumer groups are likely to oppose this strategy. The general public may support the idea of simplifying liability, though past state no-fault statutes have not been especially popular.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	

Criteria	Consideration	Likert Rating	Rationale
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	2	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	3	The operational challenges depend on the statute and whether the state has experience with no-fault automobile insurance. If the state has experience with no-fault automobile insurance, the operational challenges are likely to be fairly minimal. However, if the state has not had no-fault automobile insurance recently, the operational challenges are likely to be greater since lawyers, judges, consumers, and insurance adjusters all need to learn how this approach works.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	3	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	5	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	2	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	5	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	3	

REQUIRE MOTORISTS TO CARRY MORE INSURANCE

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	5	The economic effectiveness of eliminating the existing negative externality would be very high with the use of this strategy. Without enforcement, the strategy may have unintended consequences, namely increased incidence of consumers not purchasing *any* insurance. It may also exacerbate existing inequalities because many of the urban poor have very high automobile insurance costs.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	NA	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	3	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	5	The strategy is very efficient because it eliminates the existing externality. It is very likely to produce a net-positive socially beneficial outcome because it will eliminate the existing subsidy for unsafe vehicles and drivers.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	5	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	1	The strategy will likely increase costs placed on low-income urban groups. It will also increase costs on groups that most benefited from this negative externality. It is not likely that this strategy will result in an unfair or inequitable distribution across society because insurance costs will roughly reflect the actual costs that are imposed on others.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	1	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	3	
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	3	It is difficult to predict whether insurers would support or oppose this measure. While one might think that insurers would support state laws that required the purchase of more insurance, insurers may fear additional regulation that may go along with this. Plaintiffs' attorneys are likely to support this measure. Absent education about the benefits of this
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	2	

Criteria	Consideration	Likert Rating	Rationale
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	4	approach, the general public may oppose this strategy because it will result in an increase in their insurance costs, at least in the short term. This may result in widespread opposition. One group of beneficiaries of this approach—those who will be seriously injured as a result of crashes and who are now able to recover damages that they would not have been able to—are impossible to identify *ex ante*, prior to the crashes occurring. The societal benefits that result from increased incentives to adopt safer automobile technology are diffuse. Policy makers may accept this approach based on the arguments raised above. There are also other variations that would accomplish similar ends of reducing the negative externality created by underinsurance. For example, a state may enact an under-insured motorists pool that would pay the difference between the victim's damages and the at-fault defendant's insurance coverage. If this were funded by a tax on dangerous cars/drivers, many of the same goals would be accomplished and might well be more politically palatable than a mandatory across-the-board increase in insurance coverage. This would represent a state-run mandatory insurance policy that would cover all drivers. Assessing premiums/taxes based on true crash risk would have a similar effect in reducing externalities as requiring an increase in mandatory insurance. If the taxes to fund this pool were funded in other ways (e.g., gas tax), the incentives to shift toward safer transportation modes would be weaker.
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	5	The policy would not be operationally disruptive to the implementing entity. It would not require any new or complex governance structures if enacted at the state level. Every state already has an existing mechanism to determine whether motorists have purchased the required auto insurance. However, it may require increasing resources devoted to enforcement of these requirements.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	5	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	5	

Criteria	Consideration	Likert Rating	Rationale
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	5	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	5	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	2.5	

SUBSIDIZE CV-EQUIPPED VEHICLES

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	4	The subsidy strategy for CV technologies will enable stakeholders to internalize the costs associated with the externalities that have been identified by responding to a specific price signal that encourages the adoption of this technology. However, subsidizing this technology will, by design, accelerate the adoption of the technology, which will be disruptive even for many unrelated segments of the economy.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	N/A	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	2	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	5	CV technology subsidies would effectively recover costs from the externalities identified and would produce a net-positive outcome for society.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	4	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	5	This strategy is likely to positively affect most segments of society, although in the short term, some segments will be economically disrupted.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	4	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	4	
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	3	The general public is and will be very accepting of this technology except in the area of privacy and security, as are/will be decision makers who are responsible for deployment and management of a subsidy program, whereas decision makers in Congress may be less enamored with funding a technology subsidy.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	5	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	

Criteria	Consideration	Likert Rating	Rationale
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	3	Implementing a subsidy program would not be disruptive to USDOT or to vehicle OEMs since it would not involve any governing structures that have not been implemented in the past. The cost to implement this program would be nominal despite its size, and the stakeholders involved already have the staff and skills necessary. However, the scale of the challenges for implementation is large.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	3	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	3	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	5	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	5	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	2	

INVEST IN CV INFRASTRUCTURE

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	NA	CV infrastructure funding is marginally likely to affect the overall development of CV technologies and is unlikely to have unintended consequences.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	3	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	5	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	NA	It is still unclear whether the benefits of increased funding for CV infrastructure will be greater than its costs.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	3	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	4	CV infrastructure funding is unlikely to increase costs for any end users; however, depending on where the funding is applied, the distribution of benefits could be unevenly distributed in society.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	4	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	2	
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	4	There is no significant political opposition to this strategy, other than general opposition to spending money on transportation infrastructure.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	4	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	2	

Criteria	Consideration	Likert Rating	Rationale
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	4	Funding of CV infrastructure is unlikely to be disruptive and could easily be managed by existing resources within USDOT; however, the scale for CV infrastructure deployment is potentially massive.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	5	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	3	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	3	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	4	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	2	

GRANT AV- AND CV-EQUIPPED VEHICLES PRIVILEGED ACCESS TO DEDICATED LANES

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	N/A	If the intent is to increase market penetration of equipped vehicles, success will depend on road operators' willingness to dedicate lanes to AVs and CVs. If the intent is to reduce VMT in a restricted district or area (like an urban center), success will depend on how well the supply of SAVs matches demand.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	3	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	5	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	N/A	For minimal cost, the potential societal benefits in (primarily) reduced travel time are very large and could incentivize acceptance and adoption.
	How likely is the strategy to produce a net-positive socially beneficial outcome?*1=not at all likely, 5=extremely likely*	4	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	5	This strategy could benefit users of both dedicated lanes and general purpose lanes.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	NA	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	4	
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	4	As long as the MLs still operate at a high level of service, opposition should be relatively minimal. However, increased use of MLs will face some opposition from current users of the MLs, such as transit, low- or zero-emission vehicles, carpools, etc.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	4	

Criteria	Consideration	Likert Rating	Rationale
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	5	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	3	The amount of disruption varies directly with the market penetration of AVs and CVs. If there is a small percentage and only a few users of dedicated lanes, the disruption would be minimal. If there is a large percentage, then they may comprise the entire system, which would disrupt current users. However, those current users should benefit due to the large increase in capacity overall. Allowing AVs and CVs in dedicated lanes will require little to no change in governing structure since it is an extension of current ML practice. In addition, if using existing lanes, the strategy requires minimal cost to implement. The current workforce has the skills to incorporate another user group on MLs. This strategy represents relatively small challenges, many that are similar to ones that have been overcome on MLs already when adding other vehicle groups.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	5	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	4	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	3	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	3	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	4	

GRANT SIGNAL PRIORITY TO CVs

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	N/A	It is unlikely that this policy will be the driving force to increase market penetration because the travel time benefits will be minimal. It may also have the negative outcome of reduced priority treatment for transit.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	1	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	2	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	N/A	This strategy will require a large percentage of the fleet to be CV to obtain benefits that would exceed costs because the travel time savings will be minimal and can only be used when conditions are right.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	2	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	2	This strategy could increase travel time delay for non-CV and transit riders. It may benefit only those who own CVs, likely the more well off travelers. It will likely have the most negative impact on transit bus travelers.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	NA	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	2	
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	3	Transit operators may oppose the implementation of this strategy. There are likely to be mixed feelings among the general public since some non-CVs experience longer travel times and fewer green lights. However, this may encourage these individuals to consider owning or using CV-equipped vehicles.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	3	

Criteria	Consideration	Likert Rating	Rationale
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	4	Providing priority treatment for CVs will likely result in limited impact or disruption in traffic flow and require little to no change in government structures since it is an extension of current practice with transit sign priority treatments. Likewise, there is minimal expense to implement the strategy. The strategy is somewhat more complex than transit signal priority since there are a limited number of calls for green time by transit vehicles at any given intersection. New algorithms overseeing the priority treatment for CVs would be needed. The technical and financial challenges are minimal, but the potential positive impact of this preferential treatment is limited. Plus, CVs and transit vehicles that currently have preferential treatment may be worse off.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	5	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	4	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	3	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	3	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	3	

GRANT PARKING ACCESS TO AV- AND CV-EQUIPPED VEHICLES

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	N/A	Priority parking will have little to no effect on the market penetration of AVs and CVs. The ability of an AV to park itself will likely increase the market penetration of AVs and CVs. If implemented, it would reduce some parking availability for non-AVs.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	1	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	5	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	N/A	Costs may be minimal, but benefits will also be minimal. When AVs are in an SAV model and they are provided with priority pick-up/drop-off locations, there will likely be some positive social outcome.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	3	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	3	Well-off travelers who privately own an AV will benefit from convenient access because the vehicle itself can be parked remotely at no disadvantage to the owner. Consequently, travelers who do not own AVs also benefit because convenient parking locations are freed up for non-AV owners.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	NA	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	3	
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	4	Since AVs can be parked remotely in parking areas that are rarely used, drivers of conventional vehicles may not be in support of providing limited priority parking spaces to owners of these vehicles. Developers, typically politically powerful stakeholders, would not want to give up valuable parking to a vehicle type unlikely to use it. Policy
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	2	

Criteria	Consideration	Likert Rating	Rationale
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	4	makers may support the strategy if it were proven to be effective in spurring market penetration. However, with electric vehicles, the provision of preferential parking has only shown limited effectiveness.
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	3	The use of parking spaces will fundamentally shift. Areas of parking that are rarely used (remote parking in a shopping center or remote spaces downtown) can now be used for CV/AV parking as long as convenient curb access is provided. This allows more balanced use of parking resources and frees up close-in parking for non-CV/AV use. Additionally, if AVs are used in an SAV model, the number of parking spaces needed may be reduced and the need for curb access will increase. CV/AVs will enable reevaluation of parking criteria and space allocation. It is likely that new city codes will be needed that reduce the amount of parking required by a development. The expense to define and implement new parking guidelines will be minimal in dollars but will require careful consideration and time to develop. The current workforce lacks information about CV/AV market penetration and timing to thoughtfully provide new parking requirements. There is unlikely to be new infrastructure adaptations for AVs. If parking infrastructure is to communicate with CVs, new technology would need to be installed in parking facilities. The political forces that have interest in parking requirements are likely to be on opposite sides of the issue for CV/AVs. Developers will desire reduced parking requirements on the basis that AVs can be parked remotely and an SAV reduces the number of spaces needed. On the other hand, businesses may see reduced parking as a threat to customer access.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	3	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	4	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	2	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	3	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	4	

IMPLEMENT NEW CONTRACTUAL MECHANISMS WITH PRIVATE SERVICE PROVIDERS

Criteria	Consideration	Likert Rating	Rationale
Effectiveness	If the strategy is economic, how well does it internalize external costs into private actors' decision making? *1=not at all likely, 5=extremely likely*	NA	P3 arrangements are very effective at bringing to a market new products and services that benefit the public interest while providing financial incentives for private-sector investment. Each P3 is different, so unintended consequences are certainly a possibility with this strategy.
	If not economic, how likely is it to achieve its desired policy outcome? *1=not at all likely, 5=extremely likely*	5	
	Is the strategy likely to result in unintended consequences? *1=extremely likely, 5=extremely unlikely*	3	
Efficiency	If the strategy is economic, how well does the strategy recover the costs from the externality? *1=not at all, 5=extremely well*	NA	P3 arrangements have a long history of creating net-positive benefits to society, so this strategy for CV/AV technologies would likely have similar outcomes.
	How likely is the strategy to produce a net-positive socially beneficial outcome? *1=not at all likely, 5=extremely likely*	4	
Equity	How likely is the strategy to increase costs or place burden on low-income or other socially disadvantaged groups? *1=extremely likely, 5=extremely unlikely*	4	This strategy is unlikely to increase costs or impose other burdens on low-income groups since one of the primary focuses of P3 projects is on the public interest. However, P3s do have the potential to distribute benefits unequally across society, depending on the particular structure of the arrangement.
	How likely is the strategy to increase costs or burden on the groups responsible for the initial externality? *1=extremely likely, 5=extremely unlikely*	4	
	How likely is the strategy to result in an unfair distribution of benefits across society? *1=extremely likely, 5=extremely unlikely*	3	
Political	Are any politically powerful stakeholders likely to oppose the strategy? *1=extremely likely, 5=extremely unlikely*	3	This strategy has the potential to elicit opposition regardless of the P3 structure; however, if approached as a benefit to a large cross-section of society and industry, opposition would likely be minimal.
	How likely is the general public to accept this strategy? *1=extremely unlikely, 5=extremely likely*	4	

Criteria	Consideration	Likert Rating	Rationale
	How likely are decision makers to accept this strategy? *1=extremely unlikely, 5=extremely likely*	4	
Operational	How disruptive is implementation of the strategy to the implementing agency? *1=very disruptive, 5=not at all disruptive*	4	This strategy by itself is not disruptive to an implementing agency, and although it does require detailed and often complex governing structures, local agencies are becoming more familiar with these, and USDOT offers toolkits and conferences around forming P3s. Implementing this strategy can be expensive, but no more so than any other contract. In the case of CV/AV technology, new infrastructure would be needed.
	Does implementing the strategy require new or complex governing structures? *1=requires, 5=does not require*	3	
	How expensive is it to implement the strategy? *1=extremely expensive, 5=minimal expense to implement*	5	
	Does the agency workforce have the necessary skills and knowledge to implement the strategy? *1=does not have skills and knowledge, 5=skill-and knowledge-ready to implement*	5	
	Does implementing the strategy require new infrastructure or adaptations to existing infrastructure? *1=new infrastructure, 3=adapting infrastructure, 5=neither*	2	
	What is the overall scale of the technical, institutional, political, or financial challenge to implementing the strategy? *1=many challenges, 5=no challenges*	3	

REFERENCES

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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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