Shared Automated Vehicle (SAV) Pilots and Automated Vehicle Policy in the U.S.: Current and Future Developments

Adam Stocker and Susan Shaheen

Abstract Many automated vehicle (AV) developers and technology companies are fast pursuing the public deployment of these vehicles as part of a shared fleet. To the best of our knowledge, this chapter is the first comprehensive compilation of 17 active shared automated vehicle (SAV) pilot projects in the U.S., as of February 2018. This chapter also reviews AV regulatory efforts at the federal, state, and local levels. By tracking trends and classifying the differences between SAV pilots, we foster a better understanding of how this technology might roll out in the coming decades. While 30 states have enacted legislation or executive orders related to AVs, only two states' regulations contain provisions related to SAVs. Although future impacts of SAVs are still uncertain, this chapter begins the dialogue around the need for proactive SAV legislation to help guide beneficial societal outcomes of these emerging services.

Keywords Shared automated vehicles · Automated vehicles · Shared mobility
Automated vehicle policy · Automated vehicle pilots

1 Introduction

Automated vehicles (AVs) are vehicles that move passengers or freight with some level of automation that assists or replaces human control. AVs are being developed by over 40 companies around the world, including most major automakers and many large technology companies [1]. Between August 2014 and June 2017, there were more than 160 AV-related investments, partnerships, and acquisitions, totaling approximately $80 billion dollars [2]. With the ongoing growth of shared mobility

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services (carsharing, ridesourcing/transportation network companies (TNCs), ridesharing, bikesharing, and microtransit), many companies are interested in deploying shared AV fleets. Shared automated vehicles (SAVs) are AVs that are shared among multiple users and can be summoned on-demand similar to ridesourcing or can operate a fixed-route service like a bus. For the purposes of this research effort, we consider SAV services to be those that operate or intend to operate as a shared vehicle fleet that serves passengers in one or more travel use cases.

The Society of Automotive Engineers (SAE) have defined five levels of vehicle automation, with Level 1 signifying vehicles that automate only one primary control function (e.g., self-parking or adaptive cruise control) and Level 5 referring to vehicles capable of driving in all environments without human control [3]. The majority of SAV pilots thus far are targeting Level 4 automation, where a human operator does not need to control the vehicle as long as it is operating in a suitable operational design domain (ODD) given its capabilities. Almost all SAV pilots are aiming for Level 4 automation because the viability of future SAV business models depends on the absence of human monitors inside the vehicles. For this reason, the ODD is arguably more important than the level of automation, when discussing differences between SAV pilots. The ODD describes the specific conditions under which a given automated feature is intended to function. The ODD is the definition of where (roadway types and speed limits) and when (during what weather conditions, time of day, etc.) an AV is designed to operate [3]. SAVs differ in their scope of operations depending on the ODD, which we explore further in this chapter.

We are at the beginning stages of active SAV pilots in the U.S. and around the world. At present, all SAV pilots mentioned in this chapter have a safety engineer inside the vehicle at all times who can intervene and take control of the AV, if necessary. We are also at the early stages of AV and SAV regulations at the U.S. federal, state, and local levels of governance. While 29 U.S. states and the District of Columbia (DC) have passed legislation or issued executive orders related to AVs, there are no AV-specific laws enacted at the federal level, at present. In addition, legislation in only two states contains measures related to SAVs at this time. This chapter focuses on SAV pilots and legislation in the U.S., but please note that there are many developments around the world. The range of challenges and opportunities of SAVs are yet to be fully understood and are difficult to predict. However, the potentially lower cost per-mile of future SAV services could increase travel demand, possibly leading to a number of negative societal effects like increased vehicle miles traveled (VMT), emissions, and urban sprawl. Future SAV policy will be critical to help mitigate the potential negative impacts of these services and encourage higher-occupancy travel. This chapter serves as a compilation of SAV developments in the U.S. and uncovers trends among SAV pilots and legislation thus far. Understanding how SAVs are developing and might develop in the near future is critical when exploring possible policy actions regarding this emerging form of mobility.

2 Shared Automated Vehicle (SAV) Pilots

There have been a number of SAV developments in the U.S. over the past few years, and the pace at which pilot projects are launching appears to be speeding up. In this section, we track and map all of the continuously operating SAV pilots in the U.S. and classify whether the program is:

(1) Serving passengers or testing only,
(2) Operating on public or private roads, and
(3) Using a low-speed shuttle or a conventional vehicle.

We chose to classify SAV pilots across these three dimensions because they gauge how close each particular pilot may be to deploying and help to clarify the ODD and use case that the program is targeting. The private or public road distinction is important for regulation considerations. In almost all cases, AVs on private roads do not need to follow state regulations. Of course, these classifications could change over time as services move from testing to the deployment phase or begin to travel on additional roadways. These classifications represent the state of the SAV pilots, to the best of our knowledge, as of February 2018. Please note that we only include continuous and current SAV pilots and do not include temporary demonstrations or pilots that have ceased operations. At present, all of these SAV pilots have one or more backup safety engineers inside the vehicle, who are ready to take over in case there is a problem with the automated driving system. In addition, all of the AVs listed are Level 4 automation, unless otherwise specified. Figure 1 maps all active SAV pilot programs in the U.S.

There are 17 active SAV pilots across eight states around the U.S., eight of which are serving passengers and nine of which are in a testing only phase. The

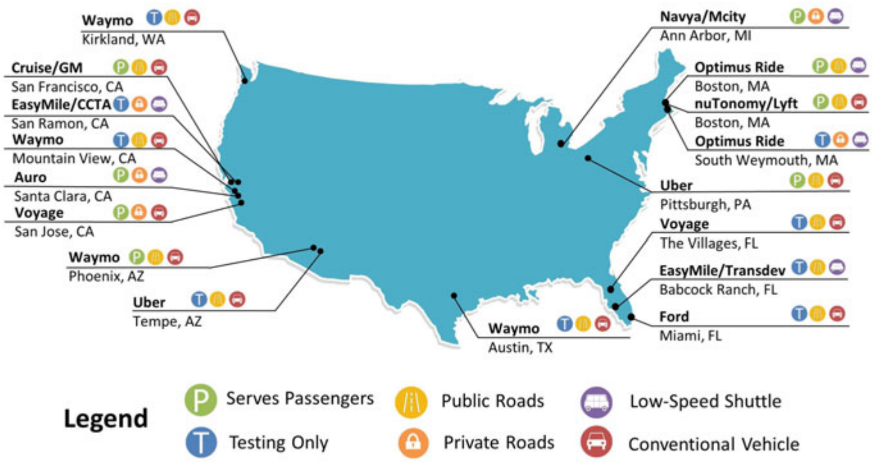

Fig. 1 Active SAV pilots in the U.S., as of February 2018

majority of SAV pilots operate on at least some public roadways, though five pilots only operate on private roads, at present. A mix of vehicle types are used in SAV pilots, although larger players tend to prefer conventional vehicles (11 pilots in total). Smaller, more specialized companies often use low-speed shuttles (six pilots in total). Across the active U.S. SAV pilots, two distinct pilot types emerge, largely depending on the ODD. The following discussion focuses on SAV pilots operating on: (1) private roads and in planned communities and (2) public roads and city streets. We describe in further detail only those pilots serving passengers.

2.1 Private Roads and Planned Communities

SAV pilots on private roads and in planned communities operate in low-speed, controlled environments, and sometimes use specialized shuttles designed to travel under 30 miles per h. These pilots often focus on serving specific locations or passenger markets, such as: office parks, housing developments, retirement communities, and universities. SAV pilots in testing phase that also fall under this category include: (1) EasyMile/CCTA at Bishop Ranch; (2) Optimus Ride in South Weymouth; (3) Voyage at The Villages, Florida; and (4) Easymile/Transdev at Babcock Ranch. The SAV pilots serving passengers in this category are described in Table 1.

2.2 Public Roads and City Streets

The other group of SAV pilots operate on city or suburban streets, and most use conventional vehicles equipped with AV technology to navigate their surroundings, often in mixed traffic. SAV pilots still in the testing phase that fall into this category include: (1) Waymo in Mountain View, California, Austin, Texas, and Kirkland, Washington, (2) Uber in Tempe, Arizona, and (3) Ford in Miami, Florida. All SAV pilots listed use pre-selected passengers and are not open to all members of the public. The current SAV pilots in this category are described in Table 2.

2.3 Planned SAV Developments

Many major automotive and technology companies have announced plans to increase their AV fleet size and further develop and launch SAV services in the coming years. In January 2018, Waymo announced plans to add thousands more automated Chrysler Pacifica Minivans to its existing fleet [4]. Similarly, Uber reportedly agreed to buy 24,000 automated XC90s from Volvo to be delivered from 2019 to 2021 [5]. In late-2017, GM announced plans to deploy fleets of SAVs in

Table 1 Private road and planned community SAV pilots serving passengers

Operator(s)	Location	Description
Auro Robotics	Santa Clara University, CA	Auro Robotics operates their low-speed AVs at Santa Clara University in California. The vehicle is a retrofitted Polaris GEM electric four-seater golf cart. It operates a fixed route service on campus for eight hours most days and three hours on sundays. The pilot became fully operational on November 14, 2016, and an Auro field engineer rides along in the driver's seat to take control, if needed. In October 2017, the mobility platform company Ridecell acquired Auro with hopes to offer a pre-packaged solution for SAV services, focusing on low-speed vehicles deployed on private property [31]
Navya/Mcity	University of Michigan, Ann Arbor, MI	The Navya ARMA is an electric low-speed automated shuttle that can transport up to 15 passengers. The vehicle began testing at Mcity, the University of Michigan's 32-acre test facility for AVs in December 2016. In Fall 2017, two of the AVs began shuttling students, faculty, and staff on a two-mile route between the engineering campus and the university's North Campus Research Complex. The SAV service is operated by Mcity [32]
Voyage	The Villages, San Jose, CA	The Villages is a 4000-resident gated retirement community in San Jose, California, containing about 15 miles of private roadways. Since October 2017, Voyage, a Udacity spin-off, has operated three of its Ford Fusion AVs as an on-demand SAV service for residents inside the community [33]. Please note this is different from Voyage's testing efforts at The Villages in Florida

large cities by 2019, and in January 2018, GM unveiled an AV design without a brake pedal or a steering wheel that it hopes to test in 2019 [6]. In addition to the larger players, smaller companies have ambitious plans as well. Navya unveiled its electric Autonom Cab designed specifically for SAV passenger services, with capacity for six passengers and center-facing interior benches [7]. In addition to its current developments, EasyMile and the San Francisco County Transportation Authority are planning a pilot to serve passengers for first- and last-mile trips to public transit on Treasure Island, California by 2020 [8]. These are just a few examples of planned SAV developments, although there exist many more announcements and partnerships with the aim of developing AV technology and SAV services.

Table 2 Public road and city street SAV pilots serving passengers

Operator(s)	Location	Description
Uber	Pittsburgh, PA	In September 2016, Uber began a SAV pilot in Pittsburgh, Pennsylvania using automated Ford Fusions. The pilot was the first SAV service in the U.S. to pick up passengers. The pilot is open to frequent uberX customers who can request a vehicle through the Uber app. At the start of 2017, the company fully transitioned its Pittsburgh fleet to Volvo XC90 SUVs equipped with AV technology. The AVs contain a backup driver plus a technician in the front passenger seat. Uber plans to incrementally remove technicians in 2018 [34]
Cruise/GM	San Francisco, CA	In February 2017, GM's Cruise began testing its automated Chevrolet Bolt EVs on roads in San Francisco, California, allowing select employees to commute to work using the vehicles. In August 2017, Cruise expanded the pilot, allowing additional employees to participate and request more than just work trips via an app called Cruise Anywhere [35]. The AVs contain test drivers in the passenger seat, as required by the California DMV. As of November 2017, GM had about 180 automated Chevrolet Bolt EVs in their fleet, some of which are being tested in Arizona and Michigan [36]
Waymo	Phoenix area, AZ	Alphabet's Waymo launched its Early Rider program in April 2017, inviting select residents of parts of the Phoenix metropolitan area to request rides in their automated Chrysler Pacifica Minivans. The AVs initially contained Waymo test engineers in the driver's seat, but they have since moved to the back seat in November 2017, meaning the AVs operate without a human directly behind the wheel [37]. Waymo received a TNC permit in Arizona in January 2018, and the company plans to launch a commercial SAV service to members of the public in the Phoenix area in 2018 [9]
NuTonomy/ Lyft	Boston Seaport, MA	NuTonomy has tested its automated Renault Zoe EVs in the Seaport and Fort Point areas of Boston since April 2017. In June 2017, Lyft and NuTonomy formed a partnership, and in December 2017, they launched a SAV pilot that will allow select Lyft riders in the Seaport area to be matched with a NuTonomy AV through the Lyft app [38]. NuTonomy has passed multiple phases of AV testing, as required by a city-level mayor's executive order [39]
Optimus Ride	Boston Seaport, MA	Optimus Ride has tested its low-speed electric AVs on streets in the Raymond Flynn Marine Park area since June 2017. In January 2018, the company was approved by city officials to carry passengers in its AVs within the Marine Park area [40]. The company is testing first- and last-mile service routes on public roads and is offering rides to employees of businesses in the area. Optimus Ride is at an earlier stage of testing with the city than is NuTonomy (who is also testing in the Seaport area); thus, their operations are restricted to the Marine Park area [39]

2.4 Key Trends Discussion

Not surprisingly, we are beginning to see some trends emerge in the U.S. SAV developments. First, no company has a commercial SAV service that is providing rides to the general public. The pilots that are serving passengers do not offer their services to the public. Instead, they only transport select passengers or members of a closed group like a university, workplace, or retirement community. Waymo is likely the closest to making their Phoenix-area SAV pilot into a commercial service and has plans for public deployment in [9]. SAV pilots in the U.S. are largely taking place on the coasts, often in states with warm weather year round, like California, Arizona, and Florida. Some of the trends in location are partially due to favorable regulatory environments in certain states; we discuss this in the next section. In the next few years, more AV pilots will likely emerge that test vehicles in more demanding weather conditions. Some companies have already started testing in snowy areas to assess how their vehicles perform there. Waymo began testing its AVs in Winter 2017 in Detroit [10], and EasyMile began a temporary winter pilot with its EZ10s in Minnesota in late-2017 [11].

In addition, all of the pilots have started very recently. Other than Waymo's AV fleet testing efforts that first began in 2012 as the Google Self-Driving Car Project, almost all of the SAV pilots began in the last 18 months. About half started within the last six months. A number of SAV passenger pilots in major U.S. cities launched during late-2016 and early-2017 (Uber in Pittsburgh, Cruise/GM in San Francisco, Waymo in Phoenix, and NuTonomy/Lyft in Boston), and these programs are making incremental improvements to their technology and preparing for public deployment. A number of the private road and planned community SAV pilots launched even more recently (i.e., within the last six months). SAV services that target low-speed and controlled environments are launching in new locations at a fast pace, and many are beginning to serve passengers. Given these developments, we will most likely see more SAV pilots emerge in 2018 and in the near-term future. In the longer term (ten to twenty years), city-level SAV programs will likely gain a much larger market share of U.S. passenger-miles than their low-speed counterparts. As shown in this analysis, large automakers and technology companies are at the beginning stages of developing SAVs for the city- or regional-level transportation market. This will likely become more competitive in the coming years and decades. On the other hand, smaller players will continue to target more niche markets and use cases, which allows for faster SAV deployment due to specially designed vehicles that do not need to function across a wide range of environments.

Despite these advancements, it is still unclear how long it will take until test engineers can be removed from SAVs. At present, all SAV developments in the U.S. have a test engineer on board. Waymo's decision to have their test engineers ride in the back seat in its Phoenix-area program is the most significant SAV development thus far toward removing the need for physical staff presence in a SAV. However, it is not clear at this time when companies will begin removing test staff from their vehicles and there is no common framework for what factors determine when they could safely be removed. Some of the low-speed SAV pilots could likely be the first in the U.S. to remove the test engineer from the vehicle, since their operating environments are often safer than those in which an AV is operating in mixed and possibly high-speed traffic. For example, the EasyMile/Transdev pilot in Babcock Ranch plans to remove the test engineer once enough testing has taken place. They will have an emergency button in the vehicle that would contact a remote safety operator [12]. Many companies testing AVs are developing remote operations capabilities, where a human operator in a control center can take over and safely maneuver or stop an AV in case of malfunctions or emergencies. Regulation will play a key role in defining many factors around AV safety, operations, and design requirements. We explore AV policy at the federal, state, and local levels in the U.S. in the following section.

3 U.S. Automated Vehicle (AV) Policy Overview

While there are very few SAV-specific policies or regulations, at present, there are a number of states with AV legislation or executive orders, along with federal and local level activity. To date, most AV legislation relates to road safety, liability and insurance, vehicle design requirements, and operational area. In this section, we discuss AV legislation and regulatory roles in the U.S. across: (1) federal, (2) state, and (3) local levels of governance.

3.1 Federal AV Policy

While there are no federal AV laws enacted at present, there has been activity in the last few years toward creating a framework and legislation around AVs. In September 2016, the National Highway Traffic Safety Administration (NHTSA), under the Obama administration, released their Federal Automated Vehicles Policy document that is intended to establish a 15-point framework for AV regulation in the U.S. This document was not intended as a concrete rulemaking but rather to provide recommendations on safety, data sharing, privacy, cybersecurity, and ethical considerations, among others [3]. NHTSA released a second iteration of the document titled Automated Driving Systems 2.0 (ADS 2.0) in September 2017, under the Trump administration. This iteration shortened the guidance and decreased the safety self-assessment from 15 to 12 areas. The document clarifies that entities do not need to wait for Federal approval to test or deploy their AVs. Similar to the first iteration, the guidelines remain voluntary [13]. A week prior to the release of ADS 2.0, the U.S. House passed the SELF DRIVE Act, a bill that aims to establish a federal framework for AV regulation. It proposes a dramatic increase in the number of exemptions from existing federal motor vehicle safety standards (FMVSS). A similar bill titled the AV START Act passed a Senate committee in October 2017, but it remains stalled in the Senate due to safety concerns, at present [14]. The bill would allow exemptions for up to 15,000 AVs per company in the first year, 40,000 by the second year of the law, and 80,000 per year thereafter. If passed in its current form, state legislation would be broadly preempted in the areas of: system safety, data recording, cybersecurity, human-machine interface, crashworthiness, capabilities of AVs or systems, post-crash behavior, vehicle programming to meet existing traffic laws, and automation function. The proposed bill also excludes large commercial vehicles. However, it must be approved by the Senate and merged with the House AV bill before becoming law [15]. While there are no enacted laws at the federal level, there are many that have been passed at the state level, which we discuss below.

3.2 State AV Policy

To date, 23 states and DC have enacted or adopted legislation, and Governors in six states have issued executive orders related to AVs [16]. These laws typically regulate liability and insurance, licensing, registration, traffic rules, and infrastructure. A small number of state laws contain aspects that relate to SAVs, which we discuss in this section. Figure 2 compares the differences in AV state regulations on testing and deployment and whether there is a requirement for a human backup driver to be

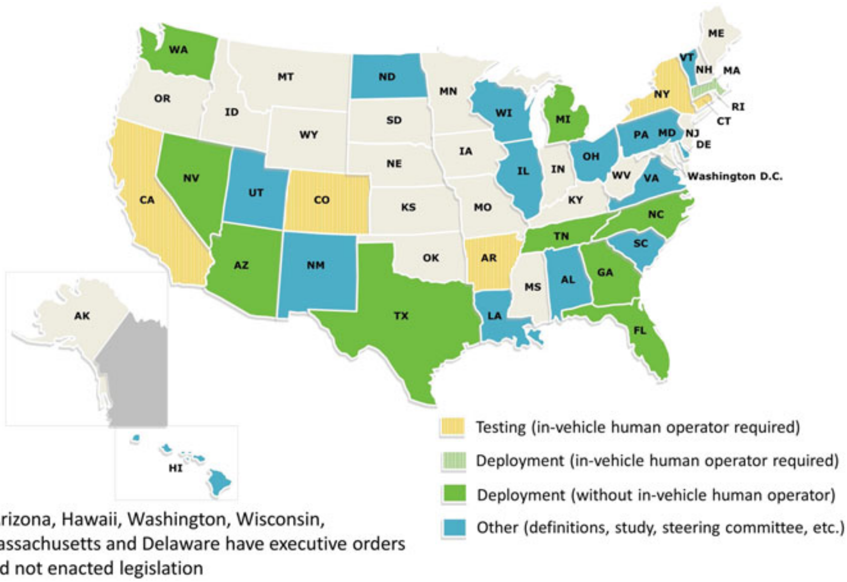

Fig. 2 Map of state AV legislation and executive orders

physically present inside the vehicle. This tracking methodology serves as a barometer for how close each state is to legally allowing commercial SAV services on public roadways. In Fig. 2, testing denotes the allowance of AVs on public roadways and deployment refers to the authorization of passengers who are not necessarily registered AV test drivers. Note that some states use the terminology “operation” to refer to stages beyond the testing phase, which we designate as deployment in Fig. 2.

As of February 2018, 29 states and DC have passed legislation or issued an executive order related to AVs. Fifteen states and DC have passed legislation or issued an executive order that allows for either AV testing or deployment on public roads. The other 14 states have enacted legislation or an executive order that does not relate to AV testing or deployment but to other AV-related measures such as requiring studies or forming steering committees. Five states have approved AV testing only (with an in-vehicle human operator), Massachusetts and DC allow deployment with passengers (with an in-vehicle human operator), and nine states permit full deployment without an operator required inside the vehicle. We classify state AV laws in this manner because SAV deployment without an in-vehicle human operator will be essential for the scaling and financial feasibility of commercial SAV services. So far, Florida, Arizona, Washington, Nevada, Texas, Georgia, Tennessee, North Carolina, and Michigan are the nine states that allow for AV deployment without an in-vehicle human monitor. While states might have favorable AV laws, this does not mean companies will choose to test or deploy there. For example, out of the 11 states that allow for SAV deployment, only four (Florida, Washington, Texas, and Massachusetts) have active SAV pilots in their states. The number of states allowing AV deployment will likely increase in the coming years, and many states are working on deployment regulations. As mentioned previously, only a few states include provisions in their AV legislation that specifically relate to SAVs. Michigan’s Senate Bills 995 and 996, passed in late-2016, initially required that “on-demand automated motor vehicle networks” be controlled by the vehicle manufacturer. However, revised bill language clarifies that a manufacturer need to only supply the vehicles used in a SAV network [17]. Assembly Bill 1444 in California authorizes the Livermore Amador Valley Transit Authority to conduct a SAV demonstration project without a driver, steering wheel, or brake pedal, but the bill only lasts for a six-month demonstration period [16]. Some state bills are beginning to address the taxation of AV and SAV operations. Both Nevada and Tennessee have enacted taxation legislation related to SAVs at this time, as outlined in Table 3.

Massachusetts has proposed a similar law that would levy a 2.5 cent-per-mile tax on AVs [18]. However, no SAV-specific taxes have been applied in practice, since neither of these two states has any active SAV pilot. While around half of the U.S. states have passed laws or issued executive orders regarding AVs, there are much fewer that have developed laws related to the management and operations of SAV fleets. Many more states will likely consider SAV-specific legislation as pilots expand to serve public passengers.

Table 3 State AV taxation legislation

State/Bill	Tax	Description
Nevada (Assembly Bill 69)	3% of total SAV fare	The most comprehensive enacted legislation related to SAVs at this time, AB 69 contains a number of provisions around what it calls "autonomous vehicle network companies." The bill authorizes an excise tax on SAV services at 3% of the total fare charged for each ride. It also contains specific provisions to ensure this tax does not apply to those carpooling with AVs, and it accounts for wheelchair accessibility of SAV services [41]
Tennessee (Senate Bill 1561)	1 cent-per-mile (passenger AVs) 2.6 cent-per-mile (AV trucks)	SB 1561 imposes a one cent-per-mile tax on AV passenger vehicles and a 2.6 cent-per-mile tax on AV trucks with more than two axles [18, 42]. The state plans to divide the revenue from the tax between the state general fund, state highway fund, counties, and localities according to a statutory formula [43]

3.3 Local AV Policy: Case Study of the City of Boston

In the U.S., there has been less local AV policy activity in contrast to the states. As more AVs operate on public roadways, local AV policy will likely regulate areas of AV and SAV operations, rights-of-way access, and local taxation. There have been a number of local laws across the nation, which allow for short-term AV demonstrations, but fewer allow for sustained AV operations [19]. One of the most comprehensive local AV policy programs is overseen by the City of Boston. Boston mayor Martin Walsh signed an executive order in October 2016 that established a multi-phase AV testing program in the city. Boston requires operators to complete a memorandum of understanding with appropriate parties and submit an application with the Massachusetts Department of Transportation before operating. The city regulates the time, place, and manner of testing and is initially restricting testing to a 1000-acre area of the South Boston Waterfront. The city also requires quarterly data reports of the two companies that are currently testing in Boston (nuTonomy and Optimus Ride). These reports include metrics like: number of passenger trips, passenger home zip codes, trip origin and destination, and qualitative user feedback [20, 21]. Other efforts at the local level include the formation of working groups, statements of principles, and the creation of roadmaps [22]. Although there are not many local AV regulations at present, these laws will likely be very important in mitigating the negative impacts of SAV operations by crafting rules that address traffic congestion, urban sprawl, and equity in each city or region.

3.4 Upcoming AV Policy Developments

Many more policy developments in the AV and SAV space are expected over the next few years and decades. In addition to the Senate's AV bill, NHTSA is preparing version 3.0 of its AV policy document and plans to include others beyond NHTSA, which will take part in overseeing the implementation of AV technologies. These regulatory bodies include the: Federal Motor Carrier Safety Administration (FMCSA), Federal Transit Administration (FTA), and Federal Highway Administration (FHWA) [23]. Although many states are hoping to pass new or additional AV regulations, the proposed California AV deployment regulations will arguably be one of the most important state legislations to come out in 2018 due to the number of companies located and testing in California. The regulations, which were recently approved by the Office of Administrative Law, are expected to take effect in April 2018 and will allow AVs without steering wheels, brake pedals, and in-vehicle human operators on public roads in the state [24].

3.5 Key Trends Discussion

At present, most policy activity around AVs is happening at the state level, with 29 states and DC passing legislation regarding public safety, legal frameworks, and requirements for insurance and liability. Key trends at the state level include:

- Nevada was the first state to pass legislation and authorize the operation of AVs in 2011,
- By 2013, three more states (California, Florida, and Michigan) and Washington DC passed bills defining various aspects of AV operations and allowed for testing on public roads,
- Florida was the first state to allow anyone with a driver's license to operate an AV on state roads. Florida was also the first state to allow the operation of AVs without a human present in the vehicle (i.e., House Bill 7027 in April 2016) [25],
- Now, nine states allow AVs without a physical operator on public roads, and more states are likely to move in this direction.

Although uncommon, more states may begin to enact per-mile or per-ride charges on SAV services, similar to Tennessee and Nevada. From 2015 through 2017, 16 states across the nation have passed an increase in their state gas taxes [26], signaling that some legislators are willing to explore creative ways to raise infrastructure funding in the absence of a federal gas tax increase. This stance may foster interest in taxing AVs, and in the coming years may see more states enact taxation mechanisms for this emerging vehicle technology. In addition, more local and regional laws will step in as an increasing number of SAV pilots are deployed. The unique urban forms of different cities will likely require cities and regional planning organizations to develop more precise guidance for testing and deployment of SAV services. SAV services will likely require close coordination with local transportation authorities, as is the case in the two SAV pilots in Boston. Federal legislation will likely impact the authority of states and localities, as suggested by the current Senate AV START bill that would preempt states from setting their own laws around AV design and safety functions. This could cause challenges, if some states do not agree with direction of the federal regulations.

4 Potential SAV Impacts and Future Policy Developments

Impacts of AVs and SAV services on travel behavior, the urban form, and the environment are unclear. Some studies predict that roadway capacity could be increased due to more efficient operations and right-sizing of AVs, while other studies predict increased vehicle miles traveled (VMT) as a result of cheaper and more convenient AV and SAV travel options [27]. The range of predicted impacts often depends on market penetration assumptions of SAVs compared to privately owned AVs. A study of predicted AV energy impacts by Ross and Guhathakurta [28] compiled findings across multiple leading studies and noted that most authors found that full automation is likely to result in more energy consumption because it will allow vehicles to travel faster, which could induce travel demand and spark new user groups. However, dynamic pooling with SAVs may be able to reduce energy consumption depending on the proportion of trips that are shared among riders. The studies analyzed by Ross and Guhathakurta [28] find that under these scenarios, total energy consumption may be reduced by more than half compared to the present day even though more VMT may be generated due to assumptions about vehicle fleet electrification.

Although the impacts of AVs and SAVs remain uncertain, multiple studies predict that emissions would be lower under a SAV scenario (especially with dynamic pooling) than a personally owned AV scenario. Future policy development in this area should take these findings into account and try to encourage not only SAVs (over private AVs) but the pooling of multiple passengers per trip (over single-occupant vehicles). Policies that more adequately charge road users for their externalities, including usage-based pricing and pooling incentives, could encourage more sustainable AV and SAV outcomes. Some of these policies are already being piloted and developed today with non-AVs.

Road usage charging (RUC) is the concept of pricing transportation infrastructure to collect funds or to achieve a desired outcome. There are different approaches to RUC, some of which have been adopted in parts of Europe and Asia. These approaches include: VMT pricing, cordon pricing, express lanes, and other methods [29]. Road pricing is gaining in popularity in the U.S., although most efforts thus far have been pilot programs at the state level. For AVs and SAVs, RUC will be an important component in mitigating some of the potential negative externalities on congestion, the environment, and equity. If AVs and SAVs are appropriately priced based on their usage, higher-occupancy forms of transportation may become more attractive and gain higher ridership than would be the case absent of any road pricing regulations. Shared-ride services, any transportation mode that allows riders to share a ride to a common destination, may become more popular as well. Examples of shared-ride services that exist today include: public transportation, ridesharing (carpooling and vanpooling), pooling (e.g., Lyft Line and UberPOOL), taxisplitting, and microtransit [30]. High-occupancy vehicle (HOV) lanes are a common example of public rights-of-way policies that aims to encourage the use of shared rides, although more specific policies may be developed for AV and SAV services.

For SAVs, while incentives for shared rides could help mitigate some negative externalities, these incentives alone will not be enough. A combination of pooling incentives with various forms of RUC and access to rights-of-way policies, tailored to city and regional travel patterns, will be necessary to curb the potential negative impacts of AVs and SAVs (e.g., equity, congestion, public transit displacement, etc.). While RUC and other forms of pricing and pooling incentives are not new, the amount of data generated by SAVs will make it easier to track and charge travel with measurable metrics like time of day, VMT/GHGs, location, vehicle type, and occupancy [29]. In addition, if SAV services become widespread, it could become easier to impose usage-based taxes on a few centralized entities than it is today on millions of individual road users. While we are at the early stages of AV pricing and only a couple of states in the U.S. have enacted basic usage-based taxes on SAV services, this topic will likely have a large impact on AVs and SAV impacts on the environment, traffic congestion, public transit, and equity in the coming decades.

5 Conclusion

While it is still early in SAV development, pilot projects are expanding rapidly, with 17 active SAV pilots in the U.S., as of February 2018. Most of the pilots began in the last 18 months and about half launched during the past six months. There are 29 states and DC with legislation or executive orders related to AVs. However, enacted legislation in only two states contains tax provisions related to SAV fleets. In addition, not many local government entities have developed SAV regulations. Given that most SAV pilots are small scale and do not involve public passengers at this time, the lack of SAV regulation has not arisen as a major concern. However, SAV policy may become a more pressing priority as AV technology improves and companies increasingly deploy public services. Policymakers must therefore be proactive in developing appropriate rules around AVs and SAV services. Once deployed and SAV service models become more commonplace, it will be hard to enact pricing regulations after the fact. Therefore, policy action is needed to mitigate the potential negative externalities of AVs and SAVs. Collaboration between public and private sector players will be important in encouraging the safe, sustainable, and equitable deployment of SAVs.

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References

1. CB Insights (2017) 44 corporations working on autonomous vehicles. Retrieved 28 Nov 2017 from https://www.cbinsights.com/research/autonomous-driverless-vehicles-corporations-list
2. Kerry CF, Karsten J (2017) Gauging investment in self-driving cars. https://www.brookings.edu/research/gauging-investment-in-self-driving-cars/. Accessed 26 Feb 2018
3. U.S. Department of Transportation (USDOT) (2016) Federal automated vehicles policy. https://www.transportation.gov/sites/dot.gov/files/docs/AV%20policy%20guidance%20PDF.pdf. Accessed 08 Nov 2016
4. Marshall A (2018) Waymo launches its self-driving Armada, 30 Jan. https://www.wired.com/story/waymo-launches-self-driving-minivans-fiat-chrysler/?mbid=social_twitter_onsiteshare. Accessed 26 Feb 2018
5. Behrmann E (2017) Uber expands driverless-car push with deal for 24,000 Volvos, 20 Nov. https://www.bloomberg.com/news/articles/2017-11-20/uber-steps-up-driverless-cars-push-with-deal-for-24-000-volvos. Accessed 26 Feb 2018
6. Bhuiyan J (2018) General motors is asking the U.S. government to let it test cars without steering wheels in 2019, 12 Jan. https://www.recode.net/2018/1/12/16880570/general-motors-self-driving-cars-cruise-steering-wheel-nhtsa-fmvss. Accessed 26 Feb 2018
7. Edelstein S (2017a) Is Navya's Autonom cab the electric, autonomous taxi of the future? 8 Nov. http://www.thedrive.com/sheetmetal/15883/is-navyas-autonom-cab-the-electric-autonomous-taxi-of-the-future. Accessed 26 Feb 2018
8. Su A (2017) Self-driving shuttles could roll out on Treasure Island by 2020, 10 Jan. https://www.bizjournals.com/sanfrancisco/news/2017/01/10/self-driving-shuttles-treasure-island.html. Accessed 26 Feb 2018
9. Barr A (2018) Waymo gets the o.k. for a commercial driverless ride-hailing service, 16 Feb. https://www.bloomberg.com/news/articles/2018-02-16/waymo-gets-o-k-for-commercial-driverless-ride-hailing-service. Accessed 26 Feb 2018
10. Bergen M (2017) Alphabet's Waymo will test self-driving cars in snowy Detroit, 26 Oct. https://www.bloomberg.com/news/articles/2017-10-26/alphabet-s-waymo-will-test-self-driving-cars-in-wintry-detroit. Accessed 26 Feb 2018
11. MnDOT (Minnesota Department of Transportation) (2017) MnDOT chooses EasyMile for autonomous shuttle bus project, 4 Oct. https://www.dot.state.mn.us/newsrels/17/10/4autonomous.html. Accessed 26 Feb 2018
12. NBC2 News (2018) Babcock Ranch testing 1 of 65 driverless shuttles worldwide, 18 Jan. http://www.nbc-2.com/story/37273402/babcock-ranch-testing-1-of-65-driverless-shuttles-worldwide. Accessed 26 Feb 2018
13. U.S. Department of Transportation (USDOT) (2017) Automated driving systems 2.0. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf. Accessed 26 Feb 2018
14. Bonazzo J (2018) Senate hits the brakes on self-driving car legislation over safety concerns, 2 Feb. http://observer.com/2018/02/senate-self-driving-car-legislation-safety-concerns/. Accessed 26 Feb 2018

15. Shepardson D (2017) U.S. Senate panel puts self-driving cars in fast lane, 4 Oct. https://uk.reuters.com/article/us-autos-selfdriving/u-s-senate-panel-puts-self-driving-cars-in-fast-lane-idUKKBN1C923N. Accessed 26 Feb 2018
16. NCSL (National Conference of State Legislatures) (2018a) Autonomous vehicles|self-driving vehicles enacted legislation, 2 Jan. http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx. Accessed 26 Feb 2018
17. Smith BW (2016) Michigan's automated driving bills, 6 Sept. http://cyberlaw.stanford.edu/blog/2016/09/michigans-automated-driving-bills. Accessed 26 Feb 2018
18. Gallagher R (2017) Autonomous vehicle taxes may arrive before the cars do, 13 Sept. https://www.dmv.org/articles/self-driving-car-taxes. Accessed 26 Feb 2018
19. Binkovitz L (2017) Arlington, Texas, experiments with driverless Shuttles, 12 May. http://www.govtech.com/fs/arlington-texas-experiments-with-driverless-shuttles.html. Accessed 26 Feb 2018
20. Fiandaca GN (2017) nuTonomy passenger pilot test plan, Boston transportation department, 20 Oct. https://www.boston.gov/sites/default/files/document-file-10-2017/nutonomypassengerpilot_letter.pdf
21. Fiandaca GN (2018) Optimus Ride passenger pilot test plan, Boston transportation department, 5 Jan. https://www.boston.gov/sites/default/files/document-file-01-2018/1_8_2018_letter_testplan_passengers.pdf
22. Rogers G (2018a) 3 ways that cities can prepare for automated vehicles today, 14 Feb. https://www.enotrans.org/article/3-ways-cities-can-prepare-automated-vehicles-today/. Accessed 26 Feb 2018
23. Rogers G (2018b) USDOT moving forward with AV policy 3.0, including truck and bus automation, 12 Jan. https://www.enotrans.org/article/usdot-moving-forward-av-policy-3-0-including-truck-bus-automation/. Accessed 26 Feb 2018
24. California DMV (Department of Motor Vehicles) (2018) Driverless testing and deployment of autonomous vehicles for public operation. https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/auto. Accessed 26 Feb 2018
25. FDOT (Florida Department of Transportation) (2016) House bill no. 7027, Florida House of Representatives, 4 Apr. https://www.flsenate.gov/Session/Bill/2016/7027/Category
26. NCSL (National Conference of State Legislatures) (2018b) Recent legislative actions likely to change gas taxes, 20 Feb. http://www.ncsl.org/research/transportation/2013-and-2014-legislative-actions-likely-to-change-gas-taxes.aspx. Accessed 26 Feb 2018
27. Stocker A, Shaheen S (2016) Shared automated vehicles: review of business models. Prepared for the roundtable on cooperative mobility systems and automated driving. Accessed https://www.itf-oecd.org/sites/default/files/docs/shared-automated-vehicles-business-models.pdf
28. Ross C, Guhathakurta S (2017) Autonomous vehicles and energy impacts: a scenario analysis. Energy Procedia 143:47–52. https://doi.org/10.1016/j.egypro.2017.12.646
29. Forscher T, Bayen A, Shaheen S (2018) Road usage charging (RUC). In: ITS Berkeley policy briefs. https://doi.org/10.7922/G2KD1W2R
30. Shaheen S, Cohen A (2018) Impacts of shared mobility: pooling. In: ITS Berkeley policy briefs. https://doi.org/10.7922/G2R49NZB
31. Edelstein S (2017b) Ridecell launches low-speed autonomous shuttle system, 9 Oct. http://www.thedrive.com/tech/14940/ridecell-launches-low-speed-autonomous-shuttle-system. Accessed 26 Feb 2018
32. Bruckner M (2017) University of Michigan readies for launch of driverless shuttles, 29 Aug. https://www.clickondetroit.com/all-about-ann-arbor/tech-arbor/university-of-michigan-readies-for-launch-of-driverless-shuttles. Accessed 26 Feb 2018
33. Cameron O (2017) Voyage's first self-driving car deployment, 4 Oct. https://news.voyage.auto/voyages-first-self-driving-car-deployment-29c7688c6a1. Accessed 26 Feb 2018
34. Linder C (2017) Say goodbye to these Uber self-driving cars. But don't worry, there's a fresh fleet coming, 20 Sept. http://www.post-gazette.com/business/tech-news/2017/09/20/uber-atg-pittsburgh-self-driving-autonomous-cars-volvo-travis-kalanick-ford-white-gray/stories/201709200162. Accessed 26 Feb 2018

35. Etherington D (2017) Cruise is running an autonomous ride-hailing service for employees in SF, 08 Aug. https://techcrunch.com/2017/08/08/cruise-is-running-an-autonomous-ride-hailing-service-for-employees-in-sf/. Accessed 26 Feb 2018
36. Vlasic B (2017) GM unveils its driverless cars, aiming to lead the pack, 29 Nov. https://www.nytimes.com/2017/11/29/business/gm-driverless-cars.html. Accessed 26 Feb 2018
37. Hawkins AJ (2017) Waymo is first to put fully self-driving cars on US roads without a safety driver, 17 Nov. https://www.theverge.com/2017/11/7/16615290/waymo-self-driving-safety-driver-chandler-autonomous. Accessed 26 Feb 2018
38. Lynley M (2017) Lyft's self-driving pilot with nuTonomy begins rolling out in Boston, 6 Dec. https://techcrunch.com/2017/12/06/lyfts-self-driving-pilot-with-nutonomy-begins-rolling-out-in-boston/. Accessed 26 Feb 2018
39. New Urban Mechanics (2018) Autonomous vehicles: Boston's approach, City of Boston, 20 Feb. https://www.boston.gov/departments/new-urban-mechanics/autonomous-vehicles-bostons-approach
40. Graham J (2018) Boston OKs autonomous Optimus cars, 18 Jan. http://www.bostonherald.com/business/business_markets/2018/01/boston_oks_autonomous_optimus_cars. Accessed 26 Feb 2018
41. Committee on Transportation (2017) Assembly bill no. 69, Nevada legislature 79th session, 16 June. https://www.leg.state.nv.us/Session/79th2017/Bills/AB/AB69_EN.pdf
42. Pare M (2016) Tennessee: a leader in self-driving vehicle development? 1 Feb. http://www.govtech.com/fs/Tennessee-A-Leader-in-Self-Driving-Vehicle-Development.html. Accessed 26 Feb 2018
43. Lewis P, Rogers G, Turner S (2017) Adopting and adapting: states and automated vehicle policy, Eno center for transportation, June. https://www.enotrans.org/wp-content/uploads/2017/06/StateAV_FINAL-1.pdf?x43122
44. NHTSA (National Highway Traffic Safety Administration) (2017) Automated driving systems 2.0: a vision for safety. U.S. Department of Transportation, Report DOT HS 812 442, Sept. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf