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Autonomous Vehicles in the United States: Understanding Why and How Cities and Regions Are Responding

A Research Report from the University of California Institute of Transportation Studies

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16. Abstract

This report analyzes how cities, transit agencies, and metropolitan planning organizations are responding to autonomous vehicles (AVs), both in terms of current testing and pilot services, as well as long-term implications of broad AV adoption. The report is based on 21 interviews with staff at cities, transportation agencies, MPOs, and select AV companies, as well as extensive document review. We found a broad spectrum of activity on the part of the public sector regarding AVs, as well as a taxonomy of motivations, which ranged from attempting to harness these vehicles to help boost transit ridership, to speeding the adoption of road pricing, increasing density, stimulating technology-sector economic development, generating revenue, and improving pedestrian safety. Agency responses to AV testing vary dramatically – from complex permitting processes and RFPs to intentional delay in developing policy so as not to deter AV activity. Publicly-led AV shuttles provide the largest opportunity for municipalities to shape AV testing, while private passenger AV testing and pilot services often provide inadequate information to cities to appraise their operations. A prospective future in which AVs make up a large share of travel has led some "early adopter" agencies to develop policies such as partnerships between public transit and AV services, changes to zoning codes to reduce parking requirements in exchange for AV drop-off and pick-up zones, and plans to tax AV passenger trips.

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Disclaimer

Autonomous Vehicles in the United States: Understanding Why and How Cities and Regions are Responding

UNIVERSITY OF CALIFORNIA INSTITUTE OF TRANSPORTATION STUDIES

August 2019

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Executive Summary

Autonomous vehicles (AVs) hold the promise of improving road safety, making travel less stressful, lowering shipping costs, and reducing the need for automobile parking. They also raise concerns about worsening congestion, declining transit ridership, competition for curb space, and even increased urban sprawl. Testing of AVs is being carried out in at least 36 states in the U.S. along with a growing number of AV pilot services (Etherington, 2019). Our focus in this report is understanding why and how cities and regions are responding to both AV testing and pilot services, and to the prospect of AVs making up a significant share of travel at some point in the near future. The report documents divergent strategies and identifies unresolved issues in how the public sector is planning for the advent of this potentially highly disruptive technology, including public agency motivations for regulating AVs.

The report is based primarily on interviews with staff at cities, transit agencies, metropolitan planning organizations, and AV companies in selected areas where AV testing has been carried out or where AV policies have been adopted, including Boston, Phoenix, Las Vegas, New York City, and Arlington (TX), along with a number of San Francisco Bay Area cities such as San Francisco, San Jose, Palo Alto, and Mountain View. The interviews were supplemented by a review of planning, regulatory, and policy documents from federal, state, and local governments and organizations. Our site selection and interview sample were developed with the goal of investigating cities and regions that have taken unique paths to AV policy making. At public agencies we sought to speak with transportation planning staff who either designed policies or were implementing them. The report is based not on an exhaustive list of AV policies or testing and pilots in the United States, but rather a qualitative assessment of public-policy approaches that deal with the present reality of AV testing and initial service, as well as the longer-term implications of possible broader AV adoption.

Among our cases we found sharp variance in the pace and degree to which cities are identifying and adopting AV policies. Some municipalities are developing policies in order to encourage AV firms to locate within their limits and increase local employment. Others are holding off from enacting AV policy in spite of AV firms carrying out testing on their roads. These approaches reflect different views about the long-term penetration of AVs, as well as the appropriate role of local government in ushering in this technology. We find there is little consensus in terms of what cities *should* do regarding AVs, and it has been established that the vast majority of municipalities have not carried out planning for AVs. Thus, this report focuses on a minority of public agencies that have proceeded with AV policy, who can be thought of as "early adopters."

Among this selected set of cases we found a broad spectrum of motivations and goals, such as boosting transit ridership, increasing density, stimulating technology-sector economic development, generating revenue, and improving the transportation system. These motivations have translated into a range of policy responses, including a variety of regulations allowing AV testing, partnerships between transit agencies and AV companies to serve in a first-mile/last-mile capacity, public autonomous shuttle services, changes to zoning codes to reduce parking requirements in exchange for drop-off and pick-up zones, and plans for taxation of AV passenger trips. Together, the policy responses of municipalities and regions so far have been exercises under intense uncertainty; AVs are a tiny fraction of roadway activity today, and predictions of their growth vary dramatically.

Municipal and regional responses to AVs are in part constrained by federal and state laws and regulations. With the U.S. Congress still debating a major AV bill (Bigelow, 2019), states have taken the lead in establishing regulatory oversight of AVs across a number of domains including liability, requirements for safety drivers, and how vehicles should engage with police. In many cases, states pre-empt municipalities from further regulating AVs, such as barring them from preventing AV testing on public roads, or prohibiting special taxation of AV operations. But municipalities still exercise land-use authority over local roads, which gives them the potential to exercise jurisdiction over AVs indirectly, through actions such as modifying curb uses and incentivizing developers to design structures more amenable to AV transport. Meanwhile, some transit agencies are pursuing partnerships with AV firms in the hopes of complementing existing transit services, reducing parking demand around stations, and augmenting or replacing traditional paratransit services.

Within this group, the policies being considered range from technological upgrades to roadways (such as the installation of connected traffic lights), to long-range plans regarding parking facilities, and infill development. We found that public agency-staff are considering AVs as a tool to deploy or approve to resolve existing transportation issues, while sometimes also considering how AV technology could more profoundly reshape urban life along with public agency budgets.

We found a clear distinction between publicly-led AV shuttles and privately-led AV ridehailing services. Development and roll-out of public AV shuttles resemble mass-transit planning processes, including heavy public involvement in route design, financing, and performance evaluation. Meanwhile testing and pilots of private AV services, spearheaded by companies such as Waymo, Uber, and Lyft, have led to some public agencies attempting to slow down the pace of testing; other public agencies proactively encouraging testing within their boundaries for the presumed publicity and economic benefits; and still others adopting testing regulations that emphasize safety, geographic boundaries on operation, access to testing data, and disclosure of technological errors.

Local and regional agencies report some difficulties with AV testing and initial pilots within their boundaries. Nearly all public-sector interviewees felt the information shared by AV companies on their operations was inadequate for their planning purposes, even in cases where explicit partnerships had been established. Many interviewees worried that their relationships with AV companies will suffer from some of the same issues that have strained those with app-based ridehailing services, such as Uber and Lyft. This includes concerns about data sharing, worsening traffic and emissions, and competition with public transit. While our interviewees were hopeful about the prospects of significant reductions in vehicle crashes, those hopes were tempered by fears of AVs further increasing auto travel by making it cheaper, more comfortable, and more convenient.

A broader range of policies is also being enacted that relate to AVs on a longer timeframe. We find that planning for the impending AV revolution is strikingly dominated by a continued attention to long-standing planning goals, such as increasing development density, boosting transit ridership, and managing road congestion. Some of these policies, like reducing on- and off-street parking requirements, do not require AVs to be deployed for cities to benefit from them. Others, like AV-transit partnerships, rely on this new technology to operate successfully and be welcomed by the public. An open issue is whether AVs should be singled out in developing transportation policy, such as through proposals for AV taxes, or mandates that all AVs be electric vehicles, or if they should instead be accounted for primarily via broader sustainable transportation strategies, such as road user charges.

U.S. cities and regions are at the beginning of their reckoning with AVs, which so far has run the gamut from cautious permission to active opposition, from public-private partnerships with AV shuttles to requests for information from AV firms. Though these approaches are far from uniform, they consistently show local and regional public agencies attempting to shape AV activity in order to improve existing and future transportation and livability.

Part I: Responses to Autonomous Vehicle Testing and Pilot Services

Introduction

Over the last decade, autonomous vehicles (AVs) have gone from hypothetical devices and prototypes to the emergence of real-world operations ferrying both passengers and goods on public roads. A number of reports have speculated about the societal impacts of AVs; they have predicted outcomes ranging from significant decreases in vehicle crashes and related fatalities, to an increase in automobile travel, a reduction in public transit, walking and cycling, and even increased sprawl given the declining financial and social costs of car travel ("Blueprint for Autonomous Urbanism," 2017; Kohlstedt, 2017; Soteropoulos et al., 2019). Within cities, transit systems may seek to take advantage of autonomous vehicle technology to automate bus lines, or deploy AV shuttles to circulate on fixed routes, such as feeders for passenger rail service. In the near future cities may choose to invest in updating traffic infrastructure to support AVs, with sensors capable of bi-directional communication, or to respond to a reduced demand for parking by transforming on-street parking into drop-off zones, and allowing off-street parking lots to be developed into other land uses (Zhang et al., 2015). App-based ridehailing services are seen by many observers as being likely to convert their manually-driven operations to AV fleets to realize labor cost savings; and there is speculation that the shared-AV fleet model will be far more prevalent than personally-owned AVs (Stocker and Shaheen, 2017; Forsgren et al., 2018; Schaller, 2018).

In conducting this research we relied on two types of data. The first consisted of existing policy and planning documents. We reviewed a wide variety of regulations, legislation, plans, and executive orders regarding AVs, across federal, state, regional, and local governments. We identified these documents based on searches for the explicit mention of AVs, aided by organizations such as the National Coalition of State Legislatures, which track AV bills as a category. The second data source consisted of 20 interviews with individuals involved in AV testing, regulation, and planning in the U.S., along with a number of site visits. We selected cities and regions known to have significant AV testing on public roads or AV-related planning, including Boston, New York City, Phoenix/Chandler, Las Vegas, Arlington (TX), San Francisco, San Jose, Palo Alto, and Mountain View. We interviewed staff working at cities, transit agencies, metropolitan planning organizations (MPOs), and AV companies in those areas (interview subjects are listed in the Appendix). We conducted interviews mainly in person, with a few conducted via telephone, and we carried out concurrent field visits, including rides in AVs when possible. Our interview protocol was submitted to and approved by UC Berkeley's committee for protection of human subjects. Interview audio was recorded and transcribed; interviewees were asked to approve excerpted quotes (although we could not reach each quoted individual prior to publication).

In Part I of the report we describe policy responses to AV testing (in order to develop three-dimensional maps, calibrate sensors, and gauge the readiness of the vehicle to operate) and pilots of initial passenger services. It includes a basic taxonomy of AV pilot types, examples of how cities have played a role in these deployments, and considerations of public opinion. **Table 1**, below, lists our cases for both parts, and summarizes them in terms of vehicle testing, pilots, permits, and relevant state regulations.

Table 1. Summary of interview locations and field visits

City	AV Testing or Pilots	Municipal Permit	Pre-Emption (and relevant law/executive order)
Chandler, AZ	Private vehicle passenger service pilot and partnership with city for employee off-site meetings	No	AV operators do not need to seek local approval before testing if state requirements are satisfied (*Executive Order No. 2015-09,* 2015).
Phoenix, AZ	Private vehicle passenger service pilot and partnership with transit agency for employee first-mile/last-mile	No	" "
Mountain View, CA	Private vehicle testing	No	Permits for AV testing in California are obtained at the state level ("Article 3.7," 2017; *SB No. 1298*, 2012).
Palo Alto, CA	Private vehicle testing	No	" "
San Francisco, CA	Private vehicle testing	No	" "
San Jose, CA	No testing yet.	RFI Process	" "
Boston, MA	Private vehicle testing	Yes	Municipalities in Massachusetts must opt-into allowing AV operations (*Executive Order No. 572*, 2016).

City	AV Testing or Pilots	Municipal Permit	Pre-Emption (and relevant law/executive order)
Las Vegas, NV	Public shuttle and private vehicle passenger service pilot	No	Municipalities in Nevada are pre-empted from imposing taxes, fees, or other requirements on AV operators (*AB No. 69,* 2017).
New York, NY	Private vehicle testing in single industrial park.	No	AV testing in New York is approved by state commissioner of motor vehicles (*SB No. 2005,* 2017).
Arlington, TX	Two different AV shuttle pilots.		Municipalities in Texas are pre-empted from regulating AVs in any way (*SB No. 2205*, 2017).

Testing of Autonomous Vehicles and Initial Pilots

Unlike other recent mobility innovations, such as dockless bikes or scooters, autonomous vehicles cannot be "dropped" into a new city and begin passenger service immediately. Instead, AV operators typically proceed with years of on-road testing so that their vehicles can first create highly detailed, three-dimensional maps of the area, and second so that they can experience driving on those roads in as many different situations as possible: at night, in the rain, during rush-hour traffic, and so on. Given this, the first interactions cities often have with AV companies centers on testing and not service provision. Thus, understanding how AV testing commences and is influenced by government agencies is a good starting place for an analysis of municipal and regional AV policy. For the purpose of this report, AVs are defined as land-based vehicles which navigate and operate with little intervention from humans to carry either passengers or goods, generally consistent with SAE level 4 ("Taxonomy and Definitions," 2018).

After testing has been deemed successful (by operators and regulators), service provision typically begins as a geographically-specific pilot, such as an initial route for an AV shuttle, or a defined area where private AVs can pick up and drop off customers. Rather than catalog all AV pilots – which other studies have done effectively (Perkins et al., 2018; "Initiative on Cities," 2019) – we will emphasize how the current taxonomy of pilots relates to public policies established in response. There are three types of AV pilots currently operating in the U.S.:

A. Publicly led or sponsored, fixed-route autonomous shuttles.

B. Private, flexible-route passenger travel in autonomous sedans, minivans, and SUVs, on a service model similar to that of app-based ridehailing services.

C. Freight deliveries carried out by autonomous sidewalk robots, road-based “microcars,” and traditionally-sized road vehicles.

A. AV Public Shuttles

Public AV shuttles have been tested in a number of contexts, including downtown circulators, as well as for campuses, office parks, and airports. Testing public AV shuttles, and subsequently offering passenger services on a pilot basis, has generally entailed significant involvement from government agencies, often including public funding, route design or route approval, marketing coordination, and performance evaluation. Many of these cases go far beyond permitting AV operations, to full public-private partnerships, often comprised of an AV shuttle manufacturer, a transportation-service operator, a host city or organization, and a funding body such as a metropolitan planning organization or the U.S. Department of Transportation. This approach is hyper-local; shuttle routes are city and neighborhood-specific, and in most cases are crafted to solve a current transportation issue, such as inadequate connections between a transit hub and downtown (Roth, 2018), or circulation within large campuses. The testing of AV shuttles generally can happen on a shorter timeframe than private, spatially-unrestricted AVs (described below) because the former operate along fixed-routes, and often in settings with simpler road conditions.

Las Vegas provides one example of this category. The city established an “Innovation District” within which an eight-passenger AV shuttle was tested and later piloted on a downtown loop with sponsorship by the local chapter of AAA and the Regional Transportation Commission of Southern Nevada, in partnership with transportation firm Keolis. Following some initial demonstrations of the shuttle’s capability at the annual CES conference in Las Vegas, there was a 10-day testing period on a city street closed to traffic. The shuttle subsequently transported passengers on a longer route for twelve months from November 2017 to October 2018, carrying approximately 32,000 riders (“AAA Free,” 2019) (See Figure 1).

Figure 1. AV passenger shuttles being piloted in Las Vegas, NV (left) and Arlington, TX (right).

Photos courtesy City of Las Vegas and City of Arlington.

Staff at the Las Vegas Innovation District approached their AV shuttle pilot in several ways. First, they treated it as a data-gathering experiment to better understand rider experiences on AVs; each shuttle rider was asked to complete a survey before and after each ride. This was part of a collaboration between the city of Las Vegas and researchers at UNLV, who also surveyed non-riders on their perceptions of AVs at local community centers ("How Do You Feel," 2018). Second, the pilot provided a chance for the city to consider the changing role of transit-agency employees in the context of automation. Joanna Wadsworth, Program Manager for the city's Information Technologies Department, said the downtown pilot demonstrated that even if Las Vegas transitions parts of its existing transit operations to AVs, there will still be a role for in-vehicle personnel, who may act more as customer-service associates. She said that while today drivers spend the bulk of their time and attention on operating the transit vehicle, in an AV future "that person could spend more time helping people, especially if it was a vehicle that would help to transport people with disabilities or people who need additional assistance."

The Las Vegas case appears to be similar to other public AV shuttles in that the city government played a large role in its design, execution, and analysis. For instance, during the first week of the pilot, the city closed off the route to traffic in one direction, and as the pilot progressed they connected the shuttle to the traffic signals along the route. This provided real-time traffic light information to the shuttle, which is more accurate than relying on the vehicle's on-board cameras. Wadsworth reported that staff in Las Vegas were now using this initial experience to inform a second, more extensive autonomous shuttle route that will serve a local medical campus (Ackers, 2018), and she stated the plan was to continue to offer future AV shuttles at no cost to riders.

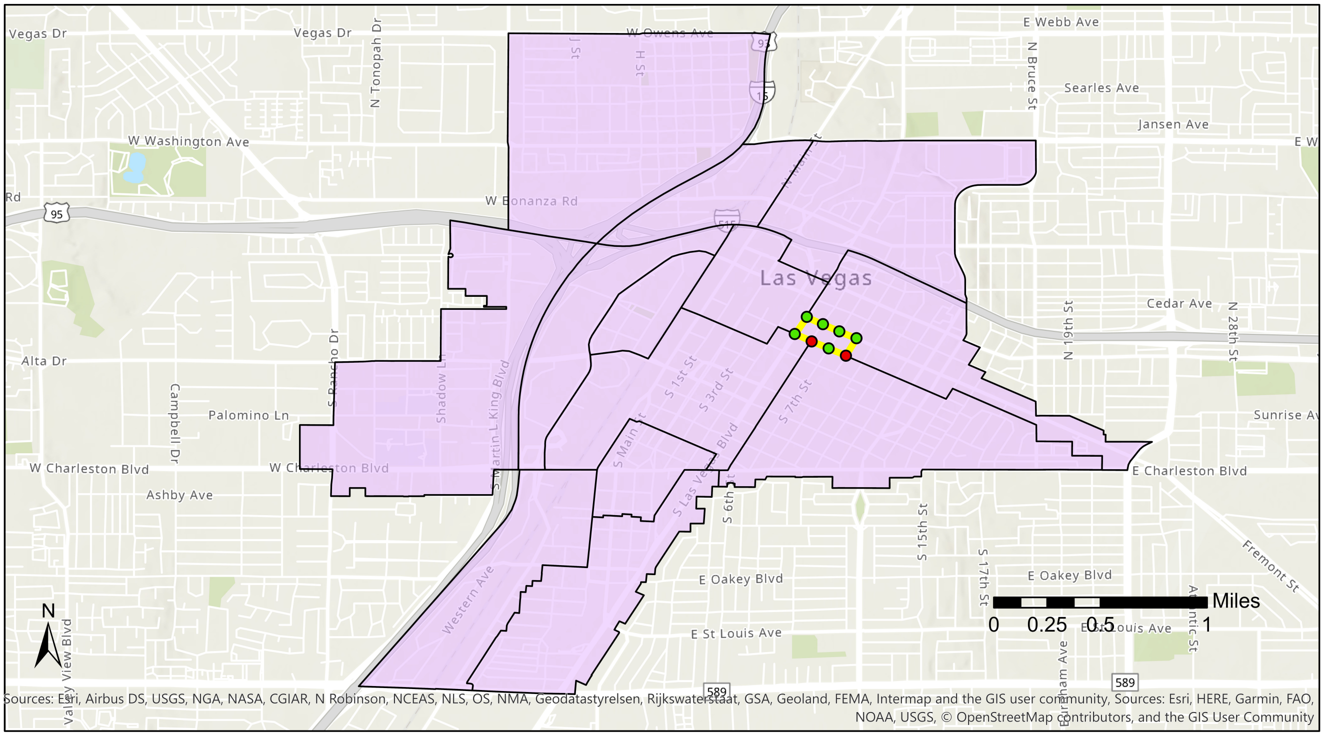

Figure 2. Map showing the route of the AV Shuttle in Las Vegas, within the city's Innovation District (light purple outline). The shuttle route is pictured in yellow, and the circles represent stops, either by traffic signal (green) or stop sign (red).

In Arlington, TX, the city leased two AV shuttles and operated them on a route within their large sports-stadium complex. Following that demonstration project, which operated on a pedestrian pathway, the city moved forward with an on-road AV shuttle route operated by Drive.AI. Although the ridership of that shuttle was modest, city staff were pleased with it because it entailed less day-to-day involvement of public employees than the sports-complex shuttle, for which a city employee served as the on-board operator. In addition, their newer AV shuttle did not experience any crashes as it transported passengers in and out of a large office park and an entertainment district ('Texas Live').

Arlington's multiple pilots illustrate a city mixing the type of AV services offered over a fairly short period of time, both in terms of private-sector partners, but also route types, staff involvement, and funding. A lesson learned for the city was that AV shuttles vary significantly in terms of speed (shuttles like those pictured in **Figure 1** generally operate under 20 MPH) and capacity, which affects what use cases each is best suited. They have also been comfortable with incremental expansion of AVs. Lyndsay Mitchell, Strategic Planning Manager in the city's Office of Strategic Initiatives, noted that while the local University of Texas campus was uninterested in AVs operating near its campus, their position softened after local AV pilots demonstrated safe operations. Changing public opinion on AVs was an explicit goal of the Arlington AVs so far, as Mitchell said:

If AVs are coming and that's going to be our future, it is a benefit to us to make sure our citizenry are prepared for that and are experiencing it on a daily basis, and are comfortable with it before there's an advent of that on a larger scale.

Another interesting aspect of Arlington's experience is that the city council has favored experimenting with such pilots over investing in traditional public transit. Arlington is known as the largest city in the U.S. without any mass transit (Harrington, 2018), and focusing on AVs is an explicit strategy to potentially "leap frog" the traditional progression in transit provision (Mitchell interview). In this vein, Arlington also launched a partnership with the app-based ridehailing company Via (in which the city subsidizes rides within a certain zone), which has carried far more riders than either of the city's two AV pilots, and recently expanded its range (Bliss, 2017; "Via-Arlington," 2019).

Besides these cases, a growing number of cities are in the process of or have already launched public AV shuttles, including Detroit and Grand Rapids, MI, Columbus, OH, Providence, RI, and Dublin, CA (Biggs, 2018; Phelan, 2018; Roth, 2018; Frick, 2019; Kransz, 2019; Hanley, 2019). Most of these are also operating free of charge; public funds provided for such demonstration projects typically cover the costs of operation (for set periods of time) and do not require fares (Little, 2019; Sevits, 2019; "Automated Driving System," 2019).

B. Private Flexible-Route AV Testing and Passenger Service Pilots

Aside from public shuttles, the other primary form of AV activity in the U.S. is privately-run AV firms testing, and in some cases providing pilot passenger service on a flexible-route, individual-rider basis. Thus far, such private AV operations have been led by companies such as Waymo (owned by Alphabet), Cruise (owned by General Motors), Uber, and Lyft. Testing AVs is a necessary and lengthy step before any type of AV passenger service can be provided on a flexible-route, point-to-point basis. Based on current technology, AVs require high-resolution maps of the roads on which they will one day operate, and must go through a repetitive process in which each road is driven numerous times so that all of the vehicle's sensors and computers can measure, record, and appropriately respond to variable conditions. AV companies also use these maps to run computer simulations of AV operation. Both of these processes have been documented by the news media (Hawkins, 2018a) and AV operators themselves, who often release figures on the number of miles driven by their fleets (e.g., "Waymo Safety Report," 2018). On top of that, Lyft has even released a dataset to the public from its AVs featuring "raw sensor camera and LiDAR inputs" ("Moving Autonomous," 2019).

These and other firms are at different points along the path to offering passenger service to the public in a full commercial launch, but almost all appear to be testing AVs with the goal of providing app-based ridehailing services. For example, Waymo has begun its "Waymo One" service in Arizona which provides rides in AVs to members of the public that are part of the company's "early rider program" (Korosec, 2018; Krafcik, 2018). Waymo has been testing its AVs in the Phoenix metropolitan region since 2016 (Randazzo, 2018), and last year applied to the Arizona state government for a license to offer app-based ridehailing services for paying passengers (Griswold, 2018). In Las Vegas, Lyft has partnered with the company Aptiv to pilot a small fleet of AV sedans (Ackers, 2019). Riders who open the Lyft smartphone application in Las Vegas are prompted with a message asking for consent to be picked up by an AV (see **Figure 3**). This May, Waymo and Lyft announced a partnership that will allow some Phoenix-area riders to hail a Waymo AV via the Lyft app (Higgins, 2019; Krafcik, 2019). This collaboration indicates that the way private AV rides are accessed may vary by metropolitan region even when provided by the same company.

Figure 3. AV consent screen in Las Vegas from the Lyft smartphone application.

Rather than a municipal (or MPO) driven process, this category of AV testing and pilots has been led by AV operators themselves, beginning with the selection of testing and pilot locations. Our interviews with staff at AV companies identified several common factors they consider when deciding where to commence testing. This includes physical features such as density, topography, and climate, as well as existing state and local regulations regarding AVs. For example, Amanda El-Dakhakhni, Senior Manager of Government Affairs at Cruise said a key component they look for when picking launch markets is whether or not there is an explicit path in regulations not simply to permit AV testing, but also deployment of a commercial service, implying "more certainty that regulators are thinking proactively about the variety of issues that would impact our business." Relatedly, many states so far have only established regulations for AV testing, and not to commercial AV ridehailing services. Adrian Fine, Director of Marketing and Communications at Drive.Ai, also pointed out the value of a defined process for AV-service roll-out. He reported that the state of Texas was an appealing location for

Drive.Ai because all that was required to move from rides with a safety-driver (or chaperone) to a fully-driverless passenger pilot was a notification to the city in which testing was being conducted. Furthermore, AV companies are not necessarily seeking out the easiest physical environments for testing. Cruise's decision to test in San Francisco was in part *because* of its complexity. El-Dakhakhni said,

> *We're testing in dense urban areas because our belief is if we can get it right here, we can get it right in other places. Technologically, it's much more challenging to get the safety aspect of this right in a dense, often chaotic environment like San Francisco.*

Compared to public AV shuttles, a consistent finding from interviews with public-sector staff is that there is inadequate coordination taking place between cities and AV companies regarding testing and pilot ridehailing services. While understanding that AV companies are operating in a highly-competitive market, staff hoped for greater clarity going forward as to such things as the number of vehicles in a given company's local AV fleet, as well as the geographic extent of testing and pilots. In many ways these mimic the characteristics of Uber and Lyft operations that cities would like to know (discussed further in Part II).

Finally, it is important to note that the lines drawn between "public" and "private" AV operations can blur. For example, while the "Waymo One" pilot is for members of the public in the "early rider program" (and not dictated by Chandler), the company is also partnering with that city to transport a small number of public employees to and from off-site meetings to determine if there are gains in productivity ("Chandler," 2019; Schmidt, 2019). While this arrangement is significantly different from managing a public AV shuttle, the pilot is similar in that a municipality and AV provider are collaborating to solve a given transportation issue.

C. AV Goods Movement

Aside from fixed-route shuttles, and private passenger services, some cities' first exposure to AVs has come in the form of goods delivery. These vehicles vary from sidewalk robots (including by Kiwi, Starship Robotics, Amazon, and FedEx), to sedan and van-size AVs, and an in-between category of road-based "micro-cars," such as those operated by the company Nuro (Diaz, 2019; Nichols, 2019). AVs for goods movement did come up in a number of interviews, although this was not a primary focus of our project. Generally, government involvement has been limited, in part because passengers are not being transported which means companies can avoid some of the associated regulatory processes. Sidewalk robots typically operate at fairly low speeds, although narrow sidewalks in many U.S. cities still raise the chances of collisions between robots and pedestrians.

To date, no significant injuries to humans from delivery robots have been reported in the U.S., which may be part of the reason why they are generally operating with less public scrutiny than passenger vehicles. In addition, there are no reports of AV goods delivery pilots being led by cities (or public agencies) in the same manner as AV passenger shuttles.

Figure 4. Sidewalk delivery robots on a public plaza in Berkeley, CA.

San Francisco has had an interesting approach to sidewalk robots during their short history of existence. Following brief testing on public sidewalks in 2017, the city passed a ban on such devices out of concern for pedestrians (Simon, 2017). However, just this month, the city awarded Postmates (an app-based goods delivery service) a municipal permit for sidewalk robots (Clark, 2019). Compared to passenger AV testing (which is regulated at the state level), San Francisco's permit application indicates tight control over sidewalk robots, including limiting them to certain streets zoned for "Production, Design, and Repair" uses, and prohibiting tests on any streets that have been designated as high-injury corridors as part of the local Vision Zero initiative ("Application for Revocable," 2019).

Approaches to Regulating Commercial AV Pilots

A. Permit or Prohibit

Whereas some cities have embarked on public AV shuttles (in collaboration with a variety of partners), many others are on the receiving end of interest by private AV companies for testing and passenger pilots. As noted above, testing refers to AVs driving on public roads without any passengers (although with staff, engineers, safety drivers) for the purpose of developing three-dimensional maps of streets as well as trialing autonomous driving. In contrast, pilots refer to initial passenger AV services, such as those being provided by Waymo in the Phoenix metropolitan area and by Lyft/Aptiv in Las Vegas.

In this vein, the most immediate policy decision cities often can make regarding AV testing and pilot services – if not pre-empted by their state – is to permit or prohibit their operation.

Massachusetts and New York make for an illustrative contrast on the topic of AV approval and pre-emption. Massachusetts has established a system that gives each municipality the ability to opt-into AV testing; companies may not test AVs without local approval. Within this framework, Boston developed a permitting process for AV testing (which has since been taken up by multiple operators). Conversely, the state of New York retains approval rights for AV testing, but New York City successfully opposed the launch of AV testing there despite technically being pre-empted from doing so.

In Massachusetts, Governor Charlie Baker's 2016 executive order on AVs included the stipulation that testing only occur in "municipalities that desire to permit such testing" (*Executive Order No. 572*, 2016). As far as we are aware, this provision is unique among state AV regulations. In effect, the order gives each Massachusetts municipality a veto over AV testing on its roads, and the ability to dictate when and where AV testing or AV pilot service can occur. The city of Boston made use of this framework to develop it AV regulations (discussed further in section B, below).

In contrast, New York State's AV laws (similar to other states currently) do not provide cities with veto power over testing or pilots. Such AV activity is approved at the state level by the commissioner of motor vehicles (*SB No. 2005*, 2017). Working under this framework, Governor Andrew Cuomo of New York announced in 2017 that Cruise would begin piloting AVs in Manhattan by "early 2018" ("Governor Cuomo Announces," 2017). However, New York City's Mayor, Bill De Blasio, quickly countered by stating the city would seek to prevent or delay such an action. The mayor's spokesperson said, "The Mayor has concerns about safety and testing an unproven technology on the busy streets of lower Manhattan. The previous GM pilot was announced by the State without first consulting the City or NYPD, exacerbating those concerns" (Felton, 2018). As of this writing, no AV testing by Cruise has occurred in New York City. This example shows that even if cities are pre-empted by states from regulating AV activity, they may find other ways to halt or slow testing by strongly conveying such opposition to those in state government. Simply because there is not an explicit mechanism for cities to resist AV activity does not mean they lack other channels of influence.

The decision by the Baker Administration in Massachusetts to give cities and towns the ability to prohibit AVs was based on the state's history of local control, and an interest in testing new technology collaboratively (Sullivan Interview). As a result, an AV company interested in operating state-wide in Massachusetts potentially needs to obtain approval from each of the 351 cities and towns. Because of this, one outcome of the Massachusetts model may be diminished operator interest in AV testing. Two AV firms, nuTonomy and Optimus Ride, have a testing presence in Massachusetts. Several interviewees in Massachusetts said they believed the "local control" component of the executive order had had a negative effect. However, one innovative response to this situation has been 15 cities forming a coalition to jointly allow AV testing (Enwemeka, 2018). The majority of these are in the Boston region (many neighbor each other) but the coalition also includes Worcester, a larger city in the center of the state (see Figure 5).

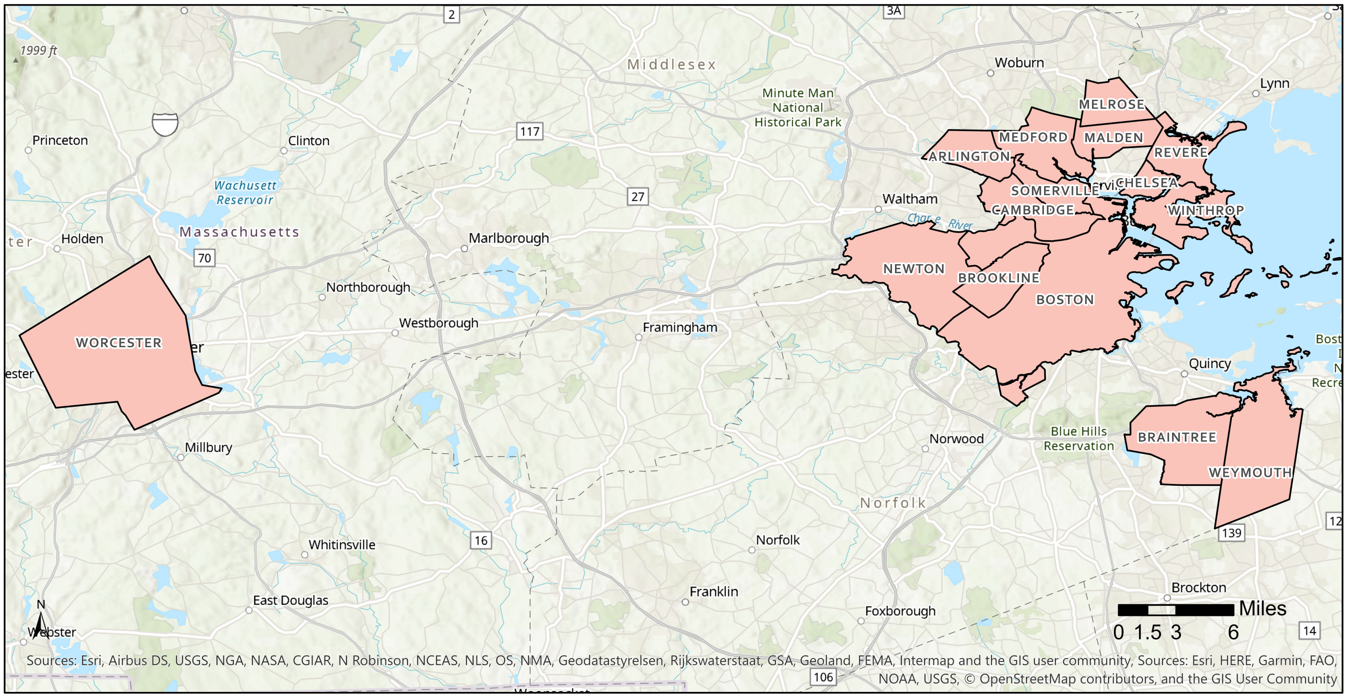

Figure 5. Map of the 15 Cities in the Massachusetts AV Coalition.

Even within this coalition, the current rules mandate that each town must submit which streets within its borders are open for testing (and which are not). This requirement has slowed the process somewhat, while some cities have chosen to expedite it by simply submitting all public roads as open to AVs. As one example, the City of Cambridge recently submitted its approved AV map, after considering road complexity and speeds, and shying away from allowing AVs into its busiest commercial area known as Central Square (Cambridge Interview). Daniel Sullivan, Policy Assistant at MassDOT, said of the coalition approach: "We have tried to streamline the process, but at the end of the day, it still requires a municipality to give individual approval for each company. Time will tell whether that's too burdensome or not."

The Metropolitan Area Planning Council (MAPC) helped devise the coalition as a response to the state's policy, in part as a way to provide interested AV companies with certainty in testing without needing to secure permission on a town-by-town basis. That means the challenge of ensuring towns have identified streets that are allowed for testing is transferred from the AV companies to MAPC. Overall, the coalition represents an attempt at balancing local control the state sought, with the scale of a metropolitan area. The combined population of the coalition cities (approximately 1.6 million) is 23% of all Massachusetts' residents ("Massachusetts Population Estimates," 2019).

B. Initial Testing Zones/Geofencing

Rather than merely permitting or prohibiting AVs within their limits, cities can also make more spatially-nuanced decisions by setting or influencing AV service areas (or 'geofences'). Boston provides such an example, as they carried out an incremental approach to testing geofences for AVs. To start, AVs were only allowed to be tested in a single industrial park. Following safe driving in that setting (documented in quarterly reports), the geofence was expanded to the

Seaport District, a relatively new neighborhood near South Boston (see Figure 6). Finally, after significant documentation by nuTonomy of safe operations within the expanded geofence, Boston approved AV testing citywide in June, 2018 for that firm ("City of Boston's", 2018).

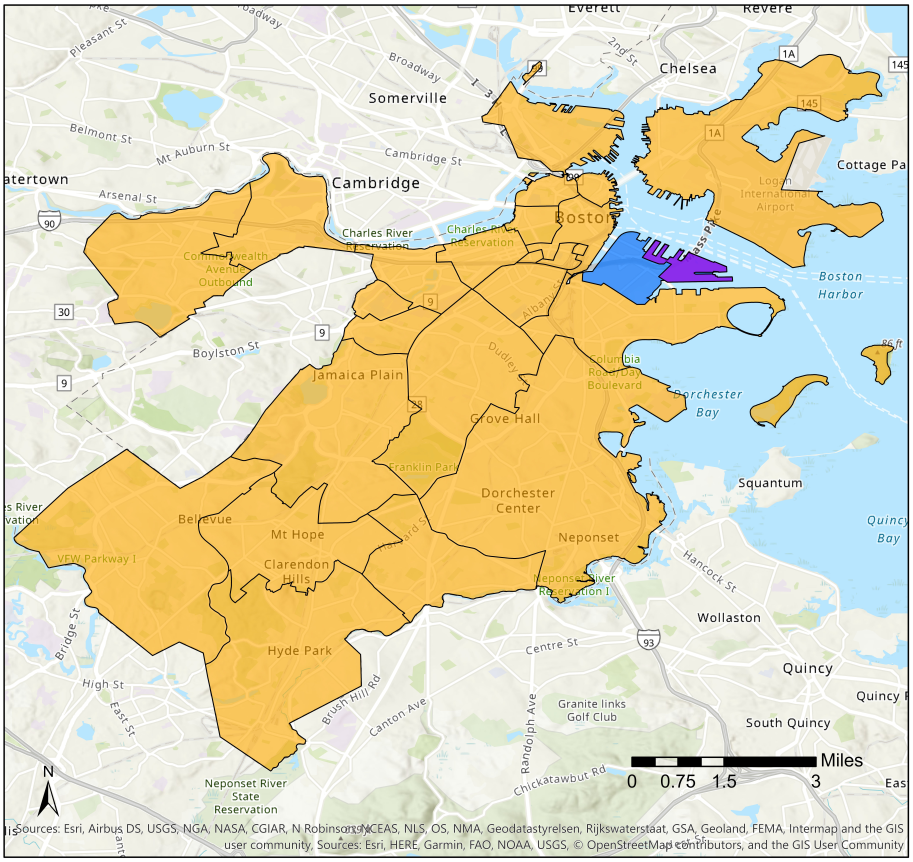

Figure 6. Within Boston, an industrial park (purple) was used as an initial geofence for AV testing. After AV companies established safe operations within that zone, Boston allowed expansion to the broader Seaport/South Waterfront Neighborhood (blue), followed by the entire city (orange).

Creating a sequence of geofences for AVs to "graduate" by demonstrating their competence represents a different – and perhaps tighter – working relationship between cities and AV companies than typical testing in the US. This process is enforceable under the Massachusetts executive order, which enables cities to dictate if and where AV testing can occur. Most cities where significant private AV testing and pilots are ongoing, such as Chandler (AZ) and San Francisco, do not designate which areas may be used for testing, nor do they monitor AV progress to nearly the same extent, or require so much documentation of each operator's activities (such as quarterly reports). This is partly because do not have the ability under respective state regulations to regulate AVs such as geographically constraining testing.

Kristopher Carter, the Co-Chair of the Mayor's Office of New Urban Mechanics, mentioned that pilots have already resulted in many lessons learned for Boston. For example, the initial industrial park – like many roads in the region – has had many of its road markings worn away by cold and snowy winters. This caused problems for piloting AVs, and raised the salience of the road markings:

> *That's been the case for some of the companies that are doing work in the Marine Industrial Park; the markings there have faded in the last three or four years, and they have noted that the vehicle struggles at times with that challenge to localize in the center of the travel lane. But it's also a problem for pedestrians and cyclists, they like clear markings, too. A lot of those learnings that we've taken on the infrastructure side, we've actually tried to match up with 'what are we trying to deliver on for vulnerable road users?' Where does the synergy of road design overlap with designing a city for people?*

The Massachusetts approach creates a gradual testing progression that is potentially easier for residents to grasp and feel comfortable with, which may engender more confidence in this technology than immediately having AVs on all city streets. Of course, some residents may object if they find themselves in the initial test neighborhood. But a sequential geofence policy does place a significant burden on cities in terms of establishing objective standards for AV companies to meet in order to obtain approval to each subsequent stage. Given that, this type of policy framework entails significant technical expertise from the municipal side, or the need for specialized consultants, and consistent communication and reporting from AV companies. For these reasons, this approach may not be emulated broadly.

From the perspective of nuTonomy, an AV company now cleared for operation throughout Boston (Acitelli, 2018), their testing process has benefited from an open line of communication between their staff and the city, as a channel for negotiations over some requirements as their testing has progressed. Matthew Wansley, formerly General Counsel at nuTonomy, described a conversation with the city that led them to allow nighttime AV testing to commence, following discussion about why such a change was important to their operations. Driving at night presents a significantly different environment for AVs, and for this reason cities have at times been slower to allow such testing. Because Boston has established relationships with each AV operator due to their testing stages, dealing with this request was not difficult (Wansley and Spieser interview).

AVs and Public Opinion

Along with dealing with pre-emption, setting geofences, and launching public shuttles, cities must also consider their residents feelings regarding AVs and safety. Indeed, most organized opposition to AVs thus far has been tied to their un-readiness for public roads, a sentiment that has been boosted by reports of AV crashes (Chang and Dormehl, 2018). Last year, a coalition of 19 pedestrian and traffic safety groups (including the Vision Zero Network) advocated for the delay of the Federal AV START Act – still tied up in Congress – following the fatal crash in

Tempe, Arizona involving an AV operated by Uber (Wakabayashi, 2018). Their letter to lawmakers includes the following:

> *By issuing only "voluntary guidelines," which are grossly inadequate and lack any sort of enforcement mechanism, the U.S. DOT has shirked its safety mission and regulatory duty. The stage is now set for what will essentially be beta-testing on public roads with families as unwitting crash test dummies.* (Letter to Senators, 2018)

According to public opinion polls, US residents harbor some concerns about AVs. In 2017, Pew Research Center found that a majority of U.S. respondents were "worried" about the development of AVs (Smith & Anderson, 2017). However, there is also some evidence that these concerns may abate as more Americans are exposed to AVs. In this regard, Pittsburgh represents an interesting example. The city was one of the first in the U.S. to have AV testing (led by Uber), which provided the opportunity to survey residents who have had in-person experiences with AVs (such as seeing them on the roads, or less frequently, riding in them). An initial survey in 2017, conducted by a cycling advocacy group, as well as a follow-up this year both found that respondents on average feel more comfortable sharing the road with AVs than human drivers ("AV Survey Results," 2019).

Moreover, our interviews uncovered little evidence of citizen opposition to the AV testing taking place or related policies to accelerate their deployment. Specifically, no interviewees cited protests or organized objection to AVs. This may be due to the fact that most AV testing and pilot services have been limited in size and geographic reach, such as shuttles circulating on short routes, or only a handful of AV cars operating in private fleets. Relatedly, cities in Massachusetts have taken steps to include their residents in the planning process for AVs, including holding public forums (*Cambridge Autonomous,* 2019), and transparently documenting AV-testing phases for the public to review ("Autonomous Vehicles: Boston's Approach," 2019). Additionally, San Jose, CA (a case described further in Part II) established a 'pop-up' exhibit in collaboration with a design firm for residents to provide feedback on how they believed AVs could fit into their lives and benefit the city (Rasmussen, 2019).

Feedback from the public can also go in the opposite direction – that a city or agency may not moving *fast enough* to embrace AVs. One interviewee reported that some residents have pushed back on existing transportation plans because of the perceived future supremacy of AVs. As they put it:

> *Since the autonomous cars have started appearing, we have received questions such as, 'Why are we planning for bike lanes if autonomous cars are just around the corner?' And, 'We probably don't need to plan more bus service, because no one's going to ride the bus when you have an autonomous vehicle fleet on the streets.'*

Conclusion for Part I

AV testing and the initial movement of passengers and goods in AVs have been taking place in the U.S. on public roads for several years. These have generally broken into three distinct categories: publicly-led AV shuttles, privately-led AV ridehailing services, and goods movement in a variety of vehicle sizes, including sidewalk robots. The first category has included the most direct involvement by the public sector, including project scoping and development, and acting as the conduit between vehicle manufacturers, funding sources, riders, and evaluators. While public AV shuttles have generally been successful in terms of rider response and safety (no fatalities or serious injuries have been reported), they have also been fairly limited in geographic reach. In addition, there has often been gaps in service between initial shuttle pilots and longer-term service provision. Public AV shuttle pilots do not always include a longer-term vision, and funding from MPOs and the U.S. DOT is often only for demonstration purposes lasting around a year, and not for continued operation.

Private AV testing and pilots put municipalities in a significantly different and more reactive posture than public AV shuttles. The Boston and New York cases highlight the contrasting steps cities can take to either standardize and smooth the way for AV deployment, or prevent it from taking place (even when technically pre-empted from doing so). Beyond this initial decision-point, Boston also stands out for establishing an AV testing progression, which takes more effort and expertise, but also provides public agencies with more control over private AV operations geographically and temporally.

Part II: Broader AV Policies – Motivations, Processes, and Early Outcomes

Introduction

Beyond the regulation of AV testing and initial pilot services (detailed in Part I), U.S. cities and regions are also enacting laws and setting regulations regarding the potential broader effects of AVs. Part II covers the primary motivations cities have in developing AV policy, followed by changes made to traffic signaling and curbs, integration with public transit, land-use and zoning modifications, and revenue extraction. The policies analyzed here largely relate to public AV shuttles and private AV ridehailing services, although curb management also factors into AV goods delivery. Based on 20 interviews (detailed in the Appendix) and document review, we identified several distinct motivations for regulating AVs, which ranged from attempting to harness these vehicles to boost transit ridership, to luring technology companies to the area, and decreasing the amount of land dedicated to parking. These goals have translated into partnerships between transit agencies and AV companies to serve in a first-mile/last-mile capacity, investment in updated traffic signaling, and consideration of AV adoption rates in long-range transportation plans. Analysis of these "early adopter" cities and regions offers insight into how AVs may relate to mobility and land-use goals, albeit under significant uncertainty given widely varying possible rates of AV deployment.

According to some advocates and published reports, AVs hold the promise of improving road safety, making travel more convenient, lowering shipping costs, and reducing the need for automobile parking ("Taming the Autonomous Vehicle," 2017). But there are also concerns that if AVs start to make up a dominant share of travel, longer term effects such as greater road congestion, declining transit ridership, competition for curb space, and even increased urban sprawl could occur (Fagnant & Kockelman, 2013; Weinberg, 2017). Our focus in this section is understanding how and why local and regional agencies are prospectively responding to the possibility of AVs making up a significant share of travel in US cities.

A. Motivations for Policy Adoption

Perhaps not surprisingly, for many cities the motivation to adopt policy regarding AVs has been concern about the impacts they will have on the transport system, including questions of safety and traffic. An initial impetus for such policy development has typically been the testing of AVs on local, regional, or state roads. AVs are highly conspicuous and tend to generate headlines, and their arrival can add urgency to planners and city councils to develop appropriate responses. However, because AVs are permitted at the state level in many cases, cities often have little ability to shape the pilots on their streets before they begin. For example, in California AV operators must apply to the state DMV for a permit, to test on public roads with a safety driver, without a safety driver, and to deploy commercially (there are three distinct permit programs). AV operators that apply for a testing permit must alert the municipalities in which they plan to test, but they are not required to obtain permission from the municipality ("Article 3.7," 2017; *SB No. 1298*, 2012). As Tilly Chang, Executive Director of the San Francisco County Transportation Authority put it:

> *The DMV requires this permit system for testing and deployment. And one of the things that's required is a local law-enforcement interaction plan to inform first responders how to interact with the vehicles when a driver is not present. And we lobbied hard to have a say in that, but the way the [regulations] are written the requirements of what must be included in the plan are vague and there is no standard format, allowing companies to write it on their own and submit it, potentially excluding critical pieces of information.*

This lack of input on AV testing by California cities is significant in comparison to the extent to which cities shape the actions of other new entrants to the mobility sector, including bike- and scooter-sharing systems, which are heavily regulated at the local level. The arrangement for AVs in California is in some ways analogous to how app-based ridehailing services like Uber and Lyft are regulated at the state level by the Public Utilities Commission. State oversight of such companies, leading to relatively little influence at the local level has frustrated some California municipalities particularly in terms of their inability to access data on the operations of the app-based ridehailing services (Rodriguez, 2017).

A second motivation for cities to adopt AV policies has been to encourage economic development. Chandler, AZ welcomed testing and passenger pilots with the explicit intention of attracting large technology companies to locate offices within the city. James Smith, previously the city's Economic Development Innovation Manager, noted that Chandler was already home to a number of large companies (including automakers and software firms), and that encouraging AV pilots would likely lead to a greater permanent footprint from those businesses:

> *When you look at the companies that are involved in autonomous vehicles, look at the logos when they're put up on a list. I mean, I don't think any city wants to be left behind.*

Beyond simply attracting AV companies, an open-door policy is also meant to signal a general forward-thinking approach in order to earn the banner of being a "smart city." Las Vegas's establishment of its innovation district to serve as "a proving ground for emerging technologies," including AVs, is one example. Indeed, one Las Vegas official said he sees cities vying for AV activity as a "competition" (Miller, 2016; "Innovation District," 2018). Cities and regions are not only pursuing AV presences by removing barriers to on-road testing, but also by erecting closed courses where AVs can face a number of simulated road scenarios. Outside of Columbus, a new AV testing campus was established as "a key component of Central Ohio's efforts to attract new manufacturing companies and a high-tech economy" (Tobias, 2019).

A third motivation for cities to incorporate AVs into their transportation planning is to align future deployments with existing municipal goals. San Jose, CA is an example of a city developing AV policy prior to deployment, by using a request for information (RFI) process ("City of San Jose," 2017). California's third largest city took this path in order to better understand how AV companies might operate in San Jose, creating the chance to appraise proposals based on established goals and existing transportation infrastructure. Jill North, Innovation Program Manager in the city's Department of Transportation, sees her role as straddling the divide between where the current AV technology stands today, and how that relates to the city's present and future needs. More than anything, she believes the RFI approach offers cities a way to organize the inputs from AV companies, and evaluate them across discrete criteria:

> *We need to organize this, we need to leverage our demonstration framework, which is what allows us to engage with the private sector with no cash exchange, to do a pilot, and create a document that organizes consistent and standard information back to us so that we can look at things comparatively, rather than looking at sales pitches. […]*
>
> *In alliance with our demonstration framework, we want to show how this technology can benefit larger city goals.*

For San Jose, 'larger city goals' also include leveraging AVs as data-collectors, which can provide feedback to the city on traffic flow and patterns:

> *But what is a smart city really about? It's about connecting residents, devices, data, doing all this so we can ultimately do things more efficiently. […]*
>
> *In our pilot, one of the things we are interested in doing is leveraging the autonomous vehicle – because it is traveling in a fixed route – to send a flag to our traffic management center when traffic time hits a certain threshold for our teams to go and clear the queue. So that's an example of the connectivity, both with our own signalized*

> *intersection network and then connecting the autonomous vehicle back into it.* (Jill North Interview)

San Jose's RFI, then, is a deliberate mechanism to contextualize potential AV operations to its specific travel patterns, land-use, and safety needs, by proactively communicating those to private companies.

Across the different motivations that cities may have, it was common in our interviews to hear that a basic starting point for AV policy is the existing situation with app-based ridehailing. Planning staff often see AV policy development not as a blank slate, but as an extension of the urban experience with Uber and Lyft, which several interviewees called "AVs 1.0." This is built on the assumption that AVs will primarily not be personally owned, but operate as part of private fleets which customers will hail from smartphones in an on-demand fashion. Uber and Lyft's large investment in AV technology supports this prediction (Hawkins, 2018b; Shields, 2019), as do reports to date that predict fleet AV services will offer significantly lower prices per ride than today's manually-driven ridehailing (Bösch et al., 2018). Thus planners are considering which ride-hailing trends AVs will hasten, including increases in road congestion (Schaller, 2017), decreases in transit use (Graehler Jr. et al., 2019), higher emissions, racial discrimination (Ge et al., 2016), data sharing (Vaccaro, 2018), licensing procedures (Batheja, 2015), and possibilities for revenues. On the latter point, some state AV regulations explicitly prevent cities from taxing AV trips, including Nevada (*AB No. 69*, 2017). While AV issues do not entirely fit neatly into a app-based ridehailing framework (especially if personal AV ownership is popular), this approach at least provides a starting point for regulation (Sage, 2018).

Along with cities and regions crafting AV policy, we came across others refraining from doing so, even amidst testing on their roads. Interviews with planners in several municipalities with current AV testing reveal a willingness to wait, often at the direction of city councils. This is not simply the case in terms of forming AV partnerships (such as for public shuttles), but also land-use decisions and longer-term planning. For example, one planner noted that the city in which they work was embarking on an expansion in parking facilities, in the face of many studies which predict a decrease in parking demand based on AVs (Nourinejad et al., 2018):

> *In an autonomous-vehicle future, you may need less space for parking garages or have repurposed parking garages, but the city is actually charging full-speed ahead with building public-parking garages. And as far as I know, there is no serious discussion on whether or not this is an appropriate use of funds, what is the autonomous variable, or do we need to be 'future-proofing' these buildings to be flexible for other uses.*

This finding is consistent with Guerra (2016), who documented that a majority of MPOs were not incorporating AVs into their long-range transportation plans, as well as recent work from Freemark and colleagues (2019) who surveyed transportation and planning officials regarding their plans for AVs, which indicated little action and few specifics. As to reasons for holding off from AV policy development, it may be the case that municipalities lack the capacity to craft new rules, or are waiting for their peers to do so in order to appraise the outcomes (Freemark did find that larger cities were better prepared for AVs). Furthermore, some may feel the technology is still too experimental and/or in flux to merit immediate responses. Finally, a challenge of planning for new technology is always that the effort entailed may not align with the time horizons of local politicians, who are logically more sensitive to their constituents needs today. It likely is difficult to shift strategies on parking – highly contentious in most cities – based on speculated changes in driving behavior when merchants and residents are worried about their businesses and daily lives in the present. Undoubtedly, planning for AVs and implementing such plans are inherently exercises in prediction, and tests of residents' trust in those predictions.

B. Curb Management

Cities maintain significant authority to shape how AVs operate by modifying rights of way and curbs. Indeed, the curb has become a highly important (and contested) feature of city planning with the rise of app-based ridehailing services, as well as shared bikes and scooters. AV passengers will presumably not remain in vehicles until they are completely parked, but instead will expect to be dropped off and picked up at each place of interest (restaurant, concert venue, residence, etc.). That use pattern requires readily-accessible curb spaces at which AVs will hypothetically turn over rapidly, and stands in contrast to current curb allotment that is dominated by parking. Joanna Wadsworth of Las Vegas summed up this issue in regards to the city's famous Strip:

> *We are seeing that the curb space is valuable. There are competing interests. Once the driverless vehicles come, they will depend on availability of space to pick up and drop off passengers. If there is an unauthorized vehicle in their space or other vehicles lingering too long, that would impact their operations.*

In the Phoenix area, information on transit-station loading zones has been provided to Waymo to aid passenger pick ups and drop offs (Antoniak Interview). As part of a partnership between Valley Metro and Waymo (described further in Section D), Waymo AVs provide first and last-mile service to some transit-agency employees. Even though Valley Metro does not own every loading zone at each station where passengers are being dropped off and picked up, staff at the agency realized they could at least supply Waymo with the geographic coordinates of all loading zones. Rob Antoniak, formerly Chief Operating Officer of Valley Metro, called this an opportunity to "leverage the public dollar that's already invested in the infrastructure." Given large headways for many of Valley Metro's bus lines, he also noted that the bus loading zones are generally open for significant periods of time and have the potential to be used by AVs.

Figure 7. Designated curb section for Uber at a hotel on the Las Vegas Strip. Cities are considering how curb space should be re-allocated in the face of AV-based ridehailing services.

C. Smart Roads

Smart roads – rights of way which incorporate technological features to communicate with vehicles, sense road conditions, and (at times) alter signaling in response – theoretically will improve the performance of AVs. This could particularly be the case for vehicles with sensors capable of bi-directional communication (known as vehicle to infrastructure, or “V2I”). Las Vegas is adding such signaling in part so that the city can receive data from vehicles to improve understanding of regional traffic flows (via measurement of flow speeds at different points). For Las Vegas, the installation of these features are beginning in the district’s core, and growing outward from there. In fact, the city’s public AV shuttle successfully transmitted information in real time to the city’s operations center (via dedicated short-range radios), and Aptiv passenger AVs on the Lyft platform are already receiving signal-phasing information (Wadsworth Interview). Like modifications to curbs, updating road signaling represents something cities can embark even if they are pre-empted from regulating AVs directly.

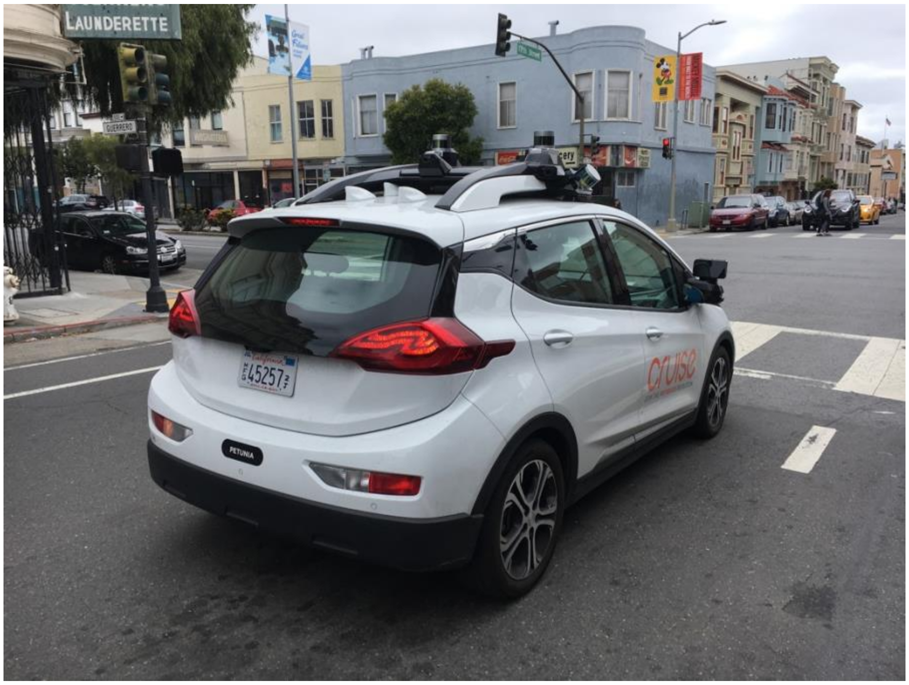

Figure 8. A Cruise AV (with a safety driver) testing on public roads in San Francisco, CA.

D. Integration with Public Transit

A prominent issue surrounding AVs in urban areas is that they are predicted to lower the cost of vehicle travel to the point that AV fleets will compete directly with public transit, as app-based ridehailing services today currently do (Rayle et al., 2016; Schaller, 2018). This scenario could lead to significant decreases in transit ridership (already on the decline in most U.S. cities) and exacerbate congestion. Others have suggested that the investment in AV-related infrastructure (such as specialized roads, lanes, or signage) will come directly at the expense of transit projects (Richland et al., 2016). The counter to this prediction is that AVs will support city residents in maintaining car-free lifestyles (through vehicle shedding and suppression), meaning more people will use a diverse portfolio of modes, including transit (Ohnemus and Perl, 2016).

Valley Metro, the Phoenix-area transit agency which operates light-rail, bus lines, and paratransit, recently formed a partnership with Waymo that may become a model for other regions in terms of AV engagement. The first part of this agreement is for Waymo AVs to transport a number of Valley Metro employees from their homes to the nearest light rail station or express-bus stop (Stern, 2018). Based on the success of this initial intervention, the use of Waymo AVs for first-mile/last-mile trips may expand to RideChoice passengers, who comprise the local paratransit program ("Partnering with Valley Metro," 2018). Rob Antoniak (the former COO of Valley Metro) indicated that transitioning RideChoice passengers from current paratransit to AVs could be significantly more convenient for customers, particularly because rides could be arranged in a more on-demand fashion rather than days in advance.

This case is also important in that it signals what can lie outside of agency discretion in terms of AVs. Antoniak noted that Valley Metro is not involved in setting or expanding Waymo's service area for Phoenix, which affects which transit stations the initial passenger groups can use AVs to reach. In addition, curb space for AV drop-offs near transit connections is often not owned or regulated by Valley Metro (noted in Section B, above), which means that there are important coordination steps needed in each community for this program to work seamlessly.

Figure 9. A Valley Metro light rail car advertising the agency's partnership with Waymo in Phoenix, AZ.

One trend in the U.S. that relates to AVs and transit is partnerships between app-based ridehailing services and cities that include subsidization. This so far has come in several forms, including subsidies for first-mile/last-mile connections to rail stations, late-night rides after subway systems close, and even subsidies within a given service area *in place* of transit altogether (Schwieterman et al., 2018). The City of Arlington, TX, is an example of this approach; in partnership with the company Via, residents can request subsidized rides (with 70% of fares covered) within a 29-square mile area (Mitchell Interview). In relation to AVs, Lyndsay Mitchell remarked that Via was experimenting with how riders will interact with an AV-fleet:

> *They're doing a pretend test, pretending that some of the vehicles are autonomous and then documenting how the customers interact with that and how they use functionality like opening doors, telling the vehicle where to go, or just removing driver communication with passengers and seeing how that works, so that they can address the customer service standpoint before they move into some of the other technology.*

This illustrates that cities (and operators) do not necessarily need to wait for vehicles to be autonomous (or functioning at a given level on the SAE scale) to glean information about how riders will react to impending technology.

E. Development, Zoning, and Parking

During interviews, planners also articulated goals related to development and urban form, particularly the reduction or removal of parking requirements from new buildings, which would in theory allow for increased density. Chandler, Arizona passed an ordinance that offers new developments a 10% reduction in parking requirements for each dedicated pick-up and drop-off zone, up to 40% (MacDonald-Evoy, 2018). According to David De La Torre, Principal Planner for Chandler, the origin of this policy was an APA report arguing that widespread AVs would dramatically lower the demand for parking (Elliot, 2017). Hoping to get in front of this trend, Chandler moved forward with the ordinance to encourage developers to avoid sinking resources into parking that could go unused. De La Torre said, "We need to provide an incentive for developers to create these passenger loading zones for their developments, whether it's a new development, or whether it's an existing development."

Perhaps the single greatest fear of AVs in the field of planning is that the combination of the expected low cost of AV use, combined with the ability for AV passengers to relax, sleep, work, or otherwise avoid the stress of driving, will lead to a massive increase in driving and urban sprawl (Crute et al., 2018). In theory, such effects could be mitigated by lowering parking requirements or eliminating them altogether, which could enable residential, commercial, and retail density to increase, depending heavily on the real estate market and other public policies such as FAR requirements and height limits. It is also thought that existing parking structures could be retrofitted to serve other purposes, such as parks and open space in the case of surface lots, and housing or offices for multi-story lots. Such concepts also played a role in the Chandler policy on parking and loading zones, as De La Torre described:

> *If autonomous vehicles increase like we expect, and a lot of people use them in the future, not only can they reduce parking and create more of a pedestrian streetscape because we're not going to have to have parking spaces in front of the buildings. But that presents opportunities for reuse of those huge parking lots that we have all over the city. Right now, when you drive around the city, you'll see a shopping center and just a*

> *sea of parking in front of it. And in the future, that could change, maybe that becomes more buildings, or more opportunities to generate revenue for businesses and for the city.*

This logic has led some to call for a redesign of all new parking lots, so that they can be more easily modified for other uses in the case that they become obsolete (Ridgeway, 2018). Transitioning parking structures for other uses is far from trivial; one study determined that roughly 30% of all land in Los Angeles county is dedicated to parking (Chester et al., 2015). Staff at the San Francisco County Transportation Authority also considered linking changes in parking regulations directly to AV services, such as providing the option for developers to opt-out of parking requirements by providing funds for a local AV shuttle serving the neighborhood (SFCTA Interview).

F. AV Taxes, Road User Charges, and Municipal Revenues

As they have begun to do for app-based ridehailing services, some cities are considering if and how they will tax or levy fees on AVs. So far, the discussion regarding AVs and revenues splits into two categories: AV-specific taxes, and a more generally applied policy of road usage charging. San Francisco, which currently has several AV companies testing on its roads (including Cruise), provides an example of a nascent proposal for AV-specific taxes. Last July, Board of Supervisors member Aaron Peskin reached an agreement with Uber and Lyft regarding a proposed ordinance of a 3.25% tax on the net fares of individual trips, and a 1.5% tax on shared rides (e.g. UberPOOL and LyftLine) (Said, 2018). This tax will be decided on by voters in the upcoming November election, and if passed, would also tax commercial AV trips (Rodriguez, 2018; Brinklow, 2019). The proposed ordinance reads as follows:

> *Ordinance amending the Business and Tax Regulations Code and Administrative Code to impose an excise tax on the net rider fares for rides facilitated by commercial ride share companies and rides provided by autonomous vehicles and private transit services vehicles, to fund transportation operations and infrastructure for traffic congestion mitigation in the City; and to increase the City's appropriations limit by the amount collected under the tax for four years from November 5, 2019.* (*Initiative Ordinance*, 2019).

In contrast to this specific focus on TNCs and AV companies, road usage charging (RUC) is intended to make all road users pay for the external costs that their driving imposes on others in the form of road wear, air pollution, congestion, and carbon emissions. RUC can take various forms in practice, including road and bridge tolls, cordon tolls, and area-wide vehicle miles traveled (VMT) fees that record distance driven within a designated area. Cordon tolls are prominently in place in London and Stockholm, where the revenues from such systems are used to improve public transit. Beyond bridge tolls and some highway tolls, RUC has remained minimal in scale in the U.S. partly given the perception of its political unpopularity, although New York City is set to establish a cordon-pricing system for Manhattan. Some interviewees said they thought AVs could be a potential lever to expedite RUC in cities, particularly area-wide

VMT schemes. If and when the majority of vehicles on city roads are owned by private fleet operators in shared autonomous fleets, it would be less challenging both logistically and politically to charge those companies for their driving directly as opposed to disseminating transponders to all private cars entering a city.

Expanding road user charging in American cities may also become more likely if AVs worsen congestion. As Jeff Hobson, previously the Deputy Director for Planning at SFCTA put it, “once AVs are on the scene, pricing is going to be necessary.” This is partly because of the potential for either personally-owned or fleet-service AVs to drive on the roads without passengers (referred to as “vehicle deadheading” or “zombie miles”), whether driving to and from remote parking places or to and from passengers. Warren Logan, formerly Senior Transportation Planner at SFCTA, noted that if street parking is expensive or scarce, then in the absence of RUC, AV operators might save money and lower wait times by simply running their vehicles on the road in between passenger requests.

Finally, plans to levy fees or begin road user charging are not only about managing the potential impacts of AVs, but also about adding new funding sources to replace the possible elimination of existing revenues from publicly owned paid parking lots and meters, if parking demand declines with greater penetration of AVs and reduction of personal vehicle ownership. A number of cities rely heavily on parking revenue in their budgets; for example, Pittsburgh receives roughly 15% of its municipal funding from parking charges (Kang, 2017).

G. Regional AV Policy and Scenario Planning

MPO staff we interviewed were particularly focused on how AVs are likely to influence long-range transport and land-use patterns. At MTC, the Bay Area’s MPO, relative rates of AV penetration are one of many factors included in their extensive scenario-planning models. Dave Vautin, Assistant Director for Regional Planning and Policy at MTC, helped lead the “Horizon” project, and described how their models vary the AV-adoption rate from low to high, in order to appraise or “stress test” their investment and infrastructure decisions (“Futures Interim Report,” 2019). The three scenarios they landed on incorporate AV penetration from 10 to 95%, and MTC’s scenario-planning attempts to account for how different AV outcomes interact with other factors including economic inequality, housing density, and changing demographics. For Vautin, these divergent futures feed back into the analysis of planning and funding decisions, generating:

> *Three benefit-cost ratios for each proposed transportation project [one per scenario]. This new approach will allow us to better understand the range of potential performance for billions of dollars of transportation investments, identifying which may be more resilient in an uncertain future.*

Planning for autonomous vehicles by the Maricopa Association of Governments (MAG), the MPO for the Phoenix region, is somewhat different than that of MTC given that their guidance does not generally include land-use planning. However, they view their role as facilitating the alignment of AV planning strategies across their region, and as a curator of AV trends nationwide. MAG interviewees reported tracking the development of "automation readiness plans" in other regions, which include appraisals of existing transportation fleets, systems, and behaviors, for the purpose of predicting how automation may happen locally. Eric Anderson, Executive Director of MAG, described it as creating a record of the local transportation inventory to improve AV forecasting (and likely sequencing), as opposed to choosing which directions it will or should proceed (i.e. 'picking winners').

MAG is also considering the need for information sharing between public agencies and AV companies when roadway construction takes place. For example, some large infrastructure projects (such as Boston's Big Dig) entail different roadway configurations on a near-daily basis, which can pose a significant source of frustration for motorists but for autonomous vehicles as well, which rely on up to date maps. To resolve this issue, one idea from MAG – still in the conceptual phase – is a type of coordinated "Atlas" of roads within a metropolitan area where road changes can be input in real time, and from which AV companies can modify their own maps.

Similarly, New York Metropolitan Transportation Council, (NYMTC, which covers New York City and surrounding counties) considers AVs in the context of longer-term funding decisions. Gerry Bogacz, Planning Director at NYMTC, noted that building infrastructure for today's needs and with today's technology (such as a tunnel under a river) creates a path dependency for how those facilities can be used for decades to come. Given this, one strategy to hedge against the changes that AVs may bring is to plan for flexible or adaptive use in new facilities. This has been discussed frequently in the context of parking structures, but it also relates to transit projects in which the vehicles used today could possibly be automated in the future, or in which light-rail systems could be replaced by autonomous shuttles.

In this vein, Bogacz pointed out that the rate of vehicle *electrification* also factors into land-use decisions (such as converting existing fueling stations into charging hubs, etc.), and the AV question cannot be addressed in isolation. To that point, legislators in Massachusetts have introduced a bill that would require all AVs be electric vehicles, demonstrating an interest in connecting these two transportation trends (Day, 2019). In the New York region, another variable is the shift in employer locations, as many large companies are moving their office locations back to city centers and out of suburban office parks (a phenomenon occurring elsewhere also: Erenhalt, 2013). This has generated increased demand for commuter rail services, and thus demand for parking around those stations, which feeds into one use case for AVs: first and last mile shuttles. This example represents the challenge for MPOs of advising members on AVs; they are not ends in and of themselves to regional problems, but possible pieces of more comprehensive land use and transportation changes.

Conclusion for Part II

A number of U.S. municipalities and agencies are developing policy to harness AVs for collective benefit, outside of regulating testing or initial pilots. This includes land-use decisions, such as incentives for developers to build features that will ease AV-based travel, partnerships with transit agencies to connect passengers to rail lines, and even modifications to traffic signals for bi-directional communication between AVs and cities. MPOs are including varying rates of AV adoption in their scenario-planning exercises, and also pursuing ways to coordinate regional responses to AVs, such as by aggregating real-time roadway construction. Policies so far are simultaneously attempting to smooth AV adoption for certain uses, while preventing them from exacerbating current road conditions (congestion, double parking, emissions) in a similar fashion to Uber and Lyft. Some steps taken (like upgrading traffic lights) require public money be spent with an AV future in mind, whereas AV-specific taxes conversely approach this mobility trend as a new source of revenue. A distinct challenge of this work is timing; building "smart roads" or re-allocating curb space for AVs may prove unhelpful if AV deployment is slower than current projections (and residents still want parking for personally-owned vehicles), and AV taxes (rather than RUC) may only address a small fraction of vehicles on the road. Indeed, these policies represent the "first draft" regarding AVs, and how they fare could make them bellwethers for broader adoption nationwide in the years to come.

Discussion

Interviews with staff at select cities, transit agencies, and MPOs in the U.S. developing policy for AVs manifest discrete motivations for such work, and various ways of encouraging AV activity that synergizes with established goals, transportation and otherwise. These break roughly into two categories: policies addressing AV testing and initial pilots on public roads today, and alterations to transportation infrastructure and urban form to accommodate and manage anticipated future use of AVs on a wider scale. The former bifurcates into leading AV shuttles to move passengers over fixed routes, or creating permits that private AV companies can apply for to begin more spatially-unrestricted testing (and eventually revenue service). The latter – broader AV policy development – has taken a number of forms, from rethinking transportation-related revenues, to changing zoning to discourage long-term parking.

Across these conversations, documents, and resulting policies, three findings stand out, and indicate possible directions for future research. First, cities are generally developing policies with the assumption that AVs will largely operate as medium-capacity shuttles and private ridehailing fleets, and not via personal ownership. This relates to AV-transit partnerships, sponsorship of public AV pilots, AV-specific taxes, and the push to transition curb space away from parking. Second, state pre-emption of AV regulation is rarely as simple as reading the given executive order or state law. Multiple cities have influenced AV testing operations (such as New York City and San Jose) even when lacking the explicit legal authority to do so. This indicates that even cities outside of Massachusetts – which is unique in granting local control over AV activity – have the ability to affect how AVs operate via multiple channels. Specifically, just because an AV operator does not need to coordinate with a city to test there, does not mean they will not be interested in doing so provided the opportunity for a meaningful partnership. Third, the role for regional agencies and MPOs in regards to AVs is far from certain. Each MPO has a different relationship with its member cities and towns, which look to it for various types of expertise and resources. This may make developing regional AV policy a challenge, particularly for those MPOs that do not advise cities and towns on land use.

The U.S. has a large amount of AV testing and pilots taking place, which has generated different policy reactions locally and regionally both in regards to the short and long term. These “early adopter” cases, drawn from across the country, provide a menu of options for others to pursue or adapt to their local context, from testing progressions for AVs, to opportunities to rethink access to public transit. Uncertainty as to the speed and degree to which AVs will be deployed runs through nearly every policy decision. As we approach the start of a new decade, the years ahead will be ripe for charting how today’s AV policies perform, change, and scale.

Appendix (Interviews Conducted)*

Adrian Fine, Director of Marketing and Communications, Drive.Ai (April 12, 2019)

Amanda El-Dakhakhni, Senior Manager of Government Affairs, and David Rubin, Policy Research Manager, Cruise (March 14, 2019)

Daniel Sullivan, Policy Assistant, Massachusetts Department of Transportation (March 28, 2019)

Dave Vautin, Assistant Director for Regional Planning and Policy, Metropolitan Transportation Commission (September 28, 2018)

David De La Torre, Principal Planner, and James Smith, Economic Development Innovation Manager Chandler, AZ (December 7, 2018)

Eric Anderson, Executive Director, Robert Hazlett, Senior Engineer, and Vladimir Livshits, Director of Transportation Technologies and Services, Maricopa Association of Governments (December 7, 2018)

Eric Bourassa, Director of Transportation Division, and Alison Felix, Senior Transportation Planner and Emerging Technologies Specialist, Metropolitan Area Planning Council (March 29, 2019)

Kristopher Carter, Co-Chair of the Mayor's Office of New Urban Mechanics, Boston, MA (March 28, 2019)

Gerry Bogacz, Planning Director, New York Metropolitan Transportation Council (January 16, 2019)

Jarrett Mullen, Senior Transportation Planner, Palo Alto, CA (November 1, 2018)

Jill North, Innovation Program Manager – Department of Transportation, San Jose, CA (November 2, 2018)

Joanna Wadsworth, Program Manager – Information Technologies Department, Las Vegas, NV (December 6, 2018)

Lyndsay Mitchell, Strategic Planning Manager – Office of Strategic Initiatives, Arlington, TX (April 10, 2019)

Martin Alkire, Principal Planner, Mountain View, CA (October 26, 2018)

Matthew Wansley, General Counsel, and Kevin Spieser, Research Scientist, nuTonomy (March 27, 2019)

Ratna Amin, Transportation Policy Director, SPUR (September 28, 2018)

Rob Antoniak, Chief Operating Officer, Valley Metro (December 7, 2018)

Susanne Rasmussen, Director of Environmental and Transportation Planning, Brooke McKenna, Assistant Director for Street Management, Joseph Barr, Director of Traffic, Parking, and Transportation, and Stephanie Groll, Parking and TDM Planning Officer, Cambridge, MA (March 28, 2019)

Tilly Chang, Executive Director, Jeff Hobson, Deputy Director for Planning, and Warren Logan, Senior Transportation Planner, San Francisco County Transportation Authority (September 29, 2018)

William Carry, Senior Director for Special Projects, Patrick Smith, New Mobility Policy Analyst, New York City Department of Transportation, and Rodney Stiles, Acting Deputy Commissioner, Taxi and Limousine Commission (January 17, 2019)

* Some interviewees have transitioned to other jobs since interviews took place. Listed above are where individuals worked at the time of each interview, conducted between August 2018 and June 2019.

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