HARVARD Kennedy School
TAUBMAN CENTER
for State and Local Government

Autonomous Vehicles Are Coming:
Five Policy Actions Cities Can Take Now to Be Ready

Mark Fagan, Daniel Comeaux, and Benjamin Gillies

March 2021

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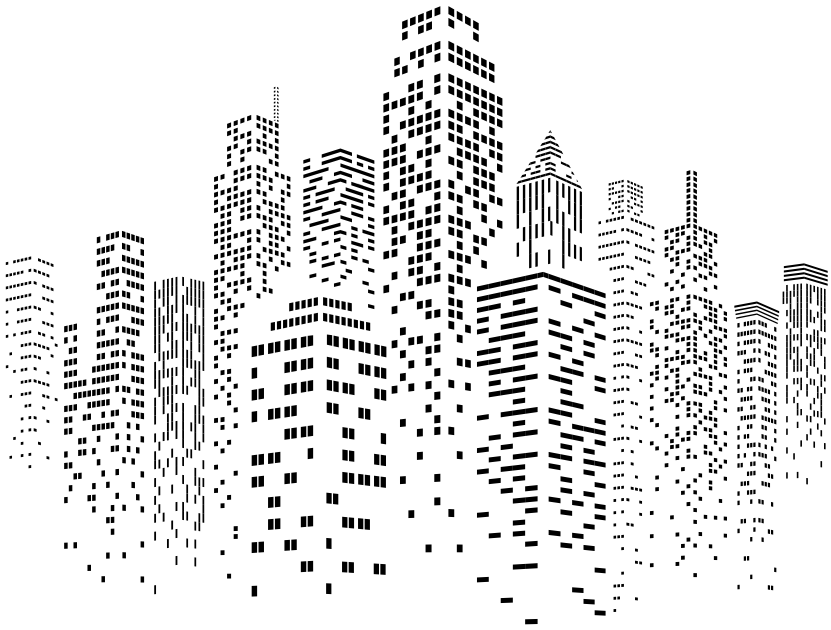

ABOUT THE AUTHORS

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ABOUT THE TAUBMAN CENTER FOR STATE AND LOCAL GOVERNMENT

The mission of the Harvard Kennedy School's Taubman Center for State and Local Government is to support current and future public sector leaders in improving the governance of states, counties, metropolitan regions, and cities through research, teaching, programs, and convenings.

The Taubman Center works to:

- Develop the next generation of state and local government leaders
- Generate big ideas and solutions to state and local government challenges
- Help state and local government implement and scale solutions

The Taubman Center focuses on urban policy issues, including economic development, transportation, education, public infrastructure, land use, social services, public sector technology and data utilization, procurement, and performance management.

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I. ABOUT THIS PAPER

Over the last three years, the Autonomous Vehicle Policy Initiative (AVPI) at the Taubman Center for State and Local Government at Harvard University's Kennedy School of Government has been helping cities and states in the United States and abroad prepare for the policy issues they'll face as AVs enter the urban environment. Faculty, staff, and students at Harvard have worked directly with Boston, Toronto, Kansas City, Rhode Island, Buenos Aires, and Detroit to help them prepare for AVs though policy scrums. These sessions begin with briefings on AV technology and policy, then provide structured sessions to identify AV objectives, alternatives, and recommendations. Through policy scrums, cities can make real progress on relevant policy issues, and develop and involve a broader AV stakeholder network for diverse inputs and improved outcomes.

This document is designed to be a resource for policymakers. In our work, we have learned city and state officials are both excited and nervous about the advent of AVs. They believe this technology can have a positive impact in helping them address some of the challenges present in their transportation systems, but they also recall the tumultuous arrival TNCs had, and do not want to face such an unplanned disruption again. Yet, with so much activity taking place in the AV space, they find themselves struggling to determine where to start in crafting the policy to prepare for AV arrival. Our purpose is to assist them in making sense of this fast-moving field in order to better craft and implement policies.

The first two sections of this paper offer a glance at the specifics of the technology, and how companies are testing new AV use cases across the country and abroad. Neither section is meant to be comprehensive, but they do offer several examples readers can investigate further based on their interest. The third section provides a series of five policy action areas we believe cities should be looking at immediately, to lay the foundation for future AV policy. While we would welcome a city government willing to tackle all five areas, we recognize most local governments will choose one initial area of focus given practical time, resource, and political constraints. We therefore encourage policymakers to consider the most pressing challenges their transportation systems face, and where those challenges align with the five action areas and the steps we propose. While these steps can help guide local AV deployment, they can also improve a transportation system dominated by conventional human-driven vehicles.

Beyond the five policy actions we offer, we encourage cities to develop pilot projects to test use cases in their jurisdiction. Local context and objectives will drive such experiments for each city, but our fourth and concluding section provides some general guidelines for conducting these pilots.

II. INTRODUCTION

On a warm fall day in 2019, four people wait at Providence Station in Rhode Island for a shuttle bus. Soon, the six-person electricity-powered vehicle that arrives takes them to Olneyville, a neighborhood that, until May of that year, offered no public transportation options. That change occurred when the Rhode Island Department of Transportation (RIDOT) and May Mobility, a Michigan-based automated shuttle start-up, introduced Little Roady, the state's first self-driving shuttle service. After winning the contract, the company established a local office and operations center in Providence and hired more than 50 employees from the region.[1] RIDOT noted that Little Roady's debut put Rhode Island at the forefront of mobility testing, while filling a gap in the state's public transportation network.[2]

In May 2019, a fleet of 12 six-seat electric autonomous vehicles (AVs)—that resemble miniature buses—began to offer free rides along a 5.3-mile route between Providence Station and Olneyville Square.[3] The vehicles were loaded with sensors, radar and LiDAR—a technology that uses laser light to perceive the surrounding landscape in three dimensions—which facilitated their travel along a pre-programmed route. Although able to operate autonomously, each vehicle was staffed by a safety driver who could take control if conditions warranted. For instance, rain, speed bumps, construction work zones, potholes, and aggressive drivers could each pose a potential challenge that might encourage the attendant to switch from autonomous operation to manual control.[4]

Both RIDOT and May Mobility considered the $1.2 million program a research project devised to study the community impact of a small-scale automated transit service. Little Roady presented RIDOT with an opportunity to better understand the risks and rewards that came with integrating this new technology into Rhode Island's transportation planning.[5] With the help of academic research and data analytics, as well as social innovation consultants, policymakers, the community, and other stakeholders,

1 Rhode Island Department of Transportation. Little Roady Autonomous Shuttle Pilot Project, http://www.dot.ri.gov/projects/trip/LittleRoady.php. Accessed September 11, 2019.

2 Carey, Christopher. "Uber resumes AV testing in San Francisco." Cities Today, March 17, 2020, https://cities-today.com/uber-resumes-av-testing-in-san-francisco/. Accessed January 23, 2021.

3 Comery, Beth. "Free Ride – Little Roady Passes The Test." Providence Daily Dose, July 12, 2019, https://providencedailydose.com/2019/07/12/free-ride-little-roady-passes-the-test/. Accessed September 11, 2019.

4 Faulkner, Tim. "Driverless Little Roady Shuttle Hits a Few Speed Bumps." ecoRI News, August 3, 2019, https://www.ecori.org/transportation/2019/8/2/little-roady-shuttle-reaches-milestone-hits-speedbumps. Accessed September 11, 2019.

5 Rhode Island Department of Transportation. Little Roady Autonomous Shuttle Pilot Project.

RIDOT hoped to use the experiment to explore mobility solutions, ridership trends, workforce opportunities and impacts, customer satisfaction, environmental impacts, and state and local policies.[6] The test pilot program engendered public enthusiasm; by July 2019, the service had picked up its 9,000th passenger.[7]

"Done right, it will be much better than the status quo."
—former National Transportation Safety Board Chair Christopher Hart, on the deployment of AVs

Three years earlier, in June 2016, Christopher Hart, then-chairman of the National Transportation Safety Board (NTSB), predicted that AVs would eventually enjoy widespread adoption and would be the best way to improve road safety. "Done right, it will be much better than the status quo," he remarked, even as he noted the technology presented significant challenges.[8]

Indeed, Hart predicted the industry would have to weather an inevitable spate of fatal crashes before the technology would be perfected.[9] Two years later, on March 18, 2018, Elaine Herzberg became the first known case of a pedestrian killed by a self-driving vehicle. Herzberg was walking her bicycle across a four-lane road in Tempe, Arizona late in the evening when she was hit by an automated Uber test vehicle, which was operating in self-drive mode with a human safety driver sitting in the driver's seat.

Uber immediately discontinued its testing of self-driving vehicles and Arizona Governor Doug Ducey suspended all testing on public roads. The incident also caused other companies to temporarily suspend their tests as well. After the investigation was concluded, the National Highway Traffic Safety Administration and the American Automobile Association flagged nighttime driving as an area for safety improvement.[10] In December 2018, Uber received permission to resume testing in

6 Ibid.

7 Faulkner, Tim. "Driverless Little Roady Shuttle Hits a Few Speed Bumps." ecoRI News, August 3, 2019, https://www.ecori.org/transportation/2019/8/2/little-roady-shuttle-reaches-milestone-hits-speedbumps. Accessed September 11, 2019.

8 Laris, Michael. "NTSB chief foresees transition to life-saving driverless cars that includes deaths." The Washington Post, June 30, 2016, https://www.washingtonpost.com/news/dr-gridlock/wp/2016/06/30/ntsb-chief-sees-deadly-transition-to-life-saving-driverless-cars/. Accessed September 11, 2019.

9 Ibid.

10 National Transportation Safety Board. "Preliminary Report Released for Crash Involving Pedestrian, Uber Technologies, Inc., Test Vehicle." National Transportation Safety Board Office of Public Affairs, May 24, 2018, https://www.ntsb.gov/news/press-releases/Pages/NR20180524.aspx. Accessed September 9, 2019; and Garcia, Uriel J. and Karina Bland. "Uber crash called 'unavoidable' for any driver." The Arizona Republic, March 20, 2018, https://www.azcentral.com/story/news/local/tempe/2018/03/20/tempe-police-chief-fatal-uber-crash-pedestrian-likely-unavoidable/442829002/. Accessed September 9, 2019.

Pittsburgh, and in March 2020 California also re-issued the company's permit to test again in San Francisco.[11]

Early AV Development Timeline

June 2016: National Transportation Safety Board (NTSB) Chairman Christopher Hart predicts AVs will enjoy widespread adoption and improve road safety.

March 2018: Elaine Herzberg is killed by a self-driving Uber test vehicle. The resulting negative publicity is a significant setback for AV development.

December 2018: Satisfied it had addressed the issue, Uber recommences AV testing.

May 2019: Rhode Island DOT and May Mobility begin operating the Little Roady electric AV shuttle, putting the state at the forefront of mobility testing while extending its public transportation network.

July 2019: The Little Roady shuttle is met with public enthusiasm, picking up its 9,000th passenger.

* * *

The Little Roady pilot and Uber's testing tragedy provide snapshots of a rapidly-evolving field, one moving inexorably toward fruition. As testing continues, we are now coming to recognize the challenges and impacts these vehicles may have on congestion, curb usage, parking revenues, and other areas of interest to local government officials—issues we address in detail in section IV of this paper. State and local governments must develop appropriate public policies if they are to yield public benefits from the inevitable arrival of AVs in their jurisdictions. We are now at a critical juncture, as AVs are poised to ride the same evolutionary road that Transportation Network Companies (TNCs)[12] such as ride-hailing services Uber and Lyft did in the 2010s. The impending arrival of AVs offers states and municipalities a chance to shape this industry with policies that will deliver public value.

Policymakers must consider many factors when weighing how best to regulate AVs. As with all change, AVs will have positive and negative impacts on municipalities. Deployment of AVs with the right policies could potentially have significant positive impacts on mobility, congestion, public finance, land use, logistics and the environment in cities across the country. But the challenges facing the industry are daunting as it struggles with issues surrounding technology, implementation costs, data security, and adoption and ridership. Cities will have to address the potential loss

11 Carey, Christopher. "Uber resumes AV testing in San Francisco." Cities Today, March 17, 2020, https://cities-today.com/uber-resumes-av-testing-in-san-francisco/. Accessed January 23, 2021.

12 A transportation network company, sometimes known as a mobility service provider, is a company that matches passengers with vehicles, via websites and mobile apps. TNCs for automobiles are commonly referred to as ride-hailing services.

of parking and other revenues as well as likely job losses as professional drivers are displaced. Adopting the right policies will position cities to maximize the upside of AVs while mitigating the downside.

COVID-19 Commentary

In early 2020 as we were synthesizing the work from our research for this paper, the United States—and the world—began to confront the unprecedented COVID-19. Unfortunately, the early evidence suggests COVID-19 may remain a part of our lives for a long time. Even with a vaccine, people may begin to change their habits, such as how they work and where they live, to reduce the risk of infection in a future pandemic. Like experts in many fields, we were left asking: How will COVID-19 specifically, and the potential of large-scale pandemics more generally, impact AV development?

It is still early on in determining the interplay between AVs and the spread and implications of disease spread. Nevertheless, we think it important to acknowledge this profound new reality, so where appropriate, we have added notes on COVID-19 in the text. Drawing on the emerging research about the urban planning and transportation impacts of coronavirus, empirical evidence on American travel more generally, along with our knowledge of the benefits and limitations of AVs, we offer some initial ideas about the role AVs can play as citizens and governments react to this pandemic.

Notwithstanding the uncertainties, we are confident that AV policy making is still a priority for city and state officials as they respond to the evolving AV mobility technology and respond to COVID-19.

III. AUTONOMOUS VEHICLES: A QUICK PRIMER

What Does It Mean to Be Autonomous?

Most automobile drivers have had some experience with autonomous driving features. According to the Society of Automotive Engineers,[13] there are several levels of automation:

Society of Automotive Engineers Levels of Vehicle Automation

Level 0: Manually controlled, with no automated features.

Level 1: A human driver controls an automated feature (for instance, cruise control, which allows drivers to set a constant vehicle speed).

Level 2: A human driver must steer, brake or accelerate to maintain safety, but some driving function is automated (for instance, lane centering).

Level 3: A vehicle is self-driving but a person must sit in the driver's seat and, in event of an imminent crisis, disengage the vehicle from autonomous operation and drive it manually.

Level 4: A vehicle is autonomous but may be limited by certain weather, lighting or road conditions, or may be restricted to operating within a pre-defined area or route.

Level 5: A vehicle operates autonomously in all driving conditions and situations.

Most AV operators are focused on developing services that can operate on levels 4 or 5 to remove the need for—and costs associated with—human intervention. While many are currently testing Level 4, Level 5 is at least 10 years—and possibly several decades—away from mass-adoption feasibility. Even so, designers are imagining—and creating—the future: first- and last-mile shuttles, land-based AV delivery vehicles and cities filled with cars, buses, and even trucks that drive themselves.

How Does Technology Enable AVs?[14]

When an AV company wants to operate in a geographic area, its workers drive the vehicle over the terrain repeatedly, each time gathering information about the operating environment including the landscape, traffic behavior, and pedestrian behavior. AVs operate based on rules, and those rules are in part governed by maps built and

13 The U.S. Department of Transportation uses the Society of Automotive Engineers' five levels of automation for on-road motor vehicles in its Federal Automated Vehicles Policy and the document became a de facto global standard adopted by stakeholders in the automated vehicle technology sphere. Source: Society of Automotive Engineers International website, https://www.sae.org/news/press-room/2018/12/sae-international-releases-updated-visual-chart-for-its-"levels-of-driving-automation"-standard-for-self-driving-vehicles, accessed September 12, 2019.

14 For more information on AV technology, please see "Self-driving car technology: When will the robots hit the road?" Available at: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/self-driving-car-technology-when-will-the-robots-hit-the-road/de-de.

updated using this data. These maps, devised from data gleaned after operating on a roadway hundreds of times, provide "virtual guardrails" for an AV's operation.

How do AVs collect the data necessary to construct these complex maps? AVs use outward-facing cameras to provide images of the surrounding environment, and technologies including light detection and ranging (LiDAR) to perceive the landscape in three dimensions. These data are fed into a powerful computer that coordinates and acts on the information provided by the peripherals.

HOW AVS WORK

1. Outward-facing cameras provide images of the environment surrounding the vehicle.
2. Vehicles use laser light technology, or LiDAR, to perceive landscape in three dimensions.
3. A powerful computer coordinates and acts on the information provided by cameras and LiDAR.

Through the mid-1980s, robots used sensors to gather information about their environment, which was then used to plan and control their movements. This was referred to as the Sense, Plan, Act paradigm. Building on this paradigm, AVs See, Think, and Act: they gather information about their surroundings, such as obstacles or "landmarks;" they form a plan to respond to the sensor data using an existing strategy (i.e., if there is an object in its path it moves to the left); and finally, they carry out the actions devised in their plan. These operations are essentially performed in real time. One technology company, ZF, claims its automotive supercomputer is capable of performing the equivalent of 150 trillion operations per second.[15]

The technology already exists to allow AVs to engage in V2V and V2I communication, and in the future, AVs will also communicate with the wider world around them using V2X functionality to operate more safely and efficiently.

Forms of AV Communication

1. Vehicle-to-Everything (V2X): Information passes from a vehicle to any person, device, entity, landmark or object that may affect the vehicle and vice versa.
2. Vehicle-to-Vehicle (V2V): Information passes from one vehicle to another.
3. Vehicle-to-Infrastructure (V2I): Information passes from a vehicle to the surrounding infrastructure.

Initially, the AV industry was focused on V2I, which involves the exchange of safety and operational data between individual vehicles and the transportation infrastructure that supports them. In addition to stop signs and crosswalks, other connected components could include RFID readers embedded in overhead signs on overpasses, as well as connected cameras, lane markers, traffic lights, and parking

15 Weitbrecht, Lars. "Autonomous Driving: The Formula for Success." ZF Vision Magazine, January 7, 2019, https://www.zf.com/site/magazine/en/articles_13440.html. Accessed September 13, 2019.

meters. However, the complexity and costs of interacting with roadside infrastructure has called into question how quickly the technology will be implemented.[16] Indeed, a 2015 U.S. Government Accountability Office report found that every individual V2I hub could cost as much as $52,000, leaving municipalities to wonder how V2I technology would be funded.[17] How could municipalities gain taxpayer support for such investments—particularly if the benefits accrue primarily to private AV fleet operators? And who specifies the parameters of the smart infrastructure? These are only a few of the issues that need to be addressed from a public perspective if V2I interaction is to become a requirement for AVs.

While V2V was also seen as an attractive option for improving safety, it will likely be decades before all vehicles on the road are capable of communicating with each other. While these and other V2X technologies may become a critical component to the future of AVs, they are likely years away from being realized.

AV Development

Many companies, from traditional car manufacturers to tech start-ups, are currently working on AVs capable of Level 4 autonomy. Traditional manufacturers including GM, Ford, and Nissan-Renault already have AVs on the road. Tesla has announced plans to roll out extensive AV coverage in the early 2020s. Alphabet (best known as Google's parent company) subsidiary Waymo is heavily invested in AVs with around 600 cars in service, and plans to deploy 20,000 through its ride-hailing service, Waymo One in the next few years.

KEY AV DEVELOPERS

Aptiv
Argo AI
Blackberry
Drive.Ai
Ford
GM
May Mobility
Nissan-Renault
Optimus Ride
Tesla
Aurora
Waymo

There are also tech startups in this space. For instance, nuTonomy, now part of Aptiv, is an MIT spinoff that has been testing vehicles capable of level 4 autonomy for more than three years in Singapore and Boston.[18]

16 Forrest, Conner. "The X-factor in our driverless future: V2V and V2I." ZD Net, February 1, 2018, https://www.zdnet.com/article/the-x-factor-in-our-driverless-future-v2v-and-v2i/. Accessed October 8, 2019.

17 United States Government Accountability Office. "Intelligent Transportation Systems: Vehicle-to-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist." United States Government Accountability Office Report to Congressional Requesters, September 2015, https://www.gao.gov/assets/680/672548.pdf. Accessed October 8, 2019.

18 Sawers, Paul. "The world's first public self-driving taxi service hits Singapore roads today." Venture Beat, August 25, 2016, https://venturebeat.com/2016/08/25/nutonomy-singapore-self-driving-car-service/. Accessed October 8, 2019; and WBUR News and Wire Services. "Buckle Up, Boston: Testing of Self-Driving Cars Begins Tuesday." WBUR, January 2, 2017, https://www.wbur.org/bostonomix/2017/01/02/self-driving-car-testing-begins. Accessed October 8, 2019.

Another set of providers are offering autonomous shuttle buses capable of transporting between four and eight passengers. Companies such as May Mobility, Optimus Ride, and Argo are designing, building, and operating these vehicles.

Today, most AVs are standard driver-based automobiles that have been modified to include AV technology. For example, Waymo uses the Chrysler Pacifica, and Uber relies on Volvo XC90 SUVs.[19] In early 2020, however, the NHTSA gave Nuro the first permit to produce vehicles specifically designed as automated: Designed for roads, but without windshields or mirrors.[20] This is a major milestone, as federal officials acknowledge and permit construction of vehicles that will never have a driver behind the wheel.

While many autonomous car companies currently put self-driving technology in and on conventional gasoline internal combustion engine vehicles, companies developing shuttles are designing and building electric from scratch. In addition, many AV providers are planning for their vehicles to be electric-powered when they operate at scale.

The rate of AV adoption, however, will be predicated on whether the cost of the technology used to convert a traditional vehicle to an AV will continue to decline. Early test passenger AV vehicles cost as much as $300,000 each but over the next 10 to 15 years, costs will likely be less than $50,000 as manufacturers scale for production. Nevertheless, some cities are currently paying high annual leasing fees for AV tests in their municipalities. For instance, French AV shuttle company EasyMile is charging $27,000 per month per shuttle. Arlington, Texas contracted with Drive.ai to fund a year-long test with a trio of AV shuttles for $435,000.[21]

How Might AVs Arrive in Your City?

AV developers and operators are determining the initial use cases for how AVs will be deployed. Given how aggressively companies are testing the technology, one of the first use cases has been ride-hailing services operating within urban areas—essentially, driverless taxis and TNCs. Several factors make this model highly attractive, including the high likelihood of consumer adoption, based on existing consumer acceptance of taxis and TNCs. Indeed, judging by the explosive growth of TNC rides, the urban

19 Gardner, Greg. "Waymo to Convert Chrysler Minivans and Jaguar I-Paces in Detroit plant." Forbes, April 23, 2019, https://www.forbes.com/sites/greggardner/2019/04/23/waymo-to-convert-chrysler-minivans-and-jaguar-i-paces-in-detroit-plant/?sh=787e2f632c08. Accessed October 8, 2019; and O'Kane, Sean. "Uber debuts a new self-driving car with more fail-safes." The Verge, June 12, 2019. Accessed October 8, 2019.

20 https://www.autonews.com/mobility-report/milestone-driverless-delivery.

21 Waddell, Kaveh. "The true cost of autonomous cars." Axios, December 9, 2018, https://www.axios.com/who-will-pay-for-autonomous-vehicles-11702624-0fbf-4b5f-9d3a-bf5c4cd3ed8a.html. Accessed September 16, 2019.

population is eager to adopt a new model for mobility that is convenient to use. Second, assuming the TNCs pass along to their riders the cost savings of operating without drivers, consumers will likely be eager to embrace a less expensive transportation option. Finally, because mapping the environment is costly and time consuming, limiting the scope of operation to a relatively small geographic area decreases time to market. AV TNCs are most likely to be implemented within dense urban cores, ensuring high utilization, which will make the economics of AVs more viable.

A second emerging use case is AV shuttle service. The initial applications have been providing fixed-route service on short routes as a first/last mile solution. For example, Drive.Ai operates an AV shuttle in Arlington, Texas that connects passengers between various downtown "last mile" destinations.

AV USE CASES

- Ride-hailing services (e.g., taxis and TNCs)
- Shuttle services (e.g., short first/last-mile transit carriers)
- On-demand mobility services (e.g., retirement communities)
- Delivery services (e.g., food, office supplies, packages)

Another likely early use case is providing on-demand mobility within specified areas, such as retirement communities. For example, Via and EasyMile currently provide a flexible, on-demand transit service to residents of the Marian Grove Retirement Village in New South Wales, Australia.[22] AVs are a particularly attractive service for this and other senior-focused communities because of the otherwise limited mobility some residents might face.

Beyond carrying passengers, land-based AVs can be used to substitute for or augment existing food and package delivery services. As demand for home and office delivery has grown, delivery services are keen to find a lower-cost way to get their goods to consumers. Several land-based delivery AVs are currently being tested. Nuro, for example, uses AVs to deliver groceries in Scottsdale, Arizona, and Houston, Texas. Amazon is testing its own delivery robot service, Scout, in Snohomish County, Washington.

While these AVs could offer attractive economics, they face the challenge of delivering their goods from the vehicle to the recipient's door—the so-called "last 100 feet" problem. To solve this problem, Agility Robotics has partnered with Ford to test a land-based AV delivery program using a new robot, Digit. When a Ford AV arrives at a delivery location, Digit "unfolds" itself from the back of the vehicle, selects the appropriate package (or pizza, for instance) to deliver then walks it to the recipient's door. Digit, which was designed to look and walk like a human, is able to climb up and

22 Intelligent Transport. "Via unveils its first autonomous vehicle service pilot." Russell Publishing Ltd, July 15, 2019, https://www.intelligenttransport.com/transport-news/84115/via-first-autonomous-vehicle-service/. Accessed February 3, 2020.

down stairs carrying packages up to 40 pounds.[23] A Digit-like solution will be part of an early use case because if and when the last 100 feet problem is solved, it will allow the realization of the holy grail of automated land-based delivery: 24/7 operation with no humans.

Which of these services arrives first in your community will depend on a number of factors, including the investment decisions of private operators, projected demand and even climate. As we discuss below, local and state governments also have a role to play in inviting or limiting companies to test in their jurisdictions, meaning the decisions you make will also influence the first use case your citizens experience.

The Regulatory Climate

Autonomous vehicles will be regulated at the federal, state and municipal level. The National Highway Traffic Safety Administration is charged with setting safety standards, though the agency has not yet established rules for the industry. In the absence of federal regulations, states and cities are stepping in. Some states, like Massachusetts, have devised an overarching set of regulations while allowing municipalities to set their own local rules. At the other end of the spectrum, some states have preempted local authority; the California Department of Motor Vehicles, for instance, is setting statewide rules for AV operations. Some analysts believe the federal government will eventually set safety standards, leaving states and municipalities responsible for devising regulations for testing and operations.

Seeing work at the state and federal level, some local officials may wonder what authority they have in AV policy development. We argue city governments can and should have a significant influence on how automated vehicles will arrive in their jurisdictions. Through their transit agencies, taxi/TNC regulations, land use planning and streetscaping priorities, parking authorities, Vision Zero initiatives, congestion pricing, fleet purchasing power, and speed limit measures, local governments have many levers to pull. While not every city will have every tool (in some parts of the country, transit and TNCs are managed by the state, for instance), we encourage all policymakers to look across their departments and see how they can shape the local rollout of AVs to the benefit of the community.

23 Yan, Michelle. "Watch Ford's delivery robot that walks on two legs like a human." Business Insider, May 23, 2019, https://www.businessinsider.com/ford-delivery-robot-digit-walks-on-two-legs-like-human-2019-5. Accessed September 22, 2019.

Challenges to Operationalizing AVs

Five challenges— (1) technological barriers; (2) data privacy and security concerns; (3) moral decision-making concerns; (4) impact on jobs; and (5) public trepidation—must be overcome for the potential of AVs to be realized. While not all of these issues are under the authority of local policymakers, city and regional officials must understand these topics and concerns in order to engage effectively with citizens and stakeholders.

Technology

AV technology needs further refinement to improve passenger and pedestrian safety. While the frequency of safety-driver interventions (i.e., disengagements) are declining (indicating that the technology is becoming more reliable), safety drivers are still necessary, and it is unclear how soon AVs will be able to operate at levels 4 or 5—in any use case scenario.

For efficient AV operation, there most be continual communication between the vehicles and the operators data management platform. As such, the availability of 5G—fifth-generation cellular network technology—is another technology issue. With speeds as much as one hundred times faster than 4G, 5G may offer AV operators speeds of up to 100 gigabits per second—speeds AV operators will need to meet the communications requirements of their fleets. While four major carriers—AT&T, Sprint, T-Mobile and Verizon—had announced plans to roll out 5G in 2019, by July 2020 only Los Angeles, Phoenix, Houston, Dallas, and Atlanta are live with 5G on all four networks and most cities have only one, or none. While 5G is a "nice to have" within the current testing environment, it will be a necessity as AVs are implemented in earnest.

Data Privacy and Cybersecurity

AVs capture an enormous amount of data about vehicle operation, passengers and the surrounding environment. Several questions arise from the collection of the data.

AVs and Data Privacy Questions

1. Who owns the information generated by AVs?
2. How can and should this information be used?
3. Can this information be transmitted and stored in a secure way?
4. Should users have to opt in or are AV operators able to legally and ethically harvest data without user consent?

An associated technology issue is cybersecurity. AVs are vulnerable to hacking. Given the potential size of AV operators' fleets, ransom demands after a successful hack could emerge as a significant concern. There is also a risk that hijacked AVs could be used as terrorist weapon.

Moral Decision-Making

Today we rely on a vehicle's driver to make moral decisions about safety while driving. For instance, if a child runs into the road and the only way to avoid the child is to swerve and hit a wall, the vehicle driver makes that decision—and is responsible for the consequences. With AVs, the software is responsible for decision-making when faced with this moral dilemma. Will passengers be comfortable "delegating" this decision to AV operators' software programmers?

MIT is collecting data on human perspectives on moral decisions and applying it to machine intelligence—such as self-driving cars. MIT's Moral Machine project website asks visitors to react to scenarios such as one in which a self-driving car will either hit a barrier wall, killing all five passengers, or swerve to avoid the barrier, killing five pedestrians. The website asks, "What should the self-driving car do?"

The MIT project synthesized website visitor responses—40 million decisions from residents of more than 200 countries—to produce aggregate information on consensus morality.[24] While the project identified much commonality among respondents' views—for instance, most preferred to save humans over animals and younger people over older people—there was a lack of consensus over other moral decisions, such as whether to prioritize pedestrian versus passenger lives.[25]

We cede control to human drivers when riding on a bus or when a family member is at the wheel, but will passengers be willing to cede control over these decisions to AV operators? It is unclear how AV operators will choose to make these decisions and what role passengers will expect to play. This will also likely lead to major changes in insurance, as the companies operating the AVs and/or writing the code behind their decision-making become liable for the results of the decisions the vehicles make and the actions they take.

Impact on Jobs

In the United States, more than 4 million Americans drive professionally for compensation. AVs are expected to significantly impact these jobs; if TNCs adopt AVs at scale, their driving workforce will no longer be needed. We have already seen significant negative impact on taxi drivers as a result of TNC growth. AVs would cause further job displacement, a concern for municipalities, especially given added uncertainty caused by the coronavirus pandemic.

24 Awad, Edmond, Sohan Dsouza, Richard Kim et al. "The Moral Machine experiment." Nature 563, 59–64, 2018, https://www.nature.com/articles/s41586-018-0637-6.

25 The Economist. "Whom should self-driving cars protect in an accident?" October 27, 2018, https://www.economist.com/science-and-technology/2018/10/27/whom-should-self-driving-cars-protect-in-an-accident. Accessed October 8, 2019.

On the positive side of the ledger, AVs offer a variety of economic opportunities for communities, ranging from the development and fabrication of AVs and software development to staffing local AV operating sites and building out 5G networks. How the positives and negatives net out will be a function of each city's intrinsic positioning for AVs and policies that are adopted by its government.

Consumer Trepidation

In early 2019, a study by the American Automobile Association (AAA) found that 71% of respondents to an annual survey on self-driving cars report being afraid to ride in a completely autonomous vehicle. Even fewer—only 19%—said they would be willing to allow a child or another family member to ride in an AV. In prior years, AAA had found more public acceptance for AVs, but press accounts of crashes and deaths during AV testing appears to be eroding public support.[26] Even so, 55% of respondents expect self-driving vehicles to become the norm by 2029. The challenge for AV operators is to build public trust and overcome current skepticism.

A 2019 AAA study found that 55% of respondents expect self-driving vehicles to become the norm by 2029.

The timing of AV deployment is currently uncertain, but when the industry is able to develop effective responses to these challenges, AVs will move from concept and testing to becoming part of the mobility ecosystem.

IV. AVS ARE COMING: THE NEED FOR PROACTIVITY

Policymakers, faced with many pressing current challenges regarding traffic safety, congestion, and sustainability, may wonder why they should give time and attention to future automated travel. We believe it is worth their while for two major reasons. Firstly, as we discuss below, the measures we advocate serve to address many existing transportation issues, while also preparing cities for the AV age. Secondly, while AV companies still have a number of hurdles to overcome, there are literally thousands of self-driving vehicles on the road across the country and around the world today, and some are coming very close to commercialization.

26 Eisenstein, Paul. "Three-quarters of Americans 'afraid' of fully autonomous vehicles." NBC News, March 14, 2019, https://www.nbcnews.com/business/autos/three-quarters-americans-afraid-fully-autonomous-vehicles-n983091. Accessed October 8, 2019.

In the early 2010s, a number of startups made bold claims around how soon we would be riding in automated cars. Their optimism was muted by technological challenges and especially the death of Elaine Herzberg in Arizona. This tragedy led to a period of self-reflection among many AV industry players, which has resulted in better testing protocols.

We will discuss a number of these accomplishments below, but perhaps the most noteworthy recent development was a simple email sent by Waymo in October 2019. Entitled "Completely driverless Waymo cars are on the way,"[27] the message informed customers of its ride-hailing service, Waymo One (currently operating only in the Phoenix East Valley region), that their next trip might not have a human safety driver behind the wheel, and as of October 2020, 5–10% of Waymo's rides are completely driverless. Certainly, there are many parameters around these Phoenix-area trips. The point is that policymakers should not see AVs as relegated to some far-off future: there are commercial ride-hailing trips underway, today, in self-driving cars.

Moreover, municipal governments have a key role to play in how AV deployment takes place. AVs have the potential for improving safety, mitigating congestion, stimulating urban vibrancy, and improving municipal finances; however, these enticing outcomes are not guaranteed. Companies have invested billions of dollars in AV development, and have their own expectations around how to maximize their use. While many stated company objectives align with urban policy goals, city officials should not assume companies will deploy their automated fleets in a manner that makes their communities more equitable, vibrant, sustainable, and safe. City officials should ensure AVs arrive in a manner that works for the people of their communities, rather than in a way that aligns with the objectives of their operators but may run counter to broader city objectives.

Policymakers should not see AVs as relegated to some far-off future: there are commercial ride-hailing trips underway, today, in self-driving cars.

One need only look to the arrival of TNCs or micromobility vehicles like scooters to understand the headaches that come when cities are unprepared for new technology, such as the scramble to regulate an industry that has already arrived and built a loyal customer base. As such, local governments should be taking immediate steps to understand the existing use cases of this technology, and preparing the policy

27 Korosec, Kirsten. "Waymo to customers: 'Completely driverless Waymo cars are on the way.'" Tech Crunch, October 9, 2019, https://techcrunch.com/2019/10/09/waymo-to-customers-completely-driverless-waymo-cars-are-on-the-way/. Accessed February 3, 2020.

structures and built environments of their communities for the arrival of these vehicles—an arrival that, relatively speaking, may not be all that far down the road. Before delving into what our research shows are the critical starting points for policymakers, we examine the applicable use cases that those policymakers may need to prepare for in their cities.

Existing Use Cases

Current and Near-Term AV Use Cases

- **Automated ride-hailing** (similar to today's TNCs)—picking riders up at a requested point and dropping them off directly at their destination
- **Automated ride-hailing with shared rides,** using algorithms to match riders going in similar directions into a combined trip for a lower price
- **Small fixed-route shuttles** to provide transit-type service in lower-demand contexts
- **Fully automated conventional transit vehicles,** such as buses and streetcars
- **Automated land-based delivery vehicles,** including the possibility of vehicles that run on the street, the sidewalk, or some combination of the two

Potential use cases—different ways users can interact with AV technology—are broad in their range. In general, our use cases may best be broken down into two categories: moving people and moving goods.

Moving People

Point-to-Point Services

From the operators' economic perspective, the most attractive use case will likely be similar to today's ride-hailing services. In this model, AVs would carry a single passenger (or passengers traveling as a group) from their origin directly to their destination for a pre-set rate. This model is familiar and comfortable to the consumer, as the service is already ubiquitous today and the network is relatively easy to manage. Further, potential operators would like to take advantage of the attractive economics of lower operating costs and the potential to earn additional revenue by selling their operating data. Your TNC operator could, for instance, sell your travel data to a fast food company so they could send you coupon notifications because it knows when you are going by one of their restaurants.

This use case would likely first emerge in a virtually defined geographic area (via what's known as *geo-fencing*), such as a city center. Since AVs improve the efficiency and reduce the uncertainty of their mapped routes by repeatedly traveling over those routes (while analyzing the movement of other vehicles, pedestrians, congestion times, etc.), operating within a restricted geographic area also serves to lower operating costs and improve safety. Waymo One is the leading example of this use case.

While still in the testing phase, their intention is to eventually cover the 600-square-mile Phoenix area with a fleet of hundreds of cars. Waymo launched its ride-hailing service in the Phoenix suburbs in 2017, first as a free testing program and, as of 2019, as a commercial service.[28] All Waymo One rides are in autonomous vehicles with a safety driver present and ready to take over if the AV is unable to safely operate in a given situation. At this time, the program is only available to a small group of Phoenix-area residents. Waymo is also partnering with Lyft to offer rides in the Phoenix area, using a small number of the same vehicles as deployed in Waymo One.

Aptiv has partnered with Lyft to provide AV ride-hailing services in Las Vegas and has provided at over 100,000 rides to date. Company officials have noted that this is the largest AV ride-hailing service in the world open to the general public. Mercedes and Bosch have also launched their Urban Automated Driving project, which is running a similar automated ride-hailing trial in San José.[29]

Passengers have generally been receptive to the experience of riding in an AV. However, in the wake of the pedestrian fatality in Arizona, there has also been some public unhappiness with AVs in Arizona, including vandalism on Waymo's vehicles. Nevertheless, more services are likely to launch in the coming months, including those by Waymo, AutoX, Zoox, and Pony.ai. Each of these firms have applied for and received permits from California to launch pilot AV ride-hailing services.[30]

Most current deployments of AVs use a staged approach, where a company will develop high-quality maps of a specific neighborhood, test in this area, then expand to the next. In Boston, for example, Aptiv began testing in the South Boston waterfront and has since grown to mapping larger portions of South Boston. It is important for policymakers to ensure that as companies enlarge their geographic footprint, they do not ignore lower-income communities. When issuing permits, city officials should understand the timeline for future deployment, so a company does not expand into only high-income areas, then cease mapping so as to avoid having to provide service to other parts of the city. Companies should also not be permitted to prioritize pick-ups in some communities or inflate wait times to discourage use among certain residents.

28 Krafcik, John. "Waymo One: The next step on our self-driving journey." Medium, December 5, 2018, https://medium.com/waymo/waymo-one-the-next-step-on-our-self-driving-journey-6d0c075b0e9b. Accessed February 3, 2020.

29 Davies, Chris. "Mercedes launches autonomous cars in first US ride-hailing pilot." SlashGear, December 9, 2019, https://www.slashgear.com/mercedes-benz-daimler-bosch-us-ride-hailing-autonomous-car-pilot-launches-09602611/. Accessed February 3, 2020.

30 Hawkins, Andrew J. "Waymo gets green light in California to pick up passengers in self-driving cars." The Verge, July 3, 2019, https://www.theverge.com/2019/7/3/20680938/waymo-self-driving-cars-passengers-permit-california-pick-up. Accessed February 3, 2020.

We do not assume companies *will* employ these strategies, but there are some examples of technology companies that have limited their services based on neighborhood. Transportation is an essential service, and it is a priority for officials to proactively ensure everyone enjoys access to the technology of the future. Cities or states not should simply rely on the goodwill of companies; they should have clear policies outlining performance expectations to operate in their jurisdictions. This will also mean contemplating how to serve those without smartphones or credit cards. We offer additional thoughts on equity throughout our policy recommendations, but this is an overarching lens through which you need to view all AV policy as this technology matures.

Shared Rides

The second use case is similar to the first but would focus on shared rides instead of serving only one origin and destination per trip. TNCs followed this evolution in their own development, starting with single rides before adding a shared-ride trip-matching capability. A shared-ride system would match two or more riders traveling in a similar direction into one combined trip, with a lower price to compensate for the potential increase in (and uncertainty of) travel time. If the shared-ride use case is the dominant one, it could have positive effects in terms of lowering congestion and emissions, particularly compared to the single-rider use case.

Shared rides in an autonomous context do present new challenges: passenger safety and security will need to be addressed, as passengers may be uncomfortable riding in a shared AV with no "norm setter" (i.e., driver) to provide reassurance or to regulate passenger behavior. To overcome these obstacles, some companies have discussed wholesale shifts in vehicle design, for instance to allow for partitions between passengers. At least in the early stages, however, this challenge, as well as the broader economic attractiveness of single-rider trips, makes it more likely that single-rider AV trips will predominate in the absence of public policy intervention.

Fixed-Route Services

AVs could also provide service along pre-set routes, similar to shuttle and bus services that operate today. In particular, low-speed shuttle services, similar to the Little Roady pilot project, are likely to be another one of the early use cases. In this deployment model, AVs would run on fixed routes in relatively small vehicles. This would reduce the complexity of operations, since running on a fixed route would reduce the scope of detailed mapping required and minimize the number of choices that the AV operating system needs to evaluate. Such services could provide so-called first- and

last-mile connections to other transportation hubs. For example, Little Roady's route begins at Providence station, the city's Amtrak and commuter rail station, allowing passengers to transition from train to bus to complete their journey.

CITIES WITH AV SHUTTLE SERVICE

Columbus, OH
Denver, CO
Detroit, MI
Grand Rapids, MI
New York, NY
Providence, RI

Beyond Providence, May Mobility has launched shuttle services in three cities: Detroit and Grand Rapids, Michigan, and Columbus, Ohio. These shuttles are operating in relatively dense, urbanized settings, with regularly scheduled headways and a fixed route. Denver's regional transit agency, RTD, is partnering with EasyMile to operate an AV shuttle between the Denver Airport and a nearby suburb. This represents the first time a U.S. transit agency has used AVs in lieu of a regularly scheduled bus route. Optimus Ride recently launched a shuttle service in the Brooklyn Navy Yard in New York City. The shuttle is designed as a "last-mile" connection for commuters from a ferry terminal to the thousands of jobs located within the complex.

AV shuttles could also provide transit-type services in other contexts, such as retirement communities and college campuses, where shuttle operations are already common today. Eventually, AVs will likely be integrated into the operations of mass transit more broadly, such as through automated bus systems in urban cores. Automated technology already exists on some urban rail systems, which benefit from a completely separated right-of-way. The introduction of AV technology could allow the benefits observed through automated trains, such as precision stopping and the ability to redeploy vehicle drivers to more customer-oriented roles, to be extended to other mass transit vehicles. However, any large-scale transit deployment is likely to come after the successful deployment of smaller vehicles in less difficult contexts.

Moving Goods

Local officials will also need to contend with heightened commercial interest in automated land-based delivery vehicles. The growth of home delivery—of everything from meals to mattresses—has caused the commercial sector to search for more efficient and cost-effective ways to deliver their goods. This impact will only become more prominent in the years to come, as internet-based deliveries skyrocket; in 2009, there was one daily Internet delivery for every 25 Americans, while today that number has jumped to one for every eight, and experts believe it will double once more by 2023.[31]

31 Sisson, Patrick. "How your online shopping snarls traffic on city streets." Curbed, January 10, 2019, https://www.curbed.com/2019/1/10/18177399/amazon-delivery-traffic-online-shopping-e-commerce. Accessed February 3, 2020.

In New York City alone, average daily deliveries tripled between 2009 and 2017, to 1.1 million.[32] It is thus not surprising that researchers at the Texas A&M University Transportation Institute found trucks cause 28 percent of all U.S. congestion, despite making up just seven percent of the nation's total vehicle fleet.[33]

Land-based AV delivery might be an easier early use case as the risk of personal injury to riders is eliminated. John Krafcik, Waymo's CEO, has stated that "driverless delivery likely has a better chance of catching on early versus passenger transportation."[34] Cities might therefore find themselves contending with these services well before they have to address automated ride-hailing in their communities.

The primary city use case for land-based delivery AVs in freight is replacing human-operated vehicles. Self-driving delivery company Udelv has already partnered with Draeger's Market in San Mateo, California, Esperanza stores in Oklahoma City, and Walmart in Surprise, Arizona.[35] As of late 2019, the company had completed around 6,000 automated deliveries (with a safety driver at the helm).[36] While Udelv and Argo's vehicles look similar to vans on the road today, Nuro has designed land-based delivery vehicles that do away with seating to offer only space for parcels. Nuro launched its first trial with Kroger in Scottsdale, Arizona, and in 2019 announced a partnership with Domino's in Houston.[37] The company uses Toyota Priuses to map the communities in which it will operate, then driverless vehicles employ the maps to run in these areas.

Commercial Delivery

Commercial drop-offs present an even more promising use case. Unlike food or package delivery routes to private homes, which require a different route every day and can have up to 150 stops, commercial services—such as running stock to a restaurant or store, or packages to an office tower—only have about ten to 15 consistent drop-offs. It is possible the same vehicle could operate on the same route to the same dozen

32 Haag, Matthew and Winnie Hu. "1.5 Million Packages a Day: The Internet Brings Chaos to N.Y. Streets." The New York Times, October 27, 2019, https://www.nytimes.com/2019/10/27/nyregion/nyc-amazon-delivery.html. Accessed February 3, 2020.

33 Sisson, "How your online shopping snarls traffic on city streets."

34 Laury, Daniel. "Autonomous Delivery: The Thesis." Medium, November 12, 2019, https://medium.com/@udelv/autonomous-delivery-the-case-for-fixed-repeatable-autonomous-delivery-routes-19044c29177. Accessed February 3, 2020.

35 Hawkins, Andrew J. "Robot delivery startup Udelv partners with Walmart and Baidu." The Verge, January 8, 2019, https://www.theverge.com/2019/1/8/18173776/udelv-self-driving-delivery-walmart-baidu-ces-2019. Accessed February 3, 2020.

36 Laury, "Autonomous Delivery: The Thesis."

37 Murphy, Mike. "Dominos is about to start delivering pizzas with autonomous robots." Quartz, June 17, 2019, https://qz.com/1644476/nuro-will-deliver-dominos-pizza-with-its-robots-in-houston/. Accessed February 3, 2020.

commercial customers every day. This would make it easier to map the route and address obstacles, remove the risk associated with carrying human beings, and even eliminate the difficulty of having someone pick up the delivery from the curb. These advantages make it one of the most achievable early deployments of AV technology, and one that Udelv has already begun to explore.

"Driverless delivery likely has a better chance of catching on early versus passenger transportation."
—Waymo CEO John Krafcik

Home Delivery

For home delivery, land-based AV delivery operators still have to tackle the "last thirty feet" problem. How will a package, or a pizza, get from the vehicle to the customer's door? Would delivery vehicles still need to be staffed as a consequence?

This issue remains unsolved. However, there are several different models that could help to address the problems of automated freight delivery. Some AV companies are now testing sidewalk-based delivery robots that could bring goods closer to the front door. Others are developing mobile kiosks that would park nearby, requiring customers to come pick up their order. Some grocery stores have even proposed mobile storefronts, where customers would be able to shop for fresh produce and more right at the curb. It is likely that some combination of these will emerge, but which model predominates will vary based on the specifics of the local built environment.

The most developed tests are those that focus on small land-based delivery robots that can traverse sidewalks and curbs. FedEx reports more than 60 percent of its retail delivery customers live within three miles of the stores from which they have ordered, which is a very manageable range for a small, wheeled robot.[38] The delivery company has launched its SameDay bot, traveling at ten miles per hour while couriering packages between the company's offices in Memphis. With multiple sets of wheels, it can climb steps and curbs to reach even difficult destinations.[39] Using its own six-wheeled robot, Europe's Starship Technologies has completed over 25,000 deliveries worldwide, with trials in nine U.S. states. Many of these trials have been food deliveries on college campuses, such as the University of Pittsburgh and George Mason University, where the services have been wildly popular. Deliveries require the

38 Vincent, James. "FedEx unveils autonomous delivery robot." The Verge, February 27, 2019, https://www.theverge.com/2019/2/27/18242834/delivery-robot-fedex-sameday-bot-autonomous-trials. Accessed February 3, 2020.

39 Ibid.

recipient to enter a passcode in order to open the robot and receive the delivery. Other companies, including Amazon Scout and Postmates' Serve, have launched similar projects designed to bring their packages as close as possible to a customer's door.

Cities are already contending with the issue of dockless bicycles and scooters on their sidewalks. Are they ready for the challenge of land-based delivery robots rolling through traffic, running beside pedestrians, or using bike lanes? These vehicles raise questions around speed, right of way, congestion, and privacy, and very few cities have even begun to design policy for these bots. While it could be advantageous for companies to "right-size" their delivery fleets instead of having large trucks moving through dense communities, an army of small bots interacting with humans may not be ideal either. Cities will therefore want to pay particular attention to developments in the delivery sector. In preparation for these and other such developments, we turn now to our recommended policy actions for cities.

COVID-19 Commentary

We see three potential impacts of COVID-19 on the initial AV use cases. First, the virus has caused a significant increase in online shopping and food deliveries. The resulting delivery vehicle congestion is a serious concern especially as the economy and traffic return from the shutdown. Given the continual progression in delivery technology, land-based delivery vehicles could well be the first prominent use case of automated technology. We do not currently see any evidence to suggest concerns regarding COVID-19 have significantly altered the development trajectory of automated freight delivery.

Second, facing a world shaken up by the coronavirus, where we are encouraged to social distance and avoid places that other people might have contaminated, it may be easy to be skeptical of some of the scenarios we describe above. Certainly, we are under no illusions the virus may deter some people from traveling in shared spaces such as a TNC or an automated transit vehicle. That said, AVs may also offer a number of benefits in our new world even for passenger service. Even without a risk of infection, a number of transportation experts pointed out that AVs might need separated pods for shared rides so each passenger can enjoy better security. It would not be a stretch to think that TNCs could incorporate a system that disinfects each pod after a customer gets out, so it is clean and ready for the next rider. Moreover, while today travelers might be concerned about getting into a car (whether a TNC or a taxi) with a human driver who has spent the day being exposed to all previous passengers, they may be more comfortable hailing a ride with no driver present making AV-TNCs more attractive than conventional ones.

Third, cities across the world face a major challenge of maintaining safety and ridership on fixed-route public transit. Thankfully for those concerned about the public transit fallout of the pandemic, early evidence shows public transit was not a major cause of viral spread. Studies from Paris and Austria, for example, found no evidence of infection clusters on transit vehicles, while cities that have reopened their transit systems "have not seen subsequent infection spikes."[40] A bus—even a busy one—where riders silently browse their phones with their mouths closed may be a much less risky place to be than a restaurant, bar, or concert venue.

Transit agencies, however, will still need to implement a number of policies to protect public health (such as ensuring frequent cleaning and perhaps mandating mask usage), and AVs can be helpful in limiting the risk of spread. First, one strategy for reducing overcrowding on buses and trains is to increase frequency. Employee costs are a major limiting factor in putting more vehicles on the roads or rails, so using automated vehicles will reduce the cost of providing more buses, in order to reduce the number of travelers per vehicle. Additionally, COVID-19 has taken a significant toll on transit workers. As of mid-April, 100 American transit workers had lost their lives due to the virus,[41] and across the Atlantic, 29 bus drivers died from COVID-19 in London alone.[42] As drivers spend a long time on a bus and in interaction with more people, they are more exposed to the virus. Switching to AVs will mean buses can still run without putting drivers at risk.

It is still too soon to know exactly what impact COVID-19 will have on the AV industry, but even if it delays deployment by months or years, we remain confident that addressing the five policy actions outlined below will remain relevant for cities looking to encourage sustainable, efficient, equitable transportation networks in the years to come.

40 Sadik-Khan, Janette and Seth Solomon. "Fear of Public Transit Got Ahead of the Evidence." The Atlantic, June 14, 2020, https://www.theatlantic.com/ideas/archive/2020/06/fear-transit-bad-cities/612979/. Accessed January 23.

41 Beckett, Lois. "Revealed: nearly 100 US transit workers have died of Covid-19 amid lack of basic protections." The Guardian, April 20, 2020, https://www.theguardian.com/world/2020/apr/20/us-bus-drivers-lack-life-saving-basic-protections-transit-worker-deaths-coronavirus. Accessed January 23, 2020.

42 "Coronavirus: London bus driver deaths to be reviewed." BBC News, May 21, 2020, https://www.bbc.com/news/uk-england-london-52752022. Accessed January 23, 2020.

V. FIVE RECOMMENDED POLICY ACTIONS FOR CITIES

Given the current AV landscape, how should you prepare your city for the arrival of AVs? Using insights we derived from our series of AV policy scrums and academic research, we conclude that there are five policy action areas cities can take on now to position themselves for successful adaptation to the AV environment.

Policy Action 1: Foster Mobility as a Service (MaaS)

The Concept

Over the last few years, cities across the country have published growth plans—such as *Boston 2030*, *Philadelphia 2035*, or Louisville's *Plan 2040*—meant to provide a roadmap for development in the first half of the 21st century. These ambitious plans often adopt a holistic perspective to urban growth, recognizing that transportation is a critical component to providing citizens with access to education, healthcare, affordable housing and other resources. Moreover, city officials now recognize that communities built on car-centric transportation networks are not only environmentally and financially unsustainable, but also limit opportunities to those who cannot afford or otherwise choose not to own a car.

In the last decade, transportation mode choices for urban travelers have multiplied. The traditional options—private cars, bus and rail transit, taxis, personal bikes, and walking—have been joined by TNCs, shared bikes, and shared scooters, modes that have grown from zero to hundreds of millions of trips per year in a matter of only a few years.

This expanded set of options gives travelers more choices when planning their journeys, including some that might be better than what existed before—cheaper, quicker, more convenient, and even more fun. However, the ever-growing number of available modes can make selecting the "best" option a daunting task, particularly when payment and trip planning requires interacting with several different services independently: one transit card for the bus, another for the subway, a key fob to unlock a shared bike, and a smartphone app to call a TNC.

A traveler's preferred travel modes are also rarely static. Cycling in colder-weather climates is a more attractive option on a beautiful day in May than a blustery one in February. Transit might be a more convenient way to get *to* the store than returning, when laden with a week's worth of groceries. Traveling alone versus traveling with young children may significantly influence mobility decisions. More broadly, travelers are searching for a way to create a dynamic travel plan responsive to their evolving needs.

Mobility as a Service (MaaS) is a nascent concept that would combine trip planning, booking, and payment within a single platform. The likeliest implementation, although not the only possible one, would be through a smartphone application. After downloading such an app, a user would enter their journey origin and destination. The MaaS platform would then provide information on all the best available transportation options, most significantly time, reliability and cost. This would also include journeys that combine multiple modes, such as a subway ride connecting to a shared bike rental for the "last mile," or a TNC connecting to a commuter rail station. The MaaS platform would also provide the ability to pay for any multi-modal trip in a single transaction, or at the very least would provide a unified payment process, such as tapping the same smartphone for payment at each leg of the journey. Alternatively, some early MaaS proposals have dispensed with payments per trip altogether, moving to a subscription-based approach where users pay a monthly fee in exchange for a set of mobility options, such as unlimited transit and bikeshare plus ten TNC rides.

MaaS proponents promise to make planning and completing multimodal journeys simple, fast, reliable and convenient. Indeed, they argue these systems will make multimodal transportation so user-friendly that travelers may be persuaded to make less use of private vehicles and more use of alternative transportation modes. As cities contemplate the potential of MaaS, they should view it as not only a transportation tool, but one that accomplishes broader planning objectives, linking more people to as many resources as possible.

MAAS CASE STUDY: WHIM

- Early multi-modal transportation app
- Offers one-app trip payments, real-time trip planning
- Launched by MaaS Global in Helsinki, December 2017
- 70,000 registered users by 2019 (10,000 use regularly)
- Promoted as "one app for all your transport needs"
- Pay-as-you-go and subscription models available
- Expanding to Antwerp, Belgium, Birmingham (UK), Miami, Vancouver, and Chicago

None of the components of a MaaS system are particularly novel. Consumers have become accustomed to planning trips using mobile platforms like Google Maps. Transit agencies across the world have embraced real-time data-sharing using the General Transit Feed Specification (GTFS) data standard, which allow platforms like Google Maps to provide directions not only for driving and walking but also transit. In the United States, apps like CityMapper and Transit allow users to plan multi-modal journeys with real-time arrival, departure, and availability data. Furthermore, TNCs have clearly demonstrated the merits of app-based trip requests and payments. Lyft, for example, acquired other mobility companies like Motivate and have begun

to incorporate the ability to reserve, unlock, and pay for vehicles like e-bikes and e-scooters into their applications.

MaaS platform innovation will come primarily from the combination of all these features, rather than the development of a host of new features—and that combination has the potential to be tremendously powerful. Travelers would have better information on ways to reach their destinations, more available options to get there, and an easier way to plan and pay for trips. Transportation operators could increase the visibility and attractiveness of their services by combining their various modes into journeys that might not have made sense alone. And public officials could tweak the structure of any MaaS platform to better align with local mobility goals and priorities, such as shifting travelers away from single-occupancy vehicles, making transit more attractive, and ensuring equitable access to transportation services.

A MaaS system would not require the development of AVs. It could—and in some places, does—exist even today, with current technology. But the arrival of AVs will likely change the economics of TNC-type trips, making them relatively more attractive. This would be true not only for individual rides but also for trips linked into a broader multimodal trip platform like a MaaS system. This might attract travelers who currently rely on their own personal vehicles to shift to a more multimodal MaaS-type system, but could also incentivize travelers who currently rely predominantly on transit to shift some of their trips toward this cheaper alternative mode. The pricing, structure, and modal inclusion in a MaaS deployment could incentivize travelers to choose shared AV rides, or transit, or single-occupancy vehicles. Which of these outcomes ultimately occurs will depend on the specific implementation of a MaaS system. Moreover, cities can influence passenger choice through financial incentives to choose public transit or shared rides over single-occupant vehicles.

The Landscape

EXISTING MAAS APPS

CityMapper
Lyft
Moovel
Transit
Uber
Whim

MaaS Global was the first to launch a MaaS-type system, known as Whim. Launched in December 2017 in Helsinki, Finland, Whim still appears to be the most developed MaaS deployment, with 70,000 registered users in 2019, of which 10,000 regularly used the app.[43] MaaS Global promoted Whim as the "one app for all your transport needs," and "the carefree way to travel."[44] Users in Helsinki can choose between a subscription-based model and a pay-as-you-go service. For a monthly fee, subscribers get access to unlimited transit, bikeshare, and depending on the subscription tier, either discounted or unlimited access to taxis and rental cars. Payment and ticketing are handled through the app. Similarly, users who select pay-as-you-go options can use the app to plan, book, and pay for trips across transit, taxi, and rental car services.

The service has since expanded to several other European cities, including Antwerp, Belgium and Birmingham, United Kingdom, and the company expects to launch in Miami, Vancouver, and Chicago in the near future.[45] MaaS Global's CEO noted that once launched, it would take three years for Whim to achieve profitability within a city, provided that three to five percent of the eligible population use the app.[46]

While Whim was an early mover, perhaps the most ambitious companies in the MaaS space are TNCs Uber and Lyft. Both companies have claimed that their overarching goal is to defeat the popularity of the private car, and in that vein, they want to make it much easier for their customers to find the alternative mode that best suits them. Travelers can now not only choose a car to pick them up, but also unlock bike-share and e-scooters owned by Uber and Lyft through their apps. Touting the success of the new initiative, Lyft president John Zimmer noted one in eight Lyft riders chose a bike or scooter in the summer after the app redesign, in the cities where these services

43 Reid, Carlton. "Netflix-Of-Transportation App Reduces Car Use and Boosts Bike and Bus Use, Finds MaaS Data Crunch." Forbes, March 28, 2019, https://www.forbes.com/sites/carltonreid/2019/03/28/netflix-of-transportation-app-reduces-car-use-and-boosts-bike-and-bus-use-finds-maas-data-crunch/?sh=36464e474923. Accessed September 17, 2019.

44 Shieber, Jonathan. "Whim, the all-in-one mobility app for ridesharing, public transit and rentals is coming to the US." Tech Crunch, January 24, 2019, https://techcrunch.com/2019/01/24/whim-the-all-in-one-mobility-app-for-ride-sharing-public-transit-and-rentals-is-coming-to-the-us/. Accessed September 17, 2019.

45 Pohjanpalo, Kati. "Mitsubishi Invests in an App That Wants to Replace Cars." Bloomberg, September 4, 2019, https://www.bloomberg.com/news/articles/2019-09-04/mitsubishi-invests-in-mobile-app-whim-that-wants-to-replace-cars. Accessed February 3, 2020.

46 Reid, "Netflix-Of-Transportation App Reduces Car Use and Boosts Bike and Bus Use, Finds MaaS Data Crunch."

were offered. And North America's largest bikeshare system, New York's Citi Bike, hit a 100,000 daily ridership record in September 2020.[47]

Going further, both apps now allow riders to assess real-time transit information in the app directly. By employing transit agency route data and predictive software, Lyft's app shows where and when transit vehicles will arrive, and Lyft says 80 percent of U.S. transit routes, along with their fares, are available in the app.[48] In Denver, Uber allows customers to pay their transit fare through the smartphone application.[49] By integrating transit, bikes, e-scooters, and cars, customers can see time and cost comparisons of the different services, helping them choose the service that works best for them.

A number of other organizations have begun to roll out similar services. Transit offers its customers the ability to book and pay for bike-share within its app. CityMapper offers its London customers a combined pass for unlimited transit and bike-share usage, with an integrated fare card that allows the seamless use of both. Moovel offers integrated payment options through its app for multimodal journeys in Stuttgart and several other German cities.

Seeing the power of making multi-modal travel more convenient, some municipalities and transit agencies are working on their own MaaS platforms. In Maryland, transit riders can search, book, and pay for their subway, light rail, and commuter train fares on a Moovel-operated application known as CharmPass. The objective is to make it more convenient for commuters in the Baltimore and Washington regions to transfer between services. As the service runs on a smartphone, it is also more flexible than traditional ticketing systems; for example, users can purchase a weekly or monthly pass based on a specific start date, rather than on a fixed calendar.[50]

Municipalities are also developing their own platforms. In May 2019, Louisville, Kentucky's transit authority became the first U.S. transit agency to release a nearly-complete MaaS platform. Louisville's app integrates transit, ride-hailing, bike-share and e-scooters to encourage multimodal trips. For now, the app only allows

47 Dwyer, Matthew et al. "Shifting Gears: As Citi Bike Ridership Spikes, Share of Women Users Increases." SamSchwartz.com, October 12, 2020, https://www.samschwartz.com/staff-reflections/2020/10/7/shifting-gears-citi-bike-demographics-change-with-ridership-increases. Accessed February 23 2021.

48 Ibid.

49 Pyzyk, Katie. "There's an app for that: Transit agencies tackle MaaS platform development." Smart Cities Dive. June 26, 2019, https://www.smartcitiesdive.com/news/theres-an-app-for-that-transit-agencies-tackle-MaaS-platform-development/557234/. Accessed September 17, 2019.

50 Moovel. "Moovel and MDOT MTA Power First Mobile Ticketing App for Baltimore Region." September 28, 2018, https://www.moovelus.com/moovel-and-mdot-mta-power-first-mobile-ticketing-app-for-baltimore-region/. Accessed February 3, 2020.

for trip planning, but the agency intends to eventually accept and process payments.[51] Other municipalities have explored providing data to and contracting directly with the private sector to deliver these services, with developers taking a small percentage fee from each ride.

Louisville, KY has developed its own app that integrates transit, ride-hailing, bike-share and e-scooters to encourage multi-modal trips.

COVID-19 Commentary

As citizens worry about crowded places, a MaaS system can help spread travel both temporally and geographically. MaaS platforms of the future might not just highlight mode, travel time, and price, but also person-to-person congestion on a bike path, bus, or (in some places like Manhattan or Central London) a busy sidewalk. When a traveler enters their destination, the platform could suggest a mode, route, or alternate time that would be less crowded. We understand many people will not be able to take a private car for various reasons (and for a host of reasons we should be encouraging less automobile travel, not more), so giving citizens information as to how they can travel safely will be a big benefit of a robust MaaS platform. While this platform can exist without AVs, these new vehicles can make a multi-modal lifestyle more affordable and reliable

The combination of MaaS and COVID-10 could also spur the use of active mobility. Studies show the most effective time to alter commuters' travel habits is during a period of change such as when they move to a new job. The pandemic has been a period of change for Americans, and already urbanists are keen to capitalize on new trends. Bicycle sales have risen during the pandemic. This provides an opportunity for municipal governments to implement active transportation corridors, which might to encourage longer-term shifts in how citizens get around. Adding a strong MaaS system onto physical infrastructure can nudge travelers away from cars and on to bikes and scooters by showing them convenient bike (and pedestrian) corridors. AVs will assist with the transition, as people will be confident that they can find a ride later, should a rainstorm arrive unexpectedly

Getting Started

As Whim's early successes show, MaaS deployments will not require the arrival of AVs. Cities can, and we believe should, pave the way for MaaS-type services to arrive even

51 Pyzyk, Katie. "There's an app for that: Transit agencies tackle MaaS platform development."

now. However, the arrival of AVs will likely make MaaS service offerings even more attractive, particularly if the economics of TNC-style AV fleets allow transportation service providers to significantly lower prices. This could increase mobility options, but it could also lead customers to substitute ride-hailing for trips currently made on transit.

Considering these opportunities and concerns, there are a number of actions that public officials can take today, both to allow for the development of MaaS and to prepare for the responsible integration of AVs into a MaaS deployment.

Step 1: Build or Foster Data-Sharing and Interoperability Requirements

A successful MaaS system relies on data-sharing and interoperability among different transportation providers. For example, Whim is able to offer one-app payments and a real-time trip planning experience for transit, taxis, bike-share, and rental cars only because these operators either make their data publicly available or because MaaS Global has secured agreements with operators. Such agreements are not guaranteed, however. In recent months, it has emerged that Lyft is no longer allowing the Transit app to provide in-app bookings of New York's Citi Bike (which is operated by Lyft's subsidiary, Motivate), an exclusion that could be a sign of broader actions and exclusions to come. To ensure that MaaS systems can emerge, public officials could require data-sharing and broader interoperability, including payments and bookings, as a condition of operating in a city or region. Showing potential riders travel information in a third-party app similar to many transit agencies' trip planner platforms will literally put the bus on the map for prospective riders. Especially in areas where transit is not as prevalent, this can show customers where transit trips are more convenient and cost-effective, with a goal of increased ridership. Similarly, for city-run bikeshares, providing information on station locations and—as much as possible—real-time availability reminds citizens of this option and makes it easier for them to choose a bike. Municipalities can prepare for interoperability now by making sure their own data is ready for a partner MaaS operator. (See Policy Action 4 for a more extended discussion of data-sharing).

Step 2: Improve Coordination of Existing Public Transportation Services

While many of the modes that MaaS promises to integrate are operated by private firms, many others, such as buses, urban rail, commuter rail, and more, are offered by public sector organizations. In many U.S. cities and regions, these services are not coordinated, requiring different fare cards, payment schedules, trip planning software, etc. For example, in the San Francisco Bay Area, there are 27 different agencies that provide transit services, with inconsistent fare structures and confusing transfers yielding a system that often operates in silos, rather than as one regional whole. The Bay Area is

not alone. From Chicago to New York to Los Angeles, public transportation services are often provided by a variety of different agencies, leaving riders unable to find (or afford) the trip that might be best for them. Thus, while a MaaS system would offer significant benefits to consumers, public sector transportation providers can start realizing some of those gains by coordinating their own offerings. Doing so would also pave the way for private providers to participate in any larger regional coordination.

Step 3: Ensure MaaS Aligns with Regional Mobility Goals

A common concern regarding MaaS is that offering existing transit riders a taxi or TNC option might divert them from public transportation. If this effect were sufficiently pronounced, it might stymie efforts by public officials to improve mobility and reduce overall traffic congestion and pollution. We recommend that policymakers consider their broader regional mobility goals when setting up, or enabling, any MaaS system. If increasing transit ridership is a regional priority, then MaaS systems should be encouraged, or even regulated, to monitor overall mode-shares and tweak the basket of available mobility options if it appears too many users are diverting from transit. Or, if policymakers want to reduce greenhouse gas emissions due to transportation, MaaS systems could be designed accordingly, to prioritize low-carbon activities like biking and/or to disincentivize single-use car rides as opposed to shared rides. A MaaS system could incentivize both, or neither, of these outcomes, or any others. It will be incumbent on public officials to weigh the tradeoffs between consumer responsiveness and overall mobility goals.

Policymakers also need to consider the equity impacts of any MaaS system. These could be significantly positive, by providing better transportation access in places that might not previously have had it, but that is not guaranteed. For example, although we anticipate the majority of travelers will access a MaaS app through their smartphones, smartphone ownership is not universal. This could leave some travelers—particularly elderly and low-income residents—unable to participate, unless other options like a "Dial-a-ride" system are made available. As with AV-TNC operations more broadly, MaaS providers must offer equitable geographic coverage of service and pricing.

Public officials will also need to be aware of smaller equity impacts. For instance, poverty advocates have noted that 'monthly passes' are unfair to lower-income transit riders, because wealthier commuters can save money overall by having enough money to buy up front, whereas those who must pay on a ride-by-ride basis enjoy no similar discount. Positively, transit fare card technology (such as London's Oyster card and Boston's CharlieCard) has improved such that it is now possible to cap charges

once a person has paid the equivalent cost of a monthly pass. Any MaaS subscription model should have a similar pricing structure. Additionally, should your transit agency already offer a low-income transit pass, the MaaS platform will need to be able to accommodate that provision.

Quick Notes

The Concept

- Travelers are frustrated as they try to piece together travel options to find the lowest cost and/or fastest combination of travel modes.
- MaaS offers a way for travelers to plan and pay for their trips quickly, easily, flexibly and through a single vendor.
- MaaS will make multimodal transportation so user-friendly that some travelers will eschew private vehicles in favor of alternative transportation modes.
- MaaS builds on the success of the TNCs' ride-hailing software.
- MaaS apps can spur use of micro-mobility, which may help reduce vehicle congestion.

The Landscape

- The first MaaS system, Whim, launched in 2017; by 2019, it was available in four European cities.
- Other platforms are appearing in Germany and England.
- Some municipalities and U.S. transit agencies are developing their own MaaS platforms.
- Louisville, Kentucky is the first transit authority to launch MaaS in the U.S. integrating transit, ride-hailing, bike-share and e-scooters.

Getting Started

1. Build or foster data-sharing and interoperability requirements.
2. Improve coordination of existing public transportation services.
3. Ensure MaaS aligns with regional mobility goals.

Policy Action 2: Rethink Curb Design and Street Space Allocation

The Concept

For most of human history, streets were for everyone—pedestrians, cyclists, and those riding in horse and carriage. In the twentieth century, however, this changed. A growing number of pedestrian fatalities had U.S. automobile companies realize that to keep everyone safer (while not banning cars or cutting their permitted speed), they needed to separate people from vehicles. The raised curb was born. Over time, cities have installed some separated bus and bike lanes, but the principle of road use separation and automobiles' supremacy remains predominant. The lane beside the curb has become the "parking" lane, providing a space for car storage out of the way of traffic, with cities sometimes charging a nominal fee for this service.

Now, several pressures—including traffic congestion, increased demand for curb use and the proliferation of delivery vehicles and TNCs—are making city planners rethink the use of the curb. Indeed, TNCs are a particular pain point as they have led to increased traffic volume while simultaneously redefining the use of the curb as a pick-up and drop-off (PUDO) point for their services. Reacting to this change in travel demand, already cities have begun to institute designated TNC PUDO zones. As we consider a shift to AVs, cities can leverage the advantages of the technology to implement restrictions on where to stop and have confidence that AVs will respect the rules regarding assigned use of street space.

In addition, it is reasonable to expect that these vehicles, which will be constantly scanning their environment, could be programmed such that if one "sees" an opening in the curb that's available, it could alert other vehicles that may be searching for a drop-off point. Alternatively, as they are connected, they could all communicate with one another or with a central system, booking space along the curb in an orderly manner (a measure that would be especially useful for deliveries). The combination of these factors has planners rethinking and redesigning curb space usage. For instance, to discourage the use of personal cars in the urban core, cities are increasing the cost of parking, which serves as a financial disincentive for personal auto use. Some are also reducing the number of parking spaces, purposely making it more difficult for drivers to park to discourage them from driving into the city center.

AVs will accelerate the opportunity to rethink both how the curb is used and how our street space is allocated. As AVs require less space, automobile lanes can be removed or narrowed in favor of buses, bikes, and wider sidewalks, or even vibrant public spaces such as parklets and patios. In some areas, cities can prohibit cars outright or drastically reduce speed limits. This becomes easier with AVs, both because of the vehicles' requirement to obey these laws and because the expectation is AV riders will be able to occupy their time while in the car, meaning they will be less put out by slower travel speeds or a need to reroute around a dedicated bus- or pedestrian-only street. Moreover, if shared ride fleets become an initial use case, many existing parking spaces can be repurposed.

AVs also raise a challenge for municipalities. If the vision of AVs replacing private vehicles becomes a reality, then parking revenues associated with private cars will decline. In many cities, street parking is a multi-million-dollar revenue source. Initial ideas on replacing parking revenues center on shifting the idea of charging a fee to warehouse cars along the road to charging a pick-up/drop-off access fee for using the curb. Shifting the mindset of drivers, delivery services and local residents from inexpensive street parking to a repurposed curb, ranging from parklets to transit lanes to

paying for access, will take time. Acting now will likely help to match the arrival of AVs with these changed mindsets. Depending on its structure, curbside pricing could be incorporated into a broader congestion pricing plan rather than being a standalone entity (as is discussed further in Policy Action 5).

The Landscape

While pricing structures may vary from one municipality to another, the potential of AVs, coupled with an already shifting transportation demand landscape, provides cities with the opportunity to dramatically re-conceptualize the streetscape. We focus on two major areas for consideration: curbside management and street space allocation.

Curbside Management

In January 2018, the National Association of City Transportation Officials introduced a program, SharedStreets, to foster mapping of curbs. As reported in *Wired*: "SharedStreets may be exactly what both sides need. First, it will establish data standards for curbs, traffic speeds, and transit data, formats that can be shared between companies, agencies, even across cities. (No more, *My computer can't open that file*.) Now, there's a common language for curb data and maps, with agreed-upon locations for curb cuts and intersections."[52] Uber is sharing data to help populate the curb profiles and, nationwide, cities have begun to institute designated zones for pick-up and/or drop-off for TNCs.

Washington, D.C.'s Approach

Washington, D.C., offers some of the most ambitious examples of rethinking the curb to reflect new priorities and demand. In D.C.'s Dupont Circle, officials noticed major congestion on weekend nights as TNC drivers blocked the travel lane to pick up passengers. As such, the City undertook a trial, turning 45 parking spaces into a pick-up/drop-off zone from Thursday to Saturday after 10:00 p.m. These zones are conceptually similar to taxi stands, but also involve restrictions on pickups outside of the designated zones within a specified area of the city (D.C.'s zones allow both TNCs and commercial deliveries to use the zones).

Results were favorable, with local businesses reporting "a decrease in curb access conflicts, and anecdotal evidence points to reduced dwell times for ride service vehicles."[53] In August 2019, the government also removed parking in 12 zones to create designated commercial pick-up/drop-off spaces in busy areas; while such loading zones are not novel, what is new is the government's partnership with the startup curbFlow, which provides a smartphone application through which registered delivery drivers can reserve a spot in the zone. In November 2019, Columbus, Ohio, followed suit with its own similar test.

52 Marshall, Aarian. "Uber Makes Peace with Cities by Spilling Its Secrets." Wired, April 16, 2018, https://www.wired.com/story/uber-nacto-data-sharing/. Accessed February 3, 2020.

53 International Transport Forum. The Shared-Use City: Managing the Curb. OECD, 2018, p. 55, https://www.itf-oecd.org/sites/default/files/docs/shared-use-city-managing-curb_3.pdf. Accessed February 3, 2020.

Cities are also experimenting with one-time or event-specific restrictions on TNC pickups and drop-offs (such as for sports events or parades). These zones have generally been successful, leveraging the TNCs' technology platforms to direct both passengers and drivers to the designated zones. Fort Lauderdale, Florida, officials found that such zones were highly utilized and served to improve traffic flow and reduce delays.[54] As we'll see below, other cities have also begun to look more closely at curbside management.

Boston's Approach

Boston has ambitious goals to reduce the number of cars on its roads, reduce congestion and boost alternative transit modes—including AVs. Boston began investing in curb management in 2013 when it launched its Complete Streets initiative, a transportation policy and design approach to creating safe and convenient transportation and access for all visitors and residents across a myriad of travel options. Roads are designed for multimodal use and designers assume that streets are shared by all—and not dominated by cars. As such, Complete Streets incorporates features like street trees and green design elements, intelligent signals, "smart" meters, wayfinding and provisions for electric vehicle sharing.[55] This initial effort was bolstered by Boston's umbrella GoBoston 2030 long-term mobility plan. Its Vision and Action Plan, released in March 2017, noted Boston's aspirational goals are to, by 2030:

- Increase public transit use by 33 percent,
- Drive a fourfold increase in bicycle use, and
- Cut the number of single passenger vehicle rides in half.[56]

Boston also aspires to double the number of vehicles providing shared transportation by 2030.[57] Curb management has emerged as an important component for achieving these goals, as pilots are beginning to show.

In February 2018, Boston's mayor announced the results of a related program: Performance Parking. During the year-long pilot, the City raised parking meter rates to learn if doing so would reduce congestion, increase roadway safety and make finding an on-street parking spot easier for drivers. Raising meter rates was proven to open up more parking spaces for residents and business customers, and reduce congestion caused by illegal parking. The city's Back Bay neighborhood realized an 11 percent increase in available metered spaces and a 14 percent drop in double parking.[58]

54 City of Fort Lauderdale. Las Olas Boulevard Six-Month Safety Improvements Demonstration Project. July 2018, https://www.fortlauderdale.gov/home/showdocument?id=31059. Accessed October 8, 2019.

55 "Boston's complete streets," City of Boston, https://www.boston.gov/departments/transportation/boston-complete-streets, accessed September 18, 2019.

56 Go Boston 2030 Action Plan. "Goals and Targets." City of Boston, https://www.boston.gov/sites/default/files/document-file-03-2017/go_boston_2030_-_4_goals_and_targets_spreads.pdf. Accessed September 18, 2019.

57 Ibid.

58 Office of Mayor Martin J. Walsh. "Results of Performance Parking Pilot Announced." City of Boston, February 21, 2018, https://www.boston.gov/news/results-performance-parking-pilot-announced. Accessed September 18, 2019.

Seattle's Approach

Seattle has been transitioning from traditional curb parking to flex-zones since 2016. Curb usage is defined by type of street and local needs. Commercial streets are prioritizing freight delivery and passenger pick-up/drop-off over private car parking. Other uses are dedicated transit and bicycle lanes. For example, the flow along Rainier Avenue was changed from two lanes in each direction to one lane in each direction, one lane in the center dedicated to left turns and one lane dedicated to bus transit. While passenger vehicles incurred a one-minute increase in travel times, transit and bicycle travel times were reduced substantially.

Street Space Allocation

As cities begin to rethink the curb, a natural next step is to reconsider how they are allocating their street space. If AVs enable traffic flow efficiency gains, cities may be able to create an environment more accommodating to the needs of non-drivers without causing a significant impact on the travel times of those in vehicles. In fact, cities can move right now to take greater control over their street space allocation such that they will be more prepared to match the arrival of AVs with a new mindset.

New York City's Approach

In New York City, a pilot program is underway that turns curbside parking spots into neighborhood loading zones from 7:00 a.m. until 7:00 p.m. on weekdays, and transportation officials "have expanded loading zones in commercial areas in recent years, creating about 2,300 new zones around the city."[59] In addition, New York has completely banned cars from dozens of areas in order to prioritize a safe pedestrian experience.

Meanwhile, New York is also assembling a new freight master plan. While much of the discussion around pick-ups and drop-offs has recently focused on TNC activity, package delivery is having an equally profound effect on North American road networks. In Manhattan, surveys show that it can take delivery drivers up to an hour to find a parking space. As a result, they often end up double-parking, or need to park for long periods of time in certain areas. It can take up to an hour to complete deliveries to a single high-rise office or apartment tower, for instance, which means the truck is on the street all that time, taking up space.

Given these congestion concerns, and as research has shown that moving to nighttime delivery more broadly could cut freight-related emissions by almost two thirds,[60] New York has launched a program to shift more deliveries to the late-night hours, with 500 companies voluntarily committing to deliver their goods between 7:00 p.m. and 6:00 a.m.[61] It might not be reasonable to expect human drivers to deliver at all hours, but bots can.

COVID-19 Commentary

As Americans struggled to maintain six feet of separation from strangers, during the pandemic it suddenly became all too obvious how little space most cities allocate to pedestrians; many sidewalks are not even wide enough to accommodate two people passing with six feet between them. To make physical distancing possible and to provide transportation options for those who do not own a car but did not want to take transit, cities closed streets to vehicles in favor of active transportation corridors. With indoor restaurant dining restricted, officials also allowed restaurant operators to expand their patios to sidewalks and parking spaces. Some cities have closed whole streets or squares to cars to accommodate restaurateurs. Though not yet as common, it is also realistic to think cities may open up street space to retailers, so customers can browse their wares outside rather than in small shops. Lastly, many urban planners have pointed out that if health officials do not want people crowding in parks, cities need to provide a lot more ordinary open space where residents can be outside without bumping into one another—and that means turning abundant roadways over to public uses instead of reserving them all for cars.

Longer term the current changes to curb use can provide an effective bridging strategy for the arrival of AVs for passengers and/or delivery. Once citizens see the benefits of less auto-focused curb usage, it will be an easier step for policymakers to create more road space for dining and retail plazas or loading zones for delivery vehicles. Moreover, AVs will always obey the law, ensuring cars stay out of bus or bike lanes; do not accidentally turn into a street where they are prohibited; and in any areas where vehicles and pedestrians share street space, will stick to lower speed limits so walkers are safe.

Additionally, employing technology to match travelers with TNCs can potentially reduce congestion on the sidewalks. Rather than having many people congregate in one area (say, around the door of a restaurant), a system that manages AVs can direct them to spread out along a series of blocks, with riders having to walk a short distance.

Getting Started

Rethinking the roles of curb and street can enhance the urban environment now and prepare for the arrival of AVs tomorrow. The following are ways to tap the value of repurposing the curb today while also positioning this valuable asset for generating greater value in the future.

Step 1: Map the Curb

The starting point for enhancing the value of the curb is understanding how it is used today. Very few municipalities have an inventory of how curb space is allocated. How much is dedicated to parking, freight zones, transit and bicycle lanes, etc.? Fewer have

a quantitative understanding of how those intended spaces are utilized. When one thinks about the miles of curbs and the multitude of uses over time, it is not surprising that curb inventories are rare. Given the importance of understanding curb usage, a number of organizations are enabling mapping the curb. Shared Streets is partnering with cities to create an open data standard for the curb. Several start-ups are offering mapping tools that track the locations of curb cuts, fire hydrants, bus stops, parking meter and other curb infrastructure and usage. The maps can be enhanced with data from AVs captured as they operate and "map" the environment.

Step 2: Establish a Prioritization Framework

Repurposing the curb is controversial. Constituents are used to parking in front of their residences, finding parking close to retail establishments, and having door-to-door TNC service. Commercial establishments want parking for their customers and access for deliveries. Municipal governments count on parking revenues. Repurposing away from traditional uses will likely be met with opposition. Establishing a prioritization framework and a supporting rationale will provide a clear structure for decision-making and hopefully reduce opposition to the change. The framework should support the municipality's long-term vision and prioritize the gamut of curb-use alternatives, from transit and bicycles to parklets and traditional parking. Priority ranking should reflect local geography and needs.

Equity is a critical consideration when establishing the framework and thinking about where you would prohibit cars. Many cities are closing streets or limiting parking on high streets or in more dense urban areas. This makes sense from a congestion and efficiency perspective, but these areas are also often where lower-income residents live—whereas many higher-income people live in less-congested suburbs. It is important when adding bike lanes or limiting parking that you address any impacts on citizens who might struggle to, say, bring home their groceries if there is no place to park. Additionally, limiting traffic and/or parking on high streets may lead to pass-through or parking spillover to adjacent residential ones. If these are also in low-income areas, officials need to consider—and likely mitigate—any impacts.

Finally, adding trees, bike lanes, and other public amenities often makes certain areas more desirable. Poverty advocates have sometimes even opposed bike lanes because they are the first step towards displacement of low-income and minority residents. We do not believe the solution is to not make investments in transportation infrastructure or policy, but instead need to use robust community consultation, clear metrics to measure any negative impacts, and have a strategy in place to mitigate the impacts as necessary.

Step 3: Pilot Alternative Curb Uses and PUDO Zones

The best way to explore alternative uses for the curb is to design a pilot project or two. The objectives of a pilot are (1) to test if a change in curb usage generates the desired outcome and (2) to understand the political and operational issues of changing the role of the curb. Ideal pilots are those where there is a direct opportunity to address a pressing problem such as safety concerns, congestion or even double-parking. The pilots should also be:

- Limited in scope,
- Limited in their funding requirements,
- Capable of providing measurable outcomes in the short-term, and
- Reversible.

Examples of pilot projects include substituting parklets for parking in Boston's Back Bay neighborhood and dedicated pick-up/drop-off sites in Washington's Dupont Circle neighborhood. For those cities where AVs are being tested, explore a pilot that leverages learning from this new mobility option.

Much like Washington, city governments can undertake a plan to release parking spaces for drop-offs in areas of high demand. Future trials can potentially go further than those in the nation's capital, though, in that passengers calling a car within a certain radius of a PUDO zone will be actively directed, through their app, to walk to the PUDO zone where the car will meet them. The purpose behind this more ambitious measure is to reduce any risk of double-parking or other dangerous maneuvers in traffic as drivers attempt to reach their customer. This concept has been successfully tested and will likely be rolled out more broadly.

The city will need to determine the appropriate placement and spacing for PUDO zones. The zones should have enough space for vehicles to pull in and out quickly and with little back-up. They will also want curb cuts so passengers of all ages and abilities can board and disembark safely. They will need to be clearly marked so passengers and drivers do not become confused or lost as they search for them, and others do not mistakenly park in them.

PUDO zones do not need to be permanent but can become parking or loading zones when PUDO demand is low. As much as possible, cities should gather data on curb and PUDO pilot projects to understand both successes and challenges. If pilots are, on balance, helpful with reducing congestion, they can become a permanent measure.

Step 4: Establish a Curb-Use and Street Space Allocation Master Plan

The curb inventory, prioritization protocol, results of pilot projects and the experience of curb reuse and street allocation efforts in other cities provides the raw material for

developing a curb use and street allocation master plan. The master plan provides all stakeholders with an understanding of how the curb and street will be used in the future, fostering better decisions ranging from residential and commercial investments to car ownership. The starting point for the master plan is a set of guiding principles as to how the plan will be constructed, which should be developed in collaboration with stakeholders. Using these principles, the plan should detail street-by-street usage. As with all plans, it will evolve over time, but having a clear starting point is a key first step.

Quick Notes

The Concept

- Traffic congestion, increased demand for curb use and the proliferation of delivery vehicles and TNCs are making city planners rethink the use of the curb.
- Cities have begun to institute new uses for the curb, from designated zones for pick-up and/or drop-off for TNCs to replacing parking with dedicated transit lanes or parklets.
- To discourage the use of personal cars in the urban core, cities are increasing the cost of parking and reducing the number of parking spaces, purposely making it more difficult for drivers to park.
- Unlike drivers, AVs can be programmed to follow curb-use rules.
- If shared-ride AV fleets become an initial use case, many existing parking spaces can be repurposed.

The Landscape

- Washington, D.C., is exploring dedicated pick-up/drop-off locations by time of day.
- Boston is experimenting with raising parking fees, removing parking spaces to reduce incentives for personal vehicles, and substituting parklets for parking.
- Seattle is testing flexible curb usage based on local context and stakeholder needs.
- New York City is piloting curbside loading zones and late-night deliveries.

Getting Started

1. Map the curb.
2. Establish a prioritization framework.
3. Pilot alterative curb uses and PUDO zones.
4. Establish a curb use and street allocation master plan.

Policy Action 3: Manage and Reduce Congestion

The Concept

AVS: POTENTIAL BENEFITS TO CITIES

- Less traffic congestion via toll pricing that encourages ridesharing
- Better public transportation as multi-modal trips become more enticing
- New revenue stream via AV access fees with easy tracking
- Increased traffic-flow control via deployment of congestion pricing

In many growing cities across the United States, congestion is on the rise. Transportation experts typically present three main strategies for mitigating congestion: encouraging increased uptake of shared rides such as those offered by TNCs; promoting increased walking and usage of public transportation options such as buses, subways, and bikeshares; and/or implementing congestion pricing programs.

With their potential for shared rides, TNCs were initially pitched as a way to address gridlock, but research has found putting ride-hailing cars on the road is often just increasing traffic by drawing people off transit and filling the streets with passenger-less vehicles. Coupled with contemporary urban growth patterns (i.e., sprawl) and natural population increases, American roads are, in many places, more clogged than ever. As AV travel will be less expensive, both economically and temporally, there is the potential for commuters to shift to automated single-occupant AVs or to live farther from their places of work. Another concern is the specter of cities clogged with "zombie" cars: automated vehicles that drive through the city awaiting a passenger. If the initial use case for AVs follows the TNC single passenger model, then the introduction of AVs is likely to make congestion worse, not better.

Fortunately, this need not be the case. AVs offer cities the opportunity to devise toll pricing that encourages ride sharing. For instance, cities can adjust the toll based on the number of people traveling in an AV or even waive the fee entirely if there are three or more passengers. Alternatively, cities can employ financial penalties for passenger-less vehicles or those with only a single passenger.

Beyond incentivizing ridesharing, AVs might also provide a boost to public transportation. Just as passengers who know that they can reliably call on a TNC throughout the day when needed might be encouraged to utilize public transportation with the security of a vehicular backup on demand, AVs may give rise to more multi-modal travelers. For instance, a commuter that previously might have driven to all stops may instead choose a bikeshare for their morning commute, take a subway to a store in the afternoon, walk back to the office, and use an AV to get home in the rain after dark. As AVs lower parking demand, some researchers argue that urban density can increase, which makes walking, cycling, and transit more appealing and, in turn, lessens congestion.

As we ponder scenarios in which congestion is either exacerbated or alleviated, we must acknowledge that the key factor will be the degree to which thoughtful policymakers are willing and able to seize the opportunity of a shifting transportation landscape to improve flow within cities. In the absence of effective public policy, we will likely see little improvement in congestion. Policymakers do not need to wait for the widespread adoption of AVs to prepare for the transportation future they want to build for their communities, as policies can be developed for TNCs today that will be applied to AVs in the future. The presence of a driver is irrelevant when considering the primary policy lever for mitigating congestion: congestion pricing.

One avenue for congestion pricing, as discussed above, involves the potential to incentivize shared rides. It's important to note that, in contrast to TNCs, tolling AVs will potentially be less expensive and easier to assess and enforce because AVs have real-time, highly-accurate continuous location monitoring. For instance, if a city decides to charge a fee each time a vehicle enters the city center, AVs will have the ability to automatically incorporate these fees into their pricing structure.

AVs offer cities another advantage: because AVs collect data on every aspect of their movement, cities will not need to pay for observational infrastructure such as cameras to collect tolls. Instead, they can use a software-based query to identify all instances of AVs entering the city center and simply invoice the AV operators.

Distance-based fees, which assess tolls based on how far a vehicle travels, could also be used to incentivize short trips. Route-based fees can be used to price discriminate, offering lower fees for AVs that travel less-congested routes, for instance. In general, with AVs, cities will have a greater set of tools to use to influence driving behavior and congestion.

The Landscape

Cordon-based congestion pricing has already met with success in London and Stockholm. London, for instance, charges a daily fee of the equivalent of $14.35 to enter the city center while Stockholm's charge changes depending on the time of day, capped at around $12.50. Both cities found trips into the city center decreased and about half of those were redirected to public transit. In addition, a study of Stockholm's air quality after the implementation of congestion pricing found a five to 15 percent decrease in pollution.[62]

62 Hawkins, Andrew J. "Why Congestion Pricing Can Save Cities from Their Worst Possible Future." The Verge, March 29, 2019, https://www.theverge.com/2019/3/29/18286830/congestion-pricing-nyc-gridlock-autonomous-vehicles-traffic. Accessed September 19, 2019.

A key policy question is this: who is subject to the congestion fee? Some experts support universal congestion pricing—levying a fee for all vehicles entering a certain area of a city. Others suggest the fee should be focused on the TNCs, who are currently viewed as adding incremental congestion to urban streets. (Currently, TNCs are exempt from the fee in London, which many policymakers now acknowledge is one reason for increasing congestion in the city's core.) TNCs, fearing that their services will be disproportionately tolled, point out that making ridesharing more expensive will encourage people to drive themselves, putting more cars on the road.63

Local traffic patterns and politics will likely shape the answer to the "who pays" question, however equity will be a second key consideration as part of a congestion pricing strategy. As it becomes more attractive to live closer to work thanks to the higher cost of travel, some lower-income residents could be at a higher risk of displacement. As with other policies above that can also lead to gentrification, it is important to have a strategy in place to address this risk. Additionally, in many cities lower-income residents have already been forced out to poorer suburbs as neighborhoods closer to the core have become more attractive over the last few years; these residents may therefore face a higher financial travel burden under congestion pricing. Officials will need to mitigate this in some manner.

One approach would be to adopt a variation on the Canadian federal government's carbon tax model: Everyone pays the carbon tax on the energy products they use, but enjoys a credit on their income tax. For cities looking at congestion pricing, they could offer a similar rebate for qualifying low-income residents.[64] Done properly, this would leave the disincentives to travel by car in place, while lessening the burden on those least able to pay.

New York City's Approach

In the United States, New York City is planning a congestion pricing program that uses an electronic tolling system to charge drivers entering parts of Manhattan. The fees are designed to both reduce personal auto use in Manhattan and to raise funds to improve transit. When implemented in 2021, New York will be the first U.S. city to enact congestion pricing but others, such as Portland, Seattle, and Los Angeles, are commissioning studies and looking to New York to see if leaders have the political support to follow through. On a state level, Oregon has a voluntary pricing plan, where drivers can opt in to paying a small fee for each mile they travel.

63 George, Tyler. "Universal congestion pricing is the way to go." CommonWealth, September 15, 2019, https://commonwealthmagazine.org/transportation/universal-congestion-pricing-is-the-way-to-go/. Accessed September 19, 2019.

64 Macdonald, Neil. "Justin Trudeau's carbon tax is revenue neutral... for now." CBC News, April 24, 2019, https://www.cbc.ca/news/opinion/carbon-tax-revenue-1.5107979. Accessed January 23, 2021.

Washington, D.C.'s Approach

While these programs all employ static costs, the true potential of congestion pricing is that it can change based on real-time demand. Washington, D.C.'s 66 Express Lanes project shows what such an initiative might look like. Implemented in late 2017, the highway's tolls cost an average of $12.59 for a two-way trip but can sometimes increase to well over $40.[65] Tolls fluctuate every six minutes to maintain a minimum average speed of 55 miles per hour.

The results of the program have been mixed. Carpooling (exempt from the toll) increased by 15 percent in the first months of the program and travel times decreased during rush hour, but off-peak hours and alternative routes have seen increased traffic.[66] Reports show that where transportation officials put in better bus service alongside the toll, transit use increased. Where better transit options are not available, however, ridership has declined, and one of the biggest criticisms of the initiative is that the government forced car commuters to pay without offering any reasonable alternatives to driving.[67]

The D.C. case study illustrates that to make congestion pricing work, cities must offer alternatives to driving. In London, the transit system offers faster travel than driving. About half of the 100,000 drivers in Stockholm who "disappeared" after the city's pricing plan went into action shifted to transit.[68] In California, tolling on the I-15 near San Diego successfully led to a nine percent increase in transit ridership.[69] Improving transit is therefore a critical component of the congestion management recipe—and should begin well before implementing road pricing.

As TNCs have reduced transit demand in some cities, some politicians suggest it is time to rollback transit. This is problematic from a number of perspectives, including the impact it could have on lower-income residents who might not be able to afford ridehail services. Instead, cities should continue to fund and expand public transportation options. They can also provide low-income transit passes, and where they have

65 Smith, Max. "I-66 tolls turn 1 year old – Are they working?" WTOP, January 4, 2019, https://wtop.com/dc-transit/2019/01/average-i-66-price-speeds-from-first-year-of-tolls-and-extended-hov-hours/. Accessed February 3, 2020.

66 Lazo, Luz and John D. Harden. "Year-old 66 Express Lanes have caused shifts in commuter behavior, but not necessarily in ways officials hoped for." The Washington Post, December 8, 2018, https://www.washingtonpost.com/local/trafficandcommuting/year-old-66-express-lanes-have-caused-shifts-in-commuter-behavior-but-not-necessarily-in-ways-officials-hoped/2018/12/08/6e78d944-e832-11e8-a939-9469f1166f9d_story.html. Accessed February 3, 2020.

67 Smith, Max. "Are I-66 tolls promoting transit use?" WTOP, June 6, 2018, https://wtop.com/dc-transit/2018/06/are-i-66-tolls-promoting-transit-use/. Accessed February 3, 2020.

68 Tools of Change. "Stockholm's Congestion Pricing." Tools of Change Highlights Series, October 2014, https://www.toolsofchange.com/userfiles/Stockholm%20Congestion%20Pricing%20-%20FINAL%202014.pdf. Accessed February 3, 2020.

69 U.S. Department of Transportation/Federal Highway Administration. "I-15 Congestion Pricing Project Monitoring and Evaluation Services." https://ops.fhwa.dot.gov/congestionpricing/value_pricing/pubs_reports/projectreports/interst15_congestion.htm. Accessed April 10, 2020.

a stake in the bikeshare program, offer subsidized memberships on those systems as well. Hamilton, Ontario, for example, offers a three-month bikeshare pass for $3 to qualifying residents.

Wrapped up in congestion pricing and better transit options is undoubtedly also the topic of land use. Many cities have segmented uses, but if people can live in the same neighborhoods as they work and play, it will cut transportation demand. Done properly, mixing uses while permitting gentle density (that we define as buildings between three and six storeys) and implementing policies that encourage more affordable housing are all key components to a holistic, inclusive travel demand management strategy.

Seattle's Approach

Seattle is the golden example of transit performance in the United States. Beginning in 2014, Seattle increased service by 270,000 hours annually, boosting the number of households within a ten-minute walk of ten-minute or better service from 25 percent to 64 percent.[70] Seattle has focused on a network system to make travel easier, rerouting bus routes as new rapid transit comes online, increasing frequency rather than simply focusing on coverage.[71] From 2000 to 2016, downtown transit increased from 29 percent to 47 percent of trips, while drive-alone trips declined from 50 to 30 percent[72]—showing that transit planning can be an effective congestion management strategy in itself.

While Seattle increased transit funding, other cities, including Houston, Texas, and Columbus, Ohio, famously redesigned their networks to do more with the same amount of money. Houston, for example, now devotes 80 percent of the transit agency's resources to maximizing ridership (versus 20 percent to providing access to people living in low-density, expensive-to-serve areas).[73] Such an approach is not limited to big cities either, as Richmond, Virginia, revamped its own network to focus on frequency, and enjoyed a ridership increase of 17 percent.[74]

70 Bliss, Laura. "Why Seattle Is America's Bus-Lovingest Town." CityLab, May 11, 2018, https://www.citylab.com/transportation/2018/05/seattle-the-city-that-respects-the-power-of-the-bus/559697/. Accessed February 3, 2020.

71 TransitCenter. "There's a Reason Transit Ridership Is Rising in These 7 Cities." TransitCenter, February 27, 2019, https://transitcenter.org/theres-a-reason-transit-ridership-is-rising-in-these-7-cities/. Accessed February 3, 2020.

72 SDOT Blog. "A closer look at Seattle's rising transit ridership." Seattle Department of Transportation, January 3, 2018, https://sdotblog.seattle.gov/2018/01/03/a-closer-look-at-Seattle's-rising-transit-ridership/. Accessed February 3, 2020.

73 Zbikowski, Conrad. "How Houston Reimagined Its Transit Network and Increased Ridership." Streets.mn, February 25, 2019, https://streets.mn/2019/02/25/how-houston-reimagined-its-transit-network-and-increased-ridership/. Accessed February 3, 2020.

74 TransitCenter. "The Network Effect: Richmond's Transit Evolution." TransitCenter, December 4, 2019, https://transitcenter.org/the-network-effect-richmonds-transit-evolution/. Accessed February 3, 2020.

Alberta's Approach

Edmonton, Alberta recently approved its own bus network redesign, which cut 240 routes to just 140. Edmonton's approach stands out because the transit agency recommends an app-based, on-demand van system to serve low-ridership areas. Edmonton would not be the first place to deploy on-demand transit; Calgary, Alberta already services suburban communities in this manner, and Cochrane, Alberta's transit system is composed solely of on-demand vans. The new Edmonton network, though, gives an example of what the future might hold for cities that use transit to address congestion management: A frequent fixed-route network serving areas where travel demand is highest and therefore cars are least efficient, supplemented by on-demand service. Elsewhere, on-demand service may be provided by a public agency, TNCs, or even commuters calling their own private cars to pick them up from a transit stop.

COVID-19 Commentary

With the rise of the pandemic, public transit use plummeted. Many systems saw ridership drops of 80 to 90 percent. Urban planners and transportation experts argue passionately that as economies reopen, shifting public transit riders to cars will have an incredible impact on congestion and emissions. Nevertheless, pundits, employers, and some politicians—not to mention car manufacturers!—are telling Americans they should avoid buses and trains in favor of an automobile. Moreover, some planners predict citizens will migrate to the suburbs or to towns outside the city in an attempt to reduce their exposure to COVID-19. On the other hand, due to the coronavirus at least some people may begin to work from home more frequently, reducing the number of travelers on the road. The long-term effect of the virus may therefore be to either exacerbate or alleviate congestion—and this will likely vary across and within cities. Either way, this will be a new factor policymakers must consider when crafting policy to address congestion.

AVs may make living in sprawling suburban communities and commuting by car relatively more appealing, so they might exacerbate a trend to stay out of urban cores and/or off transit out of fear of catching the disease. Should there be a major shift towards cars or an increase in urban sprawl (whether influenced by AVs or not), the need to address congestion and ensure motorists are paying the full and fair price of their trips will become all the more critical. This requires cities to adopt congestion pricing for all vehicles, whether owned by companies or citizens. AVs make congestion pricing technically more feasible, and possibly even politically more palatable. AVs also make multi-modal travel more appealing, so travelers may feel more comfortable opting for a bike, a bus, or a walk when they leave the house, secure in the knowledge they can hail an AV later, should they need it. As discussed above, automated transit makes public transit a more attractive option, even given COVID-19 transmission concerns.

Lastly, part of the goal of congestion pricing is to push some trips to either before or after the peak travel periods. If this is successful, a secondary impact may be that there are fewer people all arriving at work simultaneously, reducing congestion in the lobbies of major office towers. While this effect may be small, it will help with some of the policies around physical distancing and elevator use in public spaces.

Getting Started

We believe cities should take policy action on congestion reduction now, before the introduction of AVs. Why now? Once AVs are traveling city streets, it will be much more difficult to overcome industry objections to congestion pricing or similar policies. Indeed, as TNCs become more entrenched[75] it is imperative that cities move to enact policies soon. The arrival of AVs will only exacerbate the problem if cities haven't yet devised incentives for ride-sharing and other strategies for reducing congestion. The following is a road map for getting started.

Step 1: Profile Existing Traffic Patterns and Congestion

The starting point for addressing congestion is understanding the specifics of your traffic problem. Answering the following questions provides a starting point for developing congestion mitigation strategies:

Traffic Management Objectives Strategic Questions
• What outcomes should the program provide? Are the outcomes equitable? • Is the goal a reduction in travel time or in the number of cars entering the city? • Do you seek to reduce the number of residents with cars? • Is the program intended to raise funds for public transit or green transport?

Step 2: Learn from Existing Programs and Establish Objectives

Your congestion profile and insights from existing programs are the inputs needed to identify your congestion management objectives.

When establishing the objectives, ensure that the outcomes are measurable. You need to make sure you know if you were successful. While you are acting to address current congestion issues, think about future objectives in an AV environment.

Step 3: Define Your Guiding Principles

Along with the objectives, establish a set of core principles that will guide the design of the program.

75 In a 2019 assessment (commissioned jointly by Uber and Lyft) of TNCs' impact on vehicle miles traveled (VMT)—a standard metric for overall vehicle activity—the study found that in Suffolk County, which encompasses Boston, personal and commercial vehicles accounted for 92 percent of VMT while Lyft and Uber contributed eight percent.

Sample Traffic and Congestion Management Program Goals

- Provide equal treatment of all travelers.
- Create net public value (benefits greater than costs).
- Encourage transit and active mobility modes.
- Support shared ride options.
- Ensure financial and environmental sustainability.
- Minimize job loss and provide transition assistance to those negatively impacted.
- Test the program for a set period of time.

Step 4: Develop a Congestion Pricing Strategy and Communications Plan

Perhaps more than any other transportation policy, cities need a strong communications strategy to win over the public as they launch road-tolling measures. In 2019, the Eno Center for Transportation undertook an overseas study tour to gather lessons American leaders might use in pursuing congestion pricing. They propose a number of key insights (available on their website), but the overarching takeaway is that successful cities do not win over citizens by focusing on revenue. Instead, the Eno participants note policymakers should focus on equity and offering greater access to residents. New York officials positioned the plan as a way to address the woeful state of the city's transit system, while in Los Angeles it is portrayed as a way to tackle stifling congestion. While these two pitches are more likely to succeed, Chicago's mayor "suggested congestion pricing as a way to plug a hole in her city's budget."[76] The Eno team argues this narrative will likely not win the day among constituents. (And when Connecticut Governor Ned Lamont tried to sell a highway toll program to raise revenue, it similarly failed.[77])

Stockholm won over its public by launching congestion pricing as a temporary initiative. When commuters saw the impact, they became proponents of a permanent change.

The approach and narrative city officials use to promote congestion pricing will likely make or break the plan, so there must be a strong process, a policy based on data, community engagement, and a willingness to employ pilot projects and iterate based on results. Stockholm, for instance, won over its public by launching the initiative only temporarily and when commuters saw the impact, they became major proponents of a

76 Puentes, Robert and Brianne Eby. "Takeaways from a European Congestion Pricing Study Tour." Eno Center for Transportation, October 16, 2019, https://www.enotrans.org/article/takeaways-from-a-european-congestion-pricing-study-tour/. Accessed February 3, 2020.

77 Short, Aaron. "Europe's Congestion Pricing Lessons for America." Streetsblog NYC, October 31, 2019, https://nyc.streetsblog.org/2019/10/31/europes-congestion-pricing-lessons-for-america/. Accessed February 3, 2020.

permanent change. Policymakers want to have a strong narrative articulating how the plan will improve the transportation network for everyone through better travel times and other benefits.

Step 5: Improve Transit Uptake and Performance

Studies show that the best time to change someone's travel habits is when they change jobs. Transit agencies can reach out to major employers, especially those who are new to the city, to offer some kind of "Welcome Wagon" program—perhaps a free two-month transit pass for all new employees. Many companies do not want to invest in expensive parking for their staff, so they might be willing to extend the offer by supplementing the employee's transit pass in perpetuity.

On the infrastructure front, measures like all-door boarding or installing transit priority signalization improve reliability and travel times without adding more buses. Identifying major demand corridors for dedicated transit (like Toronto's King Street or Seattle's Third Avenue) can also dramatically improve performance at no additional cost.

Finally, cities can use revenue raised through congestion pricing to invest in better transit. While they can add routes and improve frequency everywhere, there is a particular benefit to looking at equity concerns, ensuring strong transit service in lower-income areas.

Step 6: Design a Pilot, Learn and Scale

As policymakers eye AVs playing a larger role in our communities, forward-thinking leaders should consider a pilot program to learn how congestion can be managed today and in the AV future. The pilot should enable learning at low risk, and could be designed based on geography, modes, or time of day. Built with a coalition of the willing, the design should reflect stakeholder interests. It should also have clear performance measures and a transparent dashboard. Ideally, such a project would be sufficiently staffed in preparation for bumps along the road.

Quick Notes

The Concept

- Congestion is a problem in many growing U.S. cities, and AVs have the potential to either alleviate or exacerbate that congestion.
- Vehicle congestion in cities will improve only via effective public policy.
- Policies can be developed for TNCs today and applied to AVs in the future.
- Unlike TNCs, tolling AVs may be less expensive and easier to assess and enforce.
- AVs offer cities more tools for influencing driving behavior and congestion.

The Landscape

- Outside the U.S., congestion pricing has already met with success in cities like London and Stockholm.
- Cities have seen significant decreases in car trips to the city center; Stockholm also reported improved air quality.
- In the U.S., New York City is taking the lead with a congestion pricing program due to begin in 2021.
- Seattle reduced drive-alone trips from 50 to 30 percent from 2000 to 2016, illustrating that transit planning can reduce congestion.

Getting Started

1. Profile existing traffic patterns and congestion.
2. Learn from existing programs and establish objectives.
3. Define your guiding principles.
4. Develop a congestion pricing strategy and communications plan.
5. Improve transit uptake and performance.
6. Design a pilot, learn and scale.

Policy Action 4: Establish Data-Sharing Guidelines and Agreements

The Concept

AVs will collect a vast amount of data about all aspects of their operation. They will be able to collect data on passengers as well as those outside of and around the vehicle. Inside the vehicle, passenger-facing cameras can watch the rider, potentially using data about their facial expressions and body language to select and display advertisements. The vehicle's outward-facing cameras will record, in real time, what is happening on the street. At the same time, the AV records data about its own behavior (speed, braking, proportion of time operating in autonomous versus manual mode, etc.) as well as external road and environmental conditions such as the weather, traffic congestion, location of potholes and the like.

AV operators are already resisting sharing their data, much as TNCs have. Indeed, TNCs collect data on their road speed and other operational data that cities could benefit from having, but they are resistant to sharing disaggregate data with municipalities.

Their concerns are tied to issues of confidentiality and competitor access through freedom of information requirements.

Least controversial is the use of vehicle operating data. AV operators say that data belongs to them and they see no reason to share it since it pertains to their own business operation. Passenger-related data is more controversial. Some argue that passengers give up their presumption of privacy—and hence data about them and their travel—when they board an AV, much the same way that the traveling public has acceded to security cameras in public venues in the name of providing increased security, but it is not clear if the public will view the cabin of a vehicle in the same way.

AV Data Questions

- Who owns AV operations data?
- How can and should that data be shared?
- Who owns passenger-related data?
- What uses of passenger-related data are acceptable and unacceptable?
- Should AV operators be able to sell passenger data to advertisers?
- Should passengers be able to opt in or out of data-sharing?
- Who owns data about the behavior of the people outside the vehicle?

While these are important issues to grapple with, cities are even more interested in the data AVs collect about their operating environment. Such data can allow mobility planners to better understand, in real time, congestion times and patterns. Cities can use this information to better time lights, understand road usage and inform their capital investments more effectively. Operators, however, plan to closely guard this data, fearing that sharing even the most basic details may put them at a competitive disadvantage. For instance, if there are only two operators in town, when that data is shared and subject to the Freedom of Information Act, operators are legitimately concerned that their competitor could calculate their data from the aggregate, thereby gaining insight into their business. This could lead to significant tension between AV operators and planners at the municipal level.

The last data tranche—information about the behavior of people outside of the vehicle—is the most disconcerting from a privacy perspective. For instance, say an external camera catches someone committing a crime. Most would support using such data for law enforcement. But what if the camera records people doing their daily activities and that footage was made available to advertisers? Though cameras are located and operating atop buildings and in locations throughout cities, most citizens expect that the footage will only be used for law enforcement. Should AV operators be able to monetize this data? How else might this information be used?

Municipalities also have concerns about sharing. Some are concerned that accepting the data will be costly. There are direct costs for data storage and protection. There are also potential liabilities and indirect costs of data breaches and responding to Freedom of Information Act requests. Some cities and privacy advocates also worry that cities do not have the internal expertise to effectively protect and analyze the massive amount of data that AVs will generate.

Data-sharing is a thorny issue because it goes to the heart of privacy and security issues around personal data. Even the notion of providing non-personal data is controversial, because operators view it as proprietary, competitive information. We believe the solution for cities is to partner with AV operators to solve problems. Cities can pose questions to AV operators and let them use their own analytics team to provide the answers. If cities want to know the congestion windows on a particular street or where traffic speeds exceed 25 miles per hour, AV operators can provide these answers without having to turn over the data they so dearly wish to keep confidential. However, in some cases, it may be necessary to obtain AV operator data to ensure they are meeting governmental expectations.

The Landscape

As municipalities grapple with mobility data issues, the following topics are being addressed:

- Guiding principles for data-sharing
- Data handling, sharing and liability
- FOIA and public record requests
- Law enforcement requests

We discuss each of these in brief below.

Guiding Principles

Los Angeles' data-sharing principles address de-identifying data, limiting the receipt of raw data, providing data to law enforcement as needed, blocking data transmissions to third parties that seek to monetize the information, and developing security protocols to ensure the safeguarding of data received by the City. Seattle's principles stress constituent privacy and using data to enhance equity and inclusion. Portland's principles add the idea of lifecycle stewardship of the data and non-discriminatory use of the data. Barcelona includes guidance for maintaining the public trust. The idea of data "from everyone and for everyone" is part of Amsterdam's data-sharing philosophy.

Sharing of TNC Data

After resisting calls for data-sharing, Uber has begun providing information to municipalities and the public though its Uber Movement application. Movement provides data and tools that enable city planners to enhance mobility. The data enable planners to better understand traffic flows, congestion, and safety risks. The information is available for more than a dozen cities in North America.

Ford, Uber and Lyft are also sharing data in conjunction with the SharedStreets initiative. This data, including pick-up and drop-off counts and road speeds, will allow urban transportation departments to improve mobility.

Sharing of AV Data

Sharing of AV data has been part of the testing protocol in many geographies. In California, AV testers are required to report disengagements to the state. This data is published annually and the results are widely covered in the press. In Boston, where AV testing has been taking place for several years, testers are required to submit quarterly performance updates containing mileage driven, reports of accidents, and lessons learned. These are public documents, but no detailed data are shared.

Beyond the statutory reporting, some AV operators have begun sharing this data with other industry participants and researchers. In August 2019, Waymo became the highest-profile AV operator to agree to release its data to researchers, following Aptiva's lead from a few months earlier.[78] Industry experts claim Waymo and others are beginning to share data with researchers because solving some of the technical challenges of AVs is proving more difficult to solve than operators had anticipated; by sharing data with researchers, they hope the entire industry can benefit.[79]

Getting Started

We believe cities should be thinking about how they can use the data that TNCs are gathering today—and that AVs will gather in the future—to make their cities more mobile, environmentally friendly, enjoyable, and livable places while protecting their citizens' privacy. If cities start now, with TNCs and micro-mobility providers, they'll be well-positioned to expand to AVs when they arrive. Those cities embarking on AV pilots should incorporate a data-sharing protocol into their testing regulations. The following steps can help municipalities address the data challenge today.

78 Hawkins, Andrew J. "Waymo is making some of its self-driving car data available for free to researchers." The Verge, August 21, 2019, https://www.theverge.com/2019/8/21/20822755/waymo-self-driving-car-data-set-free-research. Accessed September 25, 2019.

79 Stewart, Jack. "Why Waymo is sharing some of its self-driving car data." Marketplace, August 21, 2019, https://www.marketplace.org/2019/08/21/waymo-sharing-some-self-driving-car-data/. Accessed September 25, 2019.

Step 1: Determine Data Needs and Wants

The starting point for establishing a data-sharing protocol is identifying the information needs (real requirements) and wants ("nice to have" information) of the municipality. What questions can be effectively answered through mobility/AV data? The queries should span from long-term infrastructure planning to short-term pothole repair. The data can also substantially inform congestion management programs. The questions list should be developed by engaging every city department, not just the transportation department. Departments dealing with elder affairs, health, education and revenue all have an interest in learning from mobility data. The list of questions should also reflect the needs of regional and/or state planners. The city should also specify the process for asking questions and receiving answers, including the timeframe and level of detail to be provided.

Step 2: Draft Data-Sharing Guidelines

Beyond leveraging data to enhance the delivery of public services, the municipality should also define the rules of the game for data-sharing with the city and with other organizations. Based on domestic and international experience, the following are foundational principles for the guidelines:[80]

Data-Sharing Guidelines: Key Principles

- Transparency: Clarify and publicize the kind of data being collected and for what purposes. Aim for data minimization rather than maximization.
- Responsible Stewardship: Act in the best interest of citizens. Safeguard confidential information. Make data serve people, not vice versa.
- Inclusion: Use data to promote equity, target economic and social disparities, and encourage affordability.
- Public Value: Use insights gleaned from data to drive inclusive economic growth, improve security, and address climate change-related challenges. Data must bring utility to the city's residents.
- Portability: Easily move non-confidential data. Prevent information from becoming "siloed" and "sequestered."

The resulting guidelines should be documented and accessible to mobility providers and the public. The guidelines should also have built-in flexibility so that revisions can be incorporated as both the city and the public's thinking evolve.

Step 3: Begin Implementing with Existing Mobility Providers

The development of a data-sharing program can begin immediately. While AVs will gather extensive amounts of information, current and near-term mobility providers

80 Blomfield, Tim, Brian Feldman, Monica Pellerano, and Philip Essienyi. "AV Data Policy and Governance." 2019, prepared for the City of Boston by Harvard Kennedy School students.

can also be sources of data for decision-making. TNCs and taxis are existing sources that can be tapped for mobility insights. While incumbents might balk at providing information since it was not a term of their operating agreement, it is important to ask. If it is not possible now, it can be at the time of an agreement renewal. Also, it is likely that the TNCs will be some of the first AV operators in the urban core. The AV operating agreement might be tied to sharing all of the operator's data, not just the AV portion.

Micro-mobility providers present a low risk test bed for the design and operation of a data-sharing protocol. As bikeshare and electric scooter companies seek local operating agreements, cities have an opportunity to pilot data-sharing agreements.

Step 4: Evaluate the Value of Information Sharing and Refine Guidelines

Data-sharing arrangements should be evaluated periodically to confirm desired outcomes are being achieved. Are the city's questions being answered? Are there new queries? Are the data captured about users and the general public being protected as designed? Are there changes needed to meet an important public purpose? The answers to these questions will inform the process of refining and reissuing data-sharing guidelines.

Quick Notes

The Concept

- AVs collect a vast amount of data about all aspects of their operation.
- AV operators are already resisting sharing their data, much as TNCs have done.
- The open question is: who owns this data? How can and should it be used?
- Issues of privacy, security and competitiveness may position cities against AV operators.
- Cities should establish a data-sharing protocol for current and future mobility options.
- Partnering with mobility providers to answer key planning questions is an effective alternative to cities obtaining and analyzing the data themselves.

The Landscape

- Cities around the globe have established data-sharing principles that stress privacy, equitable use and transparency.
- TNCs have begun sharing data that sets a precedent for how information flows can be established.
- AV operators have begun sharing their own mapping data with others in the industry and researchers with an eye toward collectively solving technical AV operating challenges.

Getting Started

1. Determine data needs and wants.
2. Draft data-sharing guidelines.
3. Begin implementing with existing mobility providers.
4. Evaluate the value of information sharing and refine guidelines.

Policy Action 5: Reposition Revenues

The Concept

Municipal and state governments rely on revenue from private vehicles, largely derived through their state's excise tax on gasoline. As of July 2020, such taxes ranged from $0.15 per gallon in Alaska to $0.61 in California. Some states levied additional state sales or local taxes. States rely on this revenue to fund road maintenance, transportation infrastructure, and transit subsidies. Additional, significant sources of municipal revenue include parking fees, parking tickets, and moving violation fines. For a city the size of Boston, these can amount to as much as $88 million annually—the equivalent of the entire cost of snow removal for a year. The magnitude of the potential revenue loss could be more than $100 million in other major cities.

These revenues have been declining nationwide. Increasing auto fuel efficiency is reducing fuel consumption and therefore gas tax revenues are declining. In some cities, parking revenues are declining as municipalities disincentivize people from driving into town by reducing or eliminating parking spots.

The market entry of AVs will speed up the revenue decline. Autonomous vehicles will commit far fewer, if any, moving violations, drying up this revenue stream. If the shared ride AV model takes hold—or if car commuters send their vehicles home during the workday—demand for parking will also decline, taking with it parking meter fees, municipal lot parking fees, and fines for meter violations.

Because we believe AV fleets will be comprised of electric vehicles, gas tax revenues will also decline, providing an additional catalyst for cities to take action to replace these revenues.

We see two major areas where cities can look to make up for lost funds: transportation charges and land use/property taxes

Transportation Charges

While eroding traditional revenue streams in transportation (through gas taxes, parking fees, and tickets), AVs also provide a new opportunity for cities to view the transportation network more like a utility, with travelers paying for what they use. In order to operate, the expectation is that AVs will keep a record of where they travel, meaning cities can use that data to charge cars for the road space they take up. When in motion, this is not dissimilar to the congestion pricing outlined in Policy Action 3, but it goes further by charging everyone for the miles they have traveled, not just in congested downtown cores. This pricing can be first applied to TNC operators (and many states and cities already charge a fee to operate), but in the future even private drivers should pay a per-mile fee for the road space they use.

AVs provide a new opportunity for cities to view their transportation networks more like a utility, with travelers paying for what they use.

When a vehicle is stopped, they can "rent" space along the curb to drop off or pick up passengers. Cities are already familiar with the concept of charging for curb space for parked vehicles, but this is typically limited to longer stays (at least 15 minutes or more) and is generally confined to very popular locations. In the future, cities can use GPS data to charge for all passenger (and freight) loading and unloading, regardless of the duration the vehicle is stopped or the area of the city it is in. Prices can vary throughout the day depending on demand, but as with per-mile travel pricing, the goal would be to fairly charge users for the space they take up.

Land Use and Property Taxes

Cars today require a huge amount of space in cities. Researchers estimate there are anywhere from three to eight parking spaces per car in America,[81] which means all that land cannot be used for more productive—and more tax revenue-generating—activities. If AVs reduce parking demand, local governments can use policy levers to encourage residential and office development on this land, with more property tax revenues helping to offset lost revenue. Moreover, if this development leads to higher overall city density, it could reduce the per-capita amount the government must spend to provide the same level of service, easing the strain on local revenues. A study conducted in Calgary, Alberta, for example, showed that if the city could consume a quarter less land through a denser growth pattern, it could save $11 billion in capital costs alone.[82]

Governments can begin to eliminate parking minimums in their jurisdictions, leaving it up to developers (through community consultation) to determine how much space they should allocate to parking. They can also institute parking maximums, and encourage (or even require) parking garage owners to design any new garages such that they can be converted to residential or office use in the future, as some developers are already doing. More boldly, cities could begin to tax existing parking lots at a higher rate, to spur non-parking development.

81 Goldstein, David. B. "Does Every Car Need 8 Parking Spaces? Ride-Sharing Can Save Emissions by Reducing Parking, Too." National Resources Defense Council, March 9, 2015, https://www.nrdc.org/experts/david-b-goldstein/does-every-car-need-8-parking-spaces-ride-sharing-can-save-emissions. Accessed February 3, 2020.

82 Thompson, David. Suburban Sprawl: Exposing Hidden Costs, Identifying Innovations. Sustainable Prosperity, October 2013, p. 6, https://institute.smartprosperity.ca/sites/default/files/sp_suburbansprawl_oct2013_opt.pdf. Accessed February 3, 2020.

Most ambitiously of all, officials can consider moving towards split-rate property taxation, acknowledging the role their investments play in increasing the value of land. In this scenario, cities tax land at a much higher rate than they tax the building, to recognize the fact that land-value increases are oftentimes the result of new investments made by the government and surrounding landowners, rather than the direct owner. In Pittsburgh, for instance, the City taxes land at a rate five times that of the tax on buildings.[83] This encourages owners to develop their land for more productive uses, and also shares the wealth with government as land values rise, with the taxes raised being reinvested back into city services and infrastructure—that oftentimes leads to higher land value still.

Achieving revenue neutrality will likely come from a combination of AV pick-up and drop-off (PUDO) charges, vehicle miles traveled (VMT) fees, and increased property taxes coming from repurposed parking lots and spaces. In Toronto, for example, city officials, seeking a model to achieve revenue neutrality after the introduction of AVs, found that a combination of PUDO fees and repurposing parking garages into living spaces was sufficient to reach that neutrality. On top of these initiatives, split-rate property taxation attempts to encourage building upgrades and densification while more fairly distributing the financial benefits of new surrounding infrastructure—such as transit stops, parks, bike lanes, and other amenities—that make a community more desirable.

While city officials may feel trepidation at the prospect of lost transportation revenue in the years to come, the potential benefit of AVs is that local governments can become less dependent on revenue from detrimental activities (such as speeding or improper parking) and instead find new funding from more vibrant, active residential and office uses, and by charging people for the road space and services they actually use.

The Landscape

In many cities, passengers are already familiar with VMT charges thanks to taxi pricing. Taxis often impose an initial fee, then add an incremental charge based on distance and waiting time. It is therefore not a big leap to adopt a similar approach when determining a VMT fee that a TNC would need to pay to the government. Currently, cities that do charge TNCs—including Chicago, New York City, and Boston—require a flat per-trip fee (for example, $2.75 for a trip in Manhattan), but in states including Wyoming, Nevada, and Rhode Island, TNCs pay a percentage fee per ride. While this is

83 Ibid, p. 15.

not completely synonymous with a per-mile fee, it does vary the amount of revenue the government receives based on distance and, because TNCs employ "surge" pricing when demand is high, it also acts as a form of a congestion fee. It could therefore form the initial foundation of a more advanced VMT pricing plan.

AVS AND MUNICIPAL REVENUE STREAMS

- New AV pick-up and drop-off (PUDO) fees
- New vehicle miles traveled (VMT) and/or access fees
- Increased property taxes from repurposed spaces

While a very small number of cities have a form of congestion pricing (as noted in Policy Action 3), in 2015 Oregon launched a voluntary project that charges participating drivers 1.5 cents per mile. Participants attach a device to their vehicle and are refunded the state gas taxes they pay at the pump.[84] Utah offers low-emissions vehicle owners the opportunity to pay a similar charge, and Washington state is also considering a per-mile program.[85] Though these programs are voluntary, they again show the potential of a VMT charge to offset lost revenues at the pump.

Most cities are already familiar with charging a fee for curb access—but as parking, rather than for a drop-off. Charging for parking has traditionally been a very static affair, but a few cities are becoming more advanced in their approach. Los Angeles offers varying rates throughout the day in Hollywood, reflecting temporal demand. San Francisco's SF*park* program similarly varies pricing charges by time of day and day of the week, with pricing updated once a month to moderate demand.

Thus far, no cities charge for curbside drop-offs or pick-ups lasting just a few seconds, but some have begun to rethink how they manage their curb space. Seattle's latest comprehensive plan introduces the concept of "flex zones" in the parking lane, with uses changing throughout the day as demand shifts.[86] During rush hour, the lane can be designated a commuter pick-up/drop-off zone, then used for deliveries in the morning, and parking during the workday, for example. The government has prioritized activities based on the needs of the street and the activity it serves. Paris,

84 Miller, Stephen. "Oregon's Pay-Per-Mile Driving Fees: Ready for Prime Time, But Waiting for Approval." Streetsblog USA, June 26, 2017, https://usa.streetsblog.org/2017/06/26/oregons-pay-per-mile-driving-fees-ready-for-prime-time-but-waiting-for-approval/. Accessed February 3, 2020.

85 Groover, Heidi. "Long road ahead as Washington transportation officials recommend per-mile charge to replace the state's gas tax." The Seattle Times, December 17, 2019, https://www.seattletimes.com/seattle-news/transportation/long-road-ahead-as-washington-transportation-officials-recommend-per-mile-charge-to-replace-the-states-gas-tax/. Accessed February 3, 2020.

86 City of Seattle. Seattle 2035 Comprehensive Plan. December 2018 edition, p. 76, https://www.seattle.gov/Documents/Departments/OPCD/OngoingInitiatives/SeattlesComprehensivePlan/CouncilAdopted2019.pdf. Accessed February 3, 2020.

meanwhile, has removed 43 percent of its personal parking spaces from the street since 2001, while reserving some slots for deliveries on major streets.[87]

These and other initiatives are paving the way for further measures down the road. They provide cities with better data as to demand in different areas, and help drivers and passengers become more comfortable with using online platforms as part of their pick-up/drop-off activities. Moreover, these programs are making city streets more efficient today; data show Washington's three-month pilot, for example, cut double-parking by 64 percent in the study area.[88] The next step would be to develop and implement a pricing scheme for curbside activity, and while no city has formally established one yet, a major International Transport Forum study determined that were Lisbon to bring in such a measure, it could completely replace lost parking revenue by charging just 0.10–0.28 Euro ($0.11–$0.31) per pick-up or drop-off.[89]

As local governments seek to revitalize their downtowns, reduce congestion, and promote density, across the country they are lifting minimum parking requirements that have forced developers to put in a set number of parking spaces for different commercial and residential activities, whether there was a demand for those spots or not. Buffalo, New York was the first city in the country to completely remove minimum parking, but hundreds of local governments have eliminated these requirements in certain geographies.[90] This makes it less expensive to build new development, and also helps promote density and alternative transportation options.

Other cities, such as Montreal, Quebec, have adopted an even more aggressive approach. The Canadian city currently taxes parking lots at a rate of $29.70 per square meter. The government has also reformed its zoning to permit taller buildings. The effect of these two measures together has been to prompt many commercial parking owners to sell their lots to developers.[91] These taxes can provide much-needed revenue; Montreal brings in about $23 million annually, while a KPMG study found that if Toronto, Ontario were to implement a similar measure, it would net between $171 and $535 million per

87 Grabar, Henry. "Give the Curb Your Enthusiasm." Slate, July 19, 2018, https://slate.com/business/2018/07/curb-space-is-way-too-valuable-for-cities-to-waste-on-parked-cars.html. Accessed February 3, 2020.

88 Pyzyk, Katie. "CurbFlow pilot reduced double parking in DC by 64%." Smart Cities Dive, November 14, 2019, https://www.smartcitiesdive.com/news/curbflow-pilot-reduced-double-parking-in-dc-by-64/567268/. Accessed February 3, 2020.

89 International Transport Forum, The Shared-Use City: Managing the Curb, p. 80.

90 Poon, Linda. "Buffalo Becomes First City to Bid Minimum Parking Goodbye." CityLab, January 9, 2017, https://www.citylab.com/equity/2017/01/buffalo-is-first-to-remove-minimum-parking-requirements-citywide/512177/. Accessed February 3, 2020.

91 Lampert, Allison. "Taxes on Montreal parking lots have doubled." The Gazette/Global News, January 29, 2013, https://globalnews.ca/news/385451/taxes-on-montreal-parking-lots-have-doubled/. Accessed February 3, 2020.

year. The incentive to sell parking lots leads to new development down the road, with the commensurate increase in tax revenues from higher-use projects.[92]

The Calgary Parking Authority is currently constructing a 250,000-square foot, 510-car parking garage that will eventually be converted into a residential development. Acknowledging the likely trend of lower parking demand in years to come, the Authority intends to convert their garage into multi-family housing once it has outlived its usefulness as a garage, with only minimal structural alteration required.[93]

As cities encourage development, it will be important to ensure a significant amount of the new construction is of affordable—often rental—housing. Permitting only luxury condos or townhouses will raise revenue, but will be less helpful to many members of the community who cannot afford such expensive homes. Cities can also encourage more mixed-use development and gentle density (that we define as buildings between three and six storeys), which will help reduce travel demand and sprawl. Reducing travel demand and sprawl help with the wear and tear on infrastructure and cut the need to invest in more suburban infrastructure. Moreover, density makes public transit more cost effective. When managed properly, these measures will make housing and transportation more affordable for all residents and cut pressure on city finances.

COVID-19 Commentary

When the pandemic first hit, some critics were quick to assume dense urban areas exacerbated the spread of the coronavirus. Researchers are still in the data-gathering phase, but initial evidence shows it was not density that made the crisis worse, but *crowding*. There is an important difference between the two concepts—density is the number of people who live or work in a particular place, while crowding is related to direct contact with other humans. One measure to reduce crowding is increasing the supply of affordable housing. As AVs enable repurposing parking facilities into housing and reduced parking requirements for new developments lower housing costs de-crowding can take place.

Another benefit of repurposing parking into housing, office and retail space is an increase in tax revenues from these higher value land uses. This is especially attractive, as state and local government have seen their revenues plummet with COVID-19.

92 Forman, Gideon. "Why Toronto Should Issue a Commercial Parking Levy." Torontoist, September 16, 2016, https://torontoist.com/2016/09/commercial-parking-levy/. Accessed February 3, 2020.

93 Israelson, David. "Future-proofing parking lots." The Globe and Mail, July 30, 2019 (updated August 26, 2019), https://www.theglobeandmail.com/business/industry-news/property-report/article-future-proofing-parking-lots/. Accessed February 3, 2020.

Getting Started

Already, conventional TNCs are reducing parking demand in some communities, and city governments are looking to encourage greater densification and urban development for social, fiscal, and environmental reasons. We therefore believe it makes sense to move towards new revenue models today, rather than waiting for the arrival of AVs—as by then, cities will already be feeling the financial pinch of this new technology. While no single silver bullet will mitigate the decline by itself, using a range of tools will likely be more politically feasible and will lead to changes in urban form over time.

Step 1: Understand Your Revenues and the Policy Levers You Can Pull

In order to ensure that your city government will recover revenues lost during the transition to AVs, it is important to take stock of the revenue that may dwindle with their arrival. Different cities have the existing ability to levy different fees (due to state-given authority), so coming up with a comprehensive total will provide a hard number that officials can use when determining future fee rates—to cover funding losses without being excessive.

Simultaneously, officials should determine what authority they have to implement new rates on companies, passengers, and developers. While most cities across the country share a number of powers—such as the ability to charge for parking—some cities have been granted additional abilities through state legislation. Knowing whether your state has expressly permitted or prohibited certain activities, like the right to institute a charge on TNCs or to place a tax on parking lot space, will show what tools you have at your disposal as you look to recuperate lost revenue.

Where you do have authority, consider the very clear objective of imposing a new fee. A per-trip fee was an appropriate first response to this new technology on city streets, for instance, but would likely be inadequate for compensating a city for lost parking and ticket revenue, let alone trying to mitigate congestion. More advanced mechanisms can accomplish governmental goals more effectively, so understanding the tools at your disposal, and the resources necessary to enforce each one, is an important first step to ultimately solving urban challenges.

Citizens are generally not favorable to parking fees, and TNCs may try to foster opposition to future curb access fees as well. As such, officials will want to have a communications strategy in place to win support for these measures. Parking guru Donald Shoup recommends that parking charges should be set to ensure there are always one or two spaces available and that revenues raised should be invested back into the community; similarly, cities will want to make clear that their goal is to keep one or two spaces available at all times for drop-offs, and consider committing to investing at least a portion of the funds raised back into the surrounding community.

Step 2: Identify Existing Curb Demand and Areas for Flexible Curb Space

This step aligns closely with Policy Action 2, with officials better understanding the different demands of their curb space. Where possible, local government can require TNCs to provide data on pick-up and drop-off locations (batched into streets and times of day to ensure customer anonymity). Alternately, cities can use historical parking data to track downward or upward trends in parking demand, or more traditional measures such as surveys to monitor where TNC demand is greatest. Like Washington, they will then be able to determine advantageous sites for flexible curb usage pilot projects, with an eye toward eventually implementing a pilot project in the busiest areas.

If resources allow, cities can also move towards a dynamic paid parking plan, like SF*park*, to help citizens become more familiar with flexible pricing that helps shift demand.

Step 3: Ensure All Loading Zone Signage Is Specific, Visible and Managed

To help citizens become more comfortable with flexible curb use, signage should be very clear in any areas of change. Some cities offer videos explaining changes, and as much as possible, cities should launch information campaigns to inform citizens about new expectations—especially during any pilot projects. Some cities use fun informational campaigns to engender support for paid parking (for example, a parking meter posting notices such as, "Your parking fee today paid to mow 130,000 blades of grass at Huntington Park" nearby). A similar strategy can be used when informing citizens about curbside charges.

Step 4: Confirm Current Tax Code Doesn't Incentivize Parking Lots

Some municipalities vary tax rates across property classes and across neighborhoods. The tax rate on higher-density apartment buildings is greater than on single-family dwellings, for example. It is common for cities to charge a lower tax rate on parking lots than built structures, and some cities do not include parking garages when calculating the floor-area ratio of a building. These measures have made it relatively more attractive to build parking lots or garages than more productive developments.

It is important to understand the existing tax code, and then propose areas for reform. Oftentimes tax structures run counter to the stated objectives in a city's master plan, such as densification, the promotion of active public transportation, and fostering more complete communities. As much as possible, cities should modify the tax structure such that it acts as both carrot and stick to promote densification, especially as parking demand dwindles.

Step 5: Determine Appropriate Areas for Eliminating Parking Minimums

While reforming the zoning code to eliminate parking minimums often lies with city council, officials can prepare a recommendation as to where removal is most appropriate. Most cities have begun in the downtown area, but other areas might be equally suitable. Likely candidates are dense places with good access to transit that have a strong mix of uses. San Diego, for instance, eliminated requirements for parking on sites within a half-mile of a transit stop.[94]

Quick Notes

The Concept

- Municipal and state governments rely on revenue from private vehicles through gas tax, parking fees and driving or parking violations.
- These revenues have been declining; market entry of AVs will speed up the decline.
- Transportation charges and land use/property taxes can make up for the shortfall.

The Landscape

- Washington and Oregon are experimenting with vehicle miles traveled (VMT) fees.
- San Francisco and Los Angeles adjust parking fees based on demand.
- Washington, D.C.'s pick-up/drop-off zone pilot cut double parking by 64 percent in the study area.
- Buffalo has eliminated parking space requirements on new developments.
- Montreal charges a very high property tax on parking facilities to stimulate higher-value land use.

Getting Started

1. Understand your revenues and the policy levers you can pull.
2. Identify existing curb demand and areas for flexible curb space.
3. Ensure all loading zone signage is specific, visible and managed.
4. Confirm current tax code does not incentivize parking lots.
5. Determine appropriate areas for eliminating parking minimums.

94 Pacheco, Antonio. "San Diego eliminates parking requirements for transit-adjacent projects." The Architect's Newspaper, March 6, 2019, https://archpaper.com/2019/03/san-diego-eliminates-parking-requirements-for-transit-adjacent-projects/. Accessed February 3, 2020.

VI. PILOT PROJECT GUIDELINES

Municipalities around the globe are running AV experiments that explore how the policy issues described above can be addressed. Each pilot reflects the unique context and objectives of that community. Based on what we have observed, we present below the key guidelines for municipalities to consider in order to undertake a successful pilot project.

1. **Determine jurisdiction.** As creatures of their respective states, not all cities have the same authority when it comes to different AV interventions. Louisville, for example, controls its own transit network and can therefore unilaterally make choices about transit deployment, but in Boston, public transit is controlled by a state-level entity. Once you have determined an area for intervention, you must consider whether you can act alone or build a coalition of willing partners. In the latter case, you must think about how to propose the initiative to other government agencies in a way that resonates with them and craft a funding model that can satisfy all parties. If this is not possible, you might need to look at a pilot project in which you have full control.
2. **Determine what "success" looks like.** Mobility expert David Zipper has written a useful policy brief on pilot projects. His main takeaway is that a successful pilot project is not one where the specific service works, but one that "produces data that informs a public decision to either accept or reject its hypotheses about the new mobility technology." It is important to understand, specifically, what you want to know, what metrics you will use to assess that knowledge, and whether you have the capacity to gather and evaluate the metrics. Be sure to speak with officials outside of your transportation department, as they might have insights or ideas that are important but beyond the lens of transportation planning alone. As part of this process, also do not be afraid to reach out to cities and states that have pilots underway. How did they determine what success looked like and what to measure? What were they able to measure, and where did struggles arise? Finding out this information allows you to build on what has already been done, and if you offer to share data with your contacts, it can help develop a reciprocal network of data-gathering local governments. Finally, you must do thorough community consultation, in order to understand the needs of your stakeholders and what concerns and opportunities they foresee.

For policymakers, act now and proactively plan to make your community's AV future happen, rather than passively waiting for that future to "happen to you."

3. **Reach out to appropriate partners.** Once you have determined your objectives, you will need to issue a Request for Proposals. We encourage you to go beyond merely putting out a call and waiting for responses. Instead, determine which companies might have a product that can most appropriately meet your needs. Similar to firms using a headhunter to find the best candidates, cities need not be afraid to alert appropriate companies to an opportunity. If you have previously determined the specific criteria for and measurements of success, they will know what to expect from the relationship (around data-sharing, level of service, and other criteria), which should help encourage only serious candidates to apply.
4. **Craft a robust communications strategy.** We believe the potential benefits of AVs merit a controlled pilot. It is important to communicate the goals and expected advantages of the initiative (for instance, less congestion, more equitable access and environmental gains) to the public while also addressing any concerns (for instance, fears about AV safety or employment impact). Research at MIT has found many politicians view AVs as more of an economic development tool than a solution to transportation problems. If officials support the project under this pretense, they may be disappointed with future results. It is best to clarify your project's limited objectives early, show the direct benefit to citizens within the target area, and then use effective communication tools (including social media, traditional media and several others).

Above all, we encourage you to recognize that any pilot project will be about more than just moving people from place to place. It will be about introducing your citizens to automated technology, so you should think carefully about how you would like to do that: will it be in a car, or will you inject some excitement into your transit system by having people first experience automation on a bus? Whatever you ultimately decide, once AV companies put their vehicles on your roads and begin to build a coalition of supportive customers, it will be more difficult for you to modify deployment if it is not meeting local objectives around sustainability, mode shift, or equity. Therefore, we encourage you to act now and proactively plan to make your community's AV future happen, rather than passively waiting for that future to "happen to you."

VII. ACKNOWLEDGEMENTS AND CONTACT INFORMATION

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For more information about AV policy or hosting a scrum, visit the AVPI website. We welcome your questions or comments. Mark Fagan, Lecturer in Public Policy and Director of the AVPI, can be reached at mark_fagan@hks.harvard.edu.

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