NCHRP Project 20-113F

Preparing for Automated Vehicles and Shared Mobility: State-of-the-Research Topical Paper #9

IMPACTS AND OPPORTUNITIES AROUND LAND USE AND AUTOMATED VEHICLES AND SHARED MOBILITY

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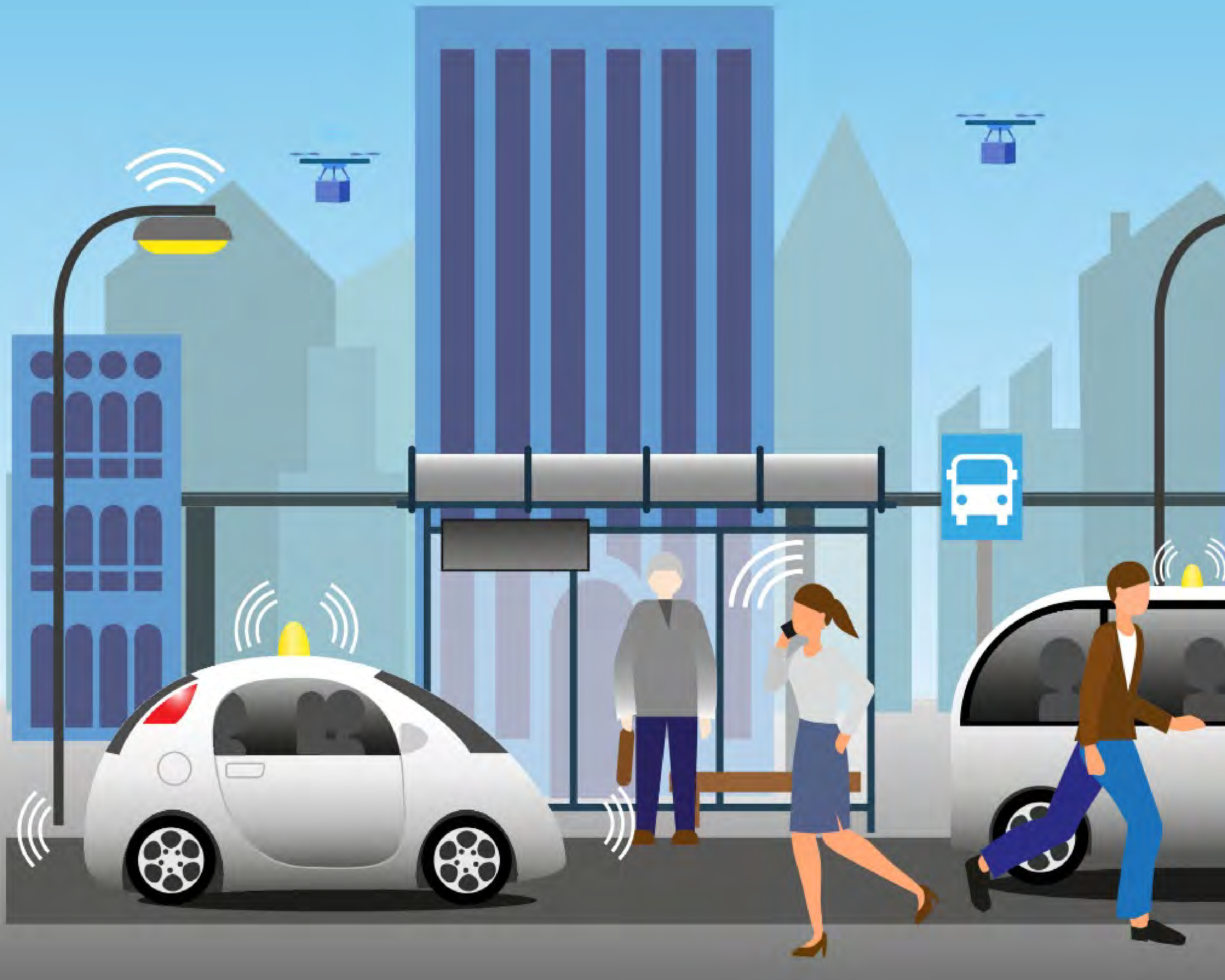
TRB AV/SM FORUM
AUTOMATED VEHICLES + SHARED MOBILITY

1 Introduction

1.1. Background

In coordination with the National Cooperative Highway Research Program (NCHRP), the TRB Forum on Preparing for Automated Vehicles and Shared Mobility (Forum) has developed nine (9) Topical Papers to support the work of the Forum (Project).

The mission of the Forum is to bring together public, private, and research organizations to share perspectives on critical issues for deploying AVs and shared mobility. This includes discussing, identifying, and facilitating fact-based research needed to deploy these mobility focused innovations and inform policy to meet long-term goals, including increasing safety, reducing congestion, enhancing accessibility, increasing environmental and energy sustainability, and supporting economic development and equity.



The Topical Areas covered as part of the Project include the following:

- Models for Data Sharing and Governance
- Safety Scenarios and Engagement during Transition to Highly Automated Vehicles
- Infrastructure Enablers for Automated Vehicles and Shared Mobility
- Maximizing Positive Social Impacts of Automated Vehicle Deployment and Shared Mobility
- Prioritizing Equity, Accessibility and Inclusion Around the Deployment of Automated Vehicles
- Potential Impacts of Highly Automated Vehicles and Shared Mobility on the Movement of Goods and People
- Impacts of Automated Vehicles and Shared Mobility on Transit and Partnership Opportunities
- Implications for Transportation Planning and Modeling
- Impacts and Opportunities Around Land Use and Automated Vehicles and Shared Mobility

For this Project, the important goals of the papers are to provide a snapshot of all research completed to date for a Topical Area and within the proposed focus areas identified below. The papers are intended to provide a high-level overview of the existing research and to make recommendations for further research within a Topical Area. The Project establishes a foundation to guide the use of resources for further development and support of more comprehensive research that tracks the identified research gaps noted in each Topical Paper and to support the Forum.

The research reviewed varies by paper, but generally, only published research was included as part of the Project. For clarity, the scope of the project is to report on research that has been done without judging or peer reviewing the research conducted to date and referenced herein. While considered for background purposes, articles, blog posts, or press releases were not a focus for the work cited in the Topical Papers. Also, in consideration of the focus of the Forum and the parameters of the Project, the research was narrowed to publications focused on the intersection between automated vehicles and shared mobility. Materials reviewed and cited also include federal policy guidance and applicable statutes and regulations.

Each of the papers are written to stand on its own while recognizing there are cross over issues between the Topical Areas. If desired, readers are encouraged to review all 9 Topical Papers for a more comprehensive view of the Project and the points where topics merge.

The goals of the Topical Papers are the following:

Snapshot of research completed under a particular topic area

Summary of research completed to date

Identification of gaps in research

Recommendations for additional research

1.2. Approach to Topical Paper Development

The approach to development of the Topical Papers and their focus included the following:

- Meetings with the Chairs of the Forum
- Engagement with the Members of the Forum, including during the Forum meetings in February and August of 2020
- Feedback from Chairs and Forum Members during the development of focus areas for the Topical Papers and receiving comments to the draft versions of the papers

During the meetings with the Forum in February 2020, the research team discussed the Project with the Forum over two days in two separate sessions. On Day 1, the research team presented the proposed scope for each Topical Paper and broke out into break-out groups to further refine the focus of each paper to match the interest and goals of the Forum and its Members. During Day 1, the Forum also heard from different organizations highlighting previous and ongoing research. These organizations[1] included the following:

- Brookings Institution
- The Eno Center for Transportation
- National Governors Association
- Future of Privacy Forum
- AARP
- American Public Transportation Association

On Day 2, the research team reconvened with the Forum to summarize the break-out discussions on Day 1 and to receive final comments on the focus for each Topical Paper.

In August 2020, the draft papers were presented to the Forum for review and feedback. Comments were received in writing and verbally during a virtual Forum meeting. The final papers incorporate the comments and feedback received as part of the review process. This paper identifies a large body of research regarding this topic area associated with shared and automated vehicles. As reviewer comments pointed out, there remains considerable uncertainty regarding if and when highly automated vehicles will be deployed on a large scale. This is reflected in much of the research that has been completed to date. Consequently, this paper summarizes common themes from the research available to date as much as possible, while acknowledging that various scenarios may impact the issues, recommendations, and areas for future research. Many of the issues addressed in this research are forward-looking and anticipate an environment where fully automated vehicles (SAE Level 5) are a ubiquitous part of the transportation system.

[1] The research team and the Forum thank these organizations for their time in sharing their work and insights in support of the development of the Topical Papers.

2 Paper Areas of Focus

This Topical Paper reviews research conducted and published as of July 10, 2020, unless specific papers were identified as part of the final review and comments process. In approaching this topic, the paper focuses on the following issue areas:

1. Examine the role that land use plays in AVs supporting a transportation future with more smart mobility innovations, including pricing of right-of-way and conversations around affordable housing
2. Discuss the practical implications of each community having different infrastructure needs, while also acknowledging the benefits of proactive alignment, including building codes for new developments, reduced parking requirements, innovation corridors, and incentives for community minded and economic focused public-private partnerships
3. Evaluate opportunities to merge policy discussions between transportation and housing
4. Consider the convergence between transportation and telecommunications, including 5G siting issues

3 Summary of Findings

The paper identifies a large body of research around land use and AVs. Through reviewing the body of literature on impacts arising from AVs/HAVs within the context of the areas of focus noted above, several common themes emerge:

- **Shifts to HAVs and greater shared mobility strategies will impact land use patterns, particularly in the urban environment**. This body of literature identifies that HAVs are likely to promote transformations in parking, curb use, and access as well as flagging considerations for needed changes to planning, urban design and development. In a predominantly HAV environment, there is the potential that the resulting decrease in road and parking space needs will open new options for land use; such as affordable housing, curb and parking space usage, and mobility deployments. There is also a small body of research around the varying infrastructure implications, with different types of community experiencing varied impacts and needs. The literature identifies ways that cities and local governments should prepare for AVs, such as through planning and new ordinances. The research also suggests merging policy discussions between traditional forms of transportation and housing, with specific focuses on transit-oriented development, multi-modal hubs and infill housing on reclaimed land.

- **The widespread use of HAVs seems likely to compound the curb/sidewalk management issues now seen with TNCs and micromobility vehicles**. The research notes that parking and curbside management are the two land use areas that are expected to be most affected by HAVs. A comprehensive use of HAVs will dramatically shift the emphasis from parking to curb management. The future view of an HAV-prominent streetscape frequently incorporates more flexible zones that change in use throughout the day. A world of HAVs precisely programmed to obey traffic laws will require specific loading and unloading zones for both passengers and freight.

- **Management of the public right-of-way in an era of increased AVs can afford greater shared mobility, equity, and accessibility.** The literature suggests that curb management will create added incentives for governmental policies that promote more shared mobility. In enabling this transformation, these changes must also ensure prioritization around equity and accessibility, in addition to considerations around existing requirements under the Americans with Disabilities Act (ADA).

- **5G telecommunications may require up to five times the number of small cells as 4G, leading to more land use conflicts in urban areas, heavy investment requirements in rural communities, and a much higher level of regulatory involvement**. The literature focuses on the types of telecommunications technology that will support automated and connected vehicles, including considerations around 5G and 5G siting issues. More research around the convergence of telecommunications and transportation within the context of future connectivity is warranted.

4 Summary of Research Reviewed

The research reviewed includes papers from academic journals, federal entities, and special interest groups. This points to a cross-sector interest in understanding the land use impacts of AVs. The following is a summary of the research reviewed. The full list of research reviewed is available in the references section of this paper.

4.1 Examine the role that land use plays in AVs supporting a transportation future with more smart mobility innovations, including pricing of ROW and conversations around affordable housing.

Much of the research around land use focuses on physical land use changes as a result of AVs, particularly HAVs. The curb is a key area of research, including changes to the curbside, right-of-way, and new curb innovations like shared-use mobility zones. Parking is perhaps the largest body of research for land use, as AVs under certain deployment scenarios are anticipated to dramatically impact parking needs. An additional area of research is how widespread use of AVs will provide opportunities for transforming former parking lots to affordable housing, among other uses.

4.1.1 AVs and Land Use

There is a growing body of research around more general land use issues associated with AVs. Rouse et al. that the shift to automated and shared mobility will change land use patterns.[2] This is echoed throughout the research reviewed. Crute et al. note that AVs will affect the built environment in various ways, including parking, curb space, right-of-way designs, access management changes, changes to signage and signals, and new models for pedestrian and bicycle infrastructure.[3] Howell et al. state that there are two major ways that AVs will affect land use.[4] First, the supply of land will increase from the decrease in the supply of parking and traditional automobile uses. Second, there will be a shift in the type and location of land needed, especially in terms of commercial and industrial land. Howell et al. also argue that this shift comes from a decreased need for traditional auto-oriented land use.[5]

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[2] David C. Rouse et al., "Preparing Communities for Autonomous Vehicles," 2018.
[3] Jeremy Crute et al., *Planning for Autonomous Mobility*, 2018, www.planning.org.
[4] Amanda Howell et al., "Multilevel Impacts of Emerging Technologies on City Form and Development," 2020.
[5] Amanda Howell et al., "Multilevel Impacts of Emerging Technologies on City Form and Development," 2020.

There is some concern in the research that AVs will increase sprawl. Howell et al. (2020) note that more people may choose to live in the suburbs if travel costs are reduced with AVs, and this may increase sprawl.[6]

Some of this research focuses on planning for AVs, land use, and the built environment. Rouse et al. discuss the approach to land use planning.[7] A key message is that the public and private sectors need to change the way they approach planning, urban design, and urban development at the street, district, city, and regional levels. Physical space is discussed as well. AVs will be able to travel closer together, reducing the width of street pavement and freeing up curb space and sidewalk space.[8] The Regional Plan Association notes that urban and suburban planning strategies for land use will be different from each other.[9] Issues for urban planning include regulating street and curb space, as well as addressing public transportation impacts.

Issues for suburban planning include managing new traffic issues from AVs, redeveloping large spaces previously used for parking, and adapting current land use policies to fit AVs. Crute et al. give strategies and recommendations for planners to prepare for AVs now.[10] They write that planners must prepare for various impacts from AVs on their communities. Planners should evaluate current parking standards, support transportation demand management work, rethink the right-of-way for non-automobile modes of transportation, and begin to evaluate how AVs can help a public transit system.

4.1.2 Land Use and the Curb

Research around curb space notes that this is one of the areas that will see the most significant change in land use. Crute et al. note that planners have already begun to see shifts in the curbside space with ridesharing.[11] Howell et al. find that the curb has a new level of importance as demands for curb space have increased.[12] Demands for curb space include parking for vehicles and micromobility like scooters or bikes, passenger and goods unloading zones, and transit lanes. The introduction of AVs into this environment will aggravate issues at the curb these vehicles will need as more loading and unloading space. Some street design and curb design changes will be needed to alleviate demands on the curb from increased loading and unloading and deliveries from AV trucks. Another report by Howell et al. notes that cities are anticipating that future commercial deployment of autonomous vehicles will function similar to current TNCs.[13] The authors write that since AVs will be precisely programmed to obey traffic

[6] Howell et al., "Multilevel Impacts of Emerging Technologies on City Form and Development."
[7] Rouse et al., "Preparing Communities for Autonomous Vehicles."
[8] Rouse et al.
[9] Regional Plan Association (RPA), "New Mobility: Autonomous Vehicles and the Region," no. October (2017): 1–36, http://library.rpa.org/pdf/RPA-New-Mobility-Autonomous-Vehicles-and-the-Region.pdf.
[10] Crute et al., *Planning for Autonomous Mobility*.
[11] Crute et al.
[12] Howell et al., "Multilevel Impacts of Emerging Technologies on City Form and Development."
[13] Amanda Howell et al., "New Mobility in the Right-Of-Way," 2019.

laws, they will need access to designated zones to pick up and drop off passengers as opposed to an ad hoc approach.[14]

One aspect of the curb that was mentioned in the research was the set of changes to the right-of-way that will come with AVs and shared mobility. Cohen and Shaheen (2016) note that shared mobility, not just automated mobility, will affect land use and the right-of-way.[15] Public

[14] Howell et al.
[15] Adam Cohen and Susan Shaheen, "PAS Report 583: Planning for Shared Mobility," 2016, 110, www.planning.org/pas/index.htm.

rights-of-way play a major role in the growth of shared mobility. The most common way that local governments provide access to curb space for shared mobility, such as carsharing, bike sharing, and loading zones for TNCs, is through the public right-of-way. If policies for the right-of-way and shared mobility are developed now, these could form the foundation for AVs and the right-of-way.[16]

Howell et al. note that increased competition for the right-of-way will impact street design and the amount of space each mode of travel is given on a street. Competition for the right-of-way will come from passenger AVs as well as parcel and freight deliveries on AV trucks. Fehr and Peers addresses this competition in a study done for Uber, noting that concerns over curb space are leading to calls to define and prioritize modes of transportation on some streets to increase the efficiency of the right-of-way.[17] Rouse et al. note that AVs will require less road space than current vehicles.[18] This may mean that future

Shared mobility, not just automated mobility, will affect land use and right-of-way

[16] Adam Cohen and Susan Shaheen, “PAS Report 583: Planning for Shared Mobility,” 2016, www.planning.org/pas/index.htm.
[17] Fehr and Peers, “San Francisco Curb Study,” 2018.
[18] Rouse et al., “Preparing Communities for Autonomous Vehicles.”

It is also important to consider how changes in land use will ensure prioritization around equity and accessibility

roads will need less pavement and space for vehicles, opening up extra space on the public right-of-way to pedestrian and bicycle networks.[19] One idea in the research around the curbside impacts of AVs was shared use mobility zones. Barth notes that shared-use mobility zones encourage eliminating small sections of street parking.[20] The curb space that was used for parking is then turned into a "terminal" at the beginning or end of a block for loading and unloading passengers and goods. Curbside flex zones are more commonly used today rather than a full shared-use mobility zone. Washington, D.C. carried out a delivery pilot with flex zones and Seattle also implements flex zones.[21]

Research found that AV parking will impact the curb. Crute et al. also discuss how pick-up and drop-offs will be different without parking.[22] The transition from parking to drop-off areas will have implications for access management. Passengers do not need to be with the AV when it parks, enabling passengers to be dropped off directly at their destination instead of where parking is available. AVs will shift priorities away from parking to loading and unloading zones. Some research found that residential development could be affected by changing parking. Howell et al. find that decreased parking may free up space for urban redevelopment.[23] This may create opportunities for new residential development on land that was previously parking. Residential development density may increase as lower parking requirements reduce housing costs. Less parking could encourage infill development and improve the viability of affordable housing. As noted below, these themes support both additional research around identifying use cases for AVs and policy development around how to prioritize space to maximize the positive benefits of AVs.

Rouse et al. discuss planning for curbside space.[24] Planners and public officials will need to address local zoning codes' requirements for passenger loading and unloading zones and parking needs.[25] Roe and Toochek recommend that cities begin to think about prioritizing

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[19] Other papers that echo this research include Steckler's "Navigating New Mobility: Policy Approaches for Cities" and Lewis and Steckler's "Emerging Technologies and Cities: Assessing the Impacts of New Mobility on Cities".
[20] Brian Barth, "Curb Control," *Planning* 85, no. 6 (2019): 18–25.
[21] Howell et al., "New Mobility in the Right-Of-Way."
[22] Crute et al., *Planning for Autonomous Mobility*.
[23] Howell et al., "Multilevel Impacts of Emerging Technologies on City Form and Development."
[24] Rouse et al., "Preparing Communities for Autonomous Vehicles."
[25] Rouse et al.

transit in curbside regulations to prepare for AVs.[26] These cities will be one step closer to incentivizing shared automated mobility and transit rather than single-occupancy travel, which will clog the curb.[27] The International Transport Forum (2018) notes that cities need to manage curbs to provide passenger loading and unloading and work that into comprehensive plans.[28] In planning for the curb and AVs, it is also important to consider how changes in land use will ensure prioritization around equity and accessibility. This includes making sure that new technologies "understand" ADA requirements. For example, there have been documented instances where sidewalk automated delivery robots have blocked curb cuts, thereby impeding people in wheelchairs from crossing the street.[29]

4.1.3 Parking

Research around AVs and parking shows that parking is one of the areas that could be most affected by AVs. Rouse et al. note that AVs are expected to free up land that is currently used for parking and remove the need for minimum parking requirements.[30] These two themes are common in research around AVs and parking. Crute et al. echo this, noting that AVs will reduce the demand for parking and alter the design and location of parking.[31] Schlossberg et al. note that it is likely that on-street parking will be eliminated, and lane width could be reduced to as little as 10 feet, allowing the repurposing of those spaces.[32] This is also echoed in Litman.[33]

Another theme around AVs and parking is the redesign of parking facilities for AVs. Howell et al. find that as parking declines, the location of parking and vehicle storage will likely shift to regional hubs for widespread access. Parking may be in concentrated hubs for storage and vehicle charging.[34] Nourinejad, Bahrami, and Roorda note that AVs will have a major impact on parking structure design. Instead of the current parking garage design, future parking structures can have rows of vehicles stacked behind each other.[35]

There are also concerns expressed around AVs and parking. Millard-Ball notes that AVs will not need to park close to their destination and could seek out free on-street parking or "cruise" without parking.[36] Cruising is less costly at low speed, and in Millard-Ball's framework, there is an incentive to cruise and generate congestion and clog local streets; a traffic simulation model

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[26] Matthew Roe and Craig Toochek, "Curb Appeal: Curbside Management Strategies for Improving Transit Reliability," no. November (2017): 1–12, https://nacto.org/wp-content/uploads/2017/11/NACTO-Curb-Appeal-Curbside-Management.pdf.
[27] Roe and Toochek.
[28] ITF Corporate Partnership Board, "The Shared-Use City: Managing the Curb Corporate Partnership Board Report Corporate Partnership Board CPB," 2018, www.itf-oecd.org.
[29] Emily Ackerman, "My Fight With a Sidewalk Robot," *CityLab*, 2019.
[30] Rouse et al., "Preparing Communities for Autonomous Vehicles."
[31] Crute et al., *Planning for Autonomous Mobility*.
[32] Marc Schlossberg et al., "Rethinking the Street in an Era of Driverless Cars," 2018.
[33] Todd Litman, "Autonomous Vehicle Implementation Predictions: Implications for Transport Planning," 2020.
[34] Howell et al., "Multilevel Impacts of Emerging Technologies on City Form and Development."
[35] Mehdi Nourinejad, Sina Bahrami, and Matthew J. Roorda, "Designing Parking Facilities for Autonomous Vehicles," *Transportation Research Part B: Methodological* 109 (2018): 110–27, https://doi.org/10.1016/j.trb.2017.12.017.
[36] Adam Millard-Ball, "The Autonomous Vehicle Parking Problem," *Transport Policy* 75, no. December 2018 (2019): 99–108, https://doi.org/10.1016/j.tranpol.2019.01.003.

shows that AVs could double vehicle travel within urban areas. Harper, Hendrickson, and Samaras also find that AVs may increase VMT while looking for parking.[37] They used data from Seattle to indicate that at low levels of AV use, an AV would travel an extra 3-4 miles per day and at high levels of AV use, an AV could travel an extra 5-8 miles a day.[38]

Crute et al. note that changing environment parking standards and requirements need attention.[39] Rouse et al. state that comprehensive plans should set the direction for the shifting land use patterns, including parking, that are anticipated with AVs.[40] Millard-Ball suggests implementing congestion pricing in urban centers to disincentivize such negative effects.[41]

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[37] Corey D. Harper, Chris T. Hendrickson, and Constantine Samaras, "Exploring the Economic, Environmental, and Travel Implications of Changes in Parking Choices Due to Driverless Vehicles: An Agent-Based Simulation Approach," *Journal of Urban Planning and Development* 144, no. 4 (2018).
[38] Harper, Hendrickson, and Samaras.
[39] Crute et al., *Planning for Autonomous Mobility*.
[40] Rouse et al., "Preparing Communities for Autonomous Vehicles."
[41] Millard-Ball, "The Autonomous Vehicle Parking Problem."

4.1.4 Affordable Housing

Research around affordable housing and AVs focuses on leveraging the availability of land no longer needed for parking to create more affordable housing. However, more research is warranted on affordable housing and AVs, including how to structure viable policy incentives to bring such ideas to fruition. Rouse et al. note that reduced space and infrastructure costs and requirements resulting from AVs can create opportunities for more affordable housing.[42] Howell et al. write that side effects from AVs on land use will likely shift housing affordability.[43] They mention that one risk is the suburbanization of poverty. Alternatively, changes in parking may lower the cost of living for low-income groups in job-rich areas. Larson and Zhao find that AVs can lead to greater housing affordability if the increased land supply resulting from unused parking is redeveloped into housing.[44] The authors note that suburban land is more accessible through lower commuting costs with AVs and urban land is more accessible through repurposing land used for parking. Due to supply and demand principles, normally with more available land, the price of housing falls. Rouse et al. mention a regulatory approach in anticipating the increased density possible with AVs to meet affordable housing goals.[45] The Regional Plan Association (2017) suggests that governments should specifically rezone and repurpose parking lots to provide affordable housing.[46]

Reduced space and infrastructure costs and requirements resulting from AVs can create opportunities for more affordable housing

[42] Rouse et al., "Preparing Communities for Autonomous Vehicles."
[43] Howell et al., "Multilevel Impacts of Emerging Technologies on City Form and Development."
[44] William Larson and Weihua Zhao, "Self-Driving Cars and the City: Effects on Sprawl, Energy Consumption, and Housing Affordability," *Regional Science and Urban Economics* 81, no. October 2019 (2020): 103484, https://doi.org/10.1016/j.regsciurbeco.2019.103484.
[45] Rouse et al., "Preparing Communities for Autonomous Vehicles."
[46] Regional Plan Association (RPA), "New Mobility: Autonomous Vehicles and the Region."

4.1.5 Pilots, Concepts and New Standards

There are several noteworthy projects, concepts, and new standards around land use that set the stage for land use considerations related to AVs and shared mobility. Examples include the following:

- Washington, D.C. completed a pilot project from August to October 2019 to allow delivery drivers to reserve space at the curb. Grid Smarter Cities created the "Kerb" software, which allows drivers to reserve virtual loading bays or turn curb space into paid loading and unloading zones. It was announced in May 2019 that Grid Smarter Cities and Dublin, Ireland were working on a pilot of Kerb.
- In 2017, the City of Buffalo was the first U.S. city to change its standards to eliminate city-wide parking minimums.
- Sidewalk Labs' Sidewalk Toronto Quayside project aimed to develop around connectivity and mobility, including complete streets, walkable streets, enhanced cycling and accessibility options, and new mobility services.[47] The new mobility services included planning for AVs and automated freight. This project was cancelled in May of 2020.
- Chandler, Arizona, is the only city in the United States that has changed its land use ordinance with a focus on increasing AVs and ridesharing, potentially reducing future parking needs by 40%.[48]
- Sacramento, CA added a transit-oriented development amendment to the land use code in 2019.

4.2 Discuss the practical implications of each community having different infrastructure needs, while also acknowledging the benefits of proactive alignment, including building codes for new developments, reduced parking requirements, innovation corridors, and incentives for community.

As indicated in 4.1.5, changes in how communities will accommodate AV are already starting. The varying approaches to infrastructure and land use offer an opportunity for research and standardization of approaches to promote the consistent deployment of AVs and to support shared mobility. As noted below, examples of new approaches to land use that communities are currently implementing can provide a good starting point to support continued coordination around land use and AVs. A common goal around these communities' investment in resources aims to prepare for the future land use and infrastructure needs of AVs.

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[47] Sidewalk Labs cancelled the Sidewalk Toronto Quayside project on May 7, 2020. Economic uncertainty was cited as a reason for canceling the project. However, the project and associated planning documents offer insights into the convergence of planning, land use, and next generational mobility solutions. For more: https://medium.com/sidewalk-talk/why-were-no-longer-pursuing-the-quayside-project-and-what-s-next-for-sidewalk-labs-9a61de3fee3a

[48] "Chandler AZ Development Sevices Memo No. PZ18-024," n.d.

4.2.1 Communities and Infrastructure

There is some research around the issue that although each community has different infrastructure needs, all communities still need to take proactive steps to address AVs. Much of this research agrees that there are no one-size-fits-all solutions and the primary focus is on what cities and local governments should do to prepare for AVs. Rouse et al. note that as cities transition away from existing ordinances that compel specific set-asides of land for parking, they need to determine the new land use and

If AVs allow for a more efficient use of existing traditional infrastructure, the result may be a reduced demand for future investments in roads and bridges

zoning ordinances that will address the next generation of transportation.[49] They suggest that part of that change should be moving from prescriptive use regulations to more flexible approaches that accommodate changing parking demand, evolving vehicle use, and the transition to more shared mobility formats. Many of the recommended changes in comprehensive plans or zoning focus on eliminating or significantly reducing minimum parking requirements.

Form-based and performance codes and zoning are two potential approaches to provide increased flexibility. Howell et al. note that density and mixed-use standards should be incorporated into comprehensive plans and zoning ordinances.[50] Duvall et al. (2019) observe that if AVs allow for a more efficient use of existing traditional infrastructure, the result may be a reduced demand for future investments in roads and bridges.[51] Further, if AVs need more advanced sensor and signal networks, governments may transition from investing in traditional traffic signals.

Chandler, Arizona is the only city in the United States that has changed its land use ordinance specifically for AVs.[52] The amendments focus on preparing Chandler for an increase in AVs and ridesharing in the future, allowing parking reductions and encouraging passenger loading zones. Chandler will have the ability to reduce up to 40% of parking when a parking demand study finds that parking demand is decreased by an increase in AVs.

4.2.2 Pilots, Concepts, and New Standards

Several policies and standards have been enacted to prepare communities for AVs and shared mobility options. As stated above, Chandler, Arizona is the only U.S. city to change a land use ordinance specifically for AVs. Other examples of new policies include Seattle, Washington; Buffalo, New York; Vancouver, British Columbia; and Sacramento, California. Seattle's Department of Transportation published Seattle's New Mobility Playbook, a set of strategies for shaping the future of transportation in Seattle.[53] In 2017 Buffalo, New York became the first major U.S. city to eliminate parking minimums citywide.[54] Vancouver, British Columbia now requires all new multifamily buildings to install electric vehicle charging stations for their residents. Sacramento, California added a transit-oriented development amendment to its land use code.[55]

4.3 Evaluate opportunities to merge policy discussions between transportation and housing.

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[49] Rouse et al., "Preparing Communities for Autonomous Vehicles."
[50] Howell et al., "Multilevel Impacts of Emerging Technologies on City Form and Development."
[51] Tyler Duvall et al., "A New Look at Autonomous Vehicle Infrastructure," 2019.
[52] "Chandler AZ Development Sevices Memo No. PZ18-024."
[53] Seattle Department of Transportation, "New Mobility Playbook, 1.0," 2017, http://www.seattle.gov/Documents/Departments/SDOT/NewMobilityProgram/NewMobility_Playbook_9.2017.pdf.
[54] Linda Poon, "Buffalo Becomes First City to Bid Minimum Parking Goodbye," *CityLab*, 2017, http://www.citylab.com/housing/2017/01/buffalo-is-first-to-remove-minimum-parking-requirements-citywide/512177/.
[55] City of Sacremento, "City Council Report," 2014, http://www.scottsdaleaz.gov/Asset51613.aspx.

Much of the research on merging transportation and housing policy focuses on TODs. However, some of the research focuses on transforming land made available by the adoption of AVs into housing as discussed in Section 4.1.4. Several cities have implemented TOD ordinances, the most notable of which is Sacramento. As new potential use cases for AVs are considered, moving outside of the urban environment and into suburban and rural areas provides the opportunity to develop new models that merge housing and mobility to take advantage of the land use efficiencies that can come from AVs.

4.3.1 Transit-Oriented Development

TODs are a key policy development merging transportation and housing. Lu et al. (2017) note that AVs could expand the reach of TODs.[56] AVs could be integrated into TODs to boost transit systems, expand their reach, reduce the need for expansion, and leave land available for higher density development rather than being developed into a transit station.[57] Howell et al. note that if AVs are limited to certain areas, they may contribute to increasingly expensive housing, potentially displacing existing populations.[58] The authors state that, in some cases, this has been seen as property values increased around transit stations and in TODs. New transportation technology, along with redevelopment of space and urban design, may mainly attract higher income populations who can afford to live in the places with those services. Shared vehicles could also expand the reach of TODs. Examples include Communauto in Canada, Car2Go (formerly in the United States), and Zipcar.[59]

4.3.2 Land for Housing

As previously discussed, as more land is available for redevelopment, the overall supply should increase. Schlossberg et al. note that the land formerly used for parking could be used for infill housing and non-auto transportation.[60] On a similar note, Appleyard and Riggs (2017) assert that lane size will be smaller for AVs and that additional space from narrower lanes could be used for housing.[61] There is the opportunity for further research around what specific policy approaches and incentives would be most effective in prioritizing this newly available land used for housing.

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[56] Zhongming Lu et al., "Data-Enabled Public Preferences Inform Integration of Autonomous Vehicles with Transit-Oriented Development in Atlanta," *Cities* 63 (2017): 118–27, https://doi.org/10.1016/j.cities.2017.01.004.
[57] Lu et al.
[58] Howell et al., "Multilevel Impacts of Emerging Technologies on City Form and Development."
[59] Car2Go is now called Share Now and as of December 2019 left the North American market. Share Now operates exclusively in Europe. https://www.engadget.com/2019-12-18-car2go-to-shut-down-in-north-america.html
[60] Schlossberg et al., "Rethinking the Street in an Era of Driverless Cars."
[61] Bruce Appleyard and William Riggs, "'Doing the Right Things' Rather than 'Doing Things Right': A Conceptual Transportation/Land Use Framework for Livability, Sustainability, and Equity in the Era of Driverless Cars," 2017.

4.4 Consider the convergence between transportation and telecommunications, including 5G siting issues.

A growing amount of research exists around the convergence of transportation and telecommunications with a focus on 5G and around 5G siting, including the related regulatory issues. There is also a significant amount of uncertainty in the research around telecommunications and AV and how users may embrace transportation technology and services.

4.4.1 Types of telecommunications infrastructure

Belcher et al. (2018) note that there are several different types of technology for telecommunications.[62] Two common types are dedicated short-range communications (DSRC) and C-V2X (cellular vehicle-to-everything). The currently common forms of C-V2X are 4G LTE, and PC5. 5G will offer more speed and capacity than either of these. DSRC is based on a wireless local area network and was designed to support communications between vehicles and roadside infrastructure. AVs already use traditional 4G LTE infrastructure. PC5 is based on 4G LTE technology and can be deployed with or without infrastructure. 5G supports a future integrated scenario of C-V2X. However, 5G is just beginning its rollout and many telecommunications companies are focused on 5G for smart phones. Brown, Thorn, and Esposito (2019) introduce a fourth type of technology for telecommunications in 802.11 Next Generation V2X.[63] Next generation V2X is intended to leverage enhancements to wireless technology and signal processing and be compatible with DSRC. It will likely improve signal efficiency, reliability, and range to potentially support AVs.

4.4.2 5G

Dale-Johnson (2019) notes that AVs will require new telecommunications infrastructure.[64] AVs will benefit from the installation of sensors and signals. Dale-Johnson argues that having AVs travel closely together and operate remotely would require the deployment of new telecommunications infrastructure, including 5G with antenna systems on buildings in urban environments.[65] Heineke et al. (2019) notes that 5G will be a key enabler of more reliable communication for vehicles, which will play a critical role in managing the safety challenges that come with vehicle automation and autonomy.[66] Belcher et al. notes that telecommunications infrastructure should be considered as the telecommunications industry builds out its 5G

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[62] Scott Belcher et al., "Roadmap To Vehicle Connectivity," no. September (2018).
[63] Michael Brown, Eric Thorn, and John Esposito, "A Review of Next Generation Communication Technology for Transportation Final Report," 2019.
[64] David Dale-Johnson, "Preparing for Autonomous Vehicles : A Survey of Local Governments," no. November (2019).
[65] Dale-Johnson.
[66] Kersten Heineke et al., "Development in the Mobility Technology Ecosystem - How Can 5G Help?," 2019.

networks.[67] Even if AVs may not be connected vehicles, wireless or remote monitoring will likely need telecommunications infrastructure and connectivity.

4.4.3 5G siting issues

The research mentions several 5G siting issues. The Small Cell Forum (2017) notes that 5G has a very limited range, requiring that 5G infrastructure be installed every few hundred feet.[68] Therefore, finding enough sites in an urban area with numerous power lines could pose a challenge. Belcher et al. echo that the transition from 4G to 5G will require densification of telecommunications infrastructure.[69] They estimate that 5G will need five times the number of small cells that are currently deployed for 4G. Belcher et al. note that rural areas require a heavy initial investment in 5G towers or roadside DSRC units that will delay the deployment of connected vehicles in rural areas.[70] They suggest that government subsidies or regulations could be implemented to spur deployment in rural areas.

Regulatory issues are also part of 5G siting issues. The Small Cell Forum (2018) finds that many siting issues are regulatory, arising from the rules and processes governing many aspects of mobile network deployment, from spectrum licensing and usage, to radiofrequency compliance, to site planning and access to right-of-way and property, and taxation.[71] In another report by the Small Cell Forum and 5G Americas (2018), key siting issues are summarized as follows: streamlining regulatory approval for small cell and 5G equipment, including large numbers of cells in the planning application process, securing sufficient sites, installation costs, radiofrequency compliance, and administrative complexity.[72]

Dale-Johnson notes that state and local governments are looking for federal guidance and funding around 5G and telecommunications infrastructure.[73] In the meantime, states have been exploring the deployment of Wi-Fi systems for connectivity. The FCC has a new 5G plan, the 5G FAST plan.[74] This includes three components: opening more of the 5G spectrum for the marketplace, updating infrastructure policy, and modernizing outdated regulations. The FCC has also proposed amending its rules for the 5.9 GHz band.[75] It would allow unlicensed devices to operate in the lower portion of the band and permit intelligent transportation system operations in the upper portion of the band. Intelligent transportation system operations would include cellular vehicle to everything and/or DSRC. Organizational comments have been submitted to the proposal noting that numerous public and private sector transportation safety experts opposed the FCC's amendment, arguing that it negatively impacts transportation safety.[76]

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[67] Belcher et al., "Roadmap To Vehicle Connectivity."
[68] Small Cell Forum and 5G Americas, "Small Cell Siting: Regulatory and Deployment Considerations," 2017.
[69] Belcher et al., "Roadmap To Vehicle Connectivity."
[70] Belcher et al.
[71] Small Cell Forum and 5G Americas, "Small Cell Siting: Regulatory and Deployment Considerations."
[72] Small Cell Forum and 5G Americas, "Small Cell Siting Challenges and Recommendations," 2018.
[73] Dale-Johnson, "Preparing for Autonomous Vehicles : A Survey of Local Governments."
[74] Federal Communications Commission, "The FCC's 5G FAST Plan," Federal Communications Commission, 2020.
[75] Federal Communications Commission, "Use of the 5.850-5.925 GHz Band," *Federal Register*, 2020.
[76] Intelligent Transportation Society of America, "Reply Comments of the Intelligent Transportation Society of America," 2020.

5 Further Research Opportunities

The suggestions below identify topics for future research to inform and focus the important discussion around *Impacts and Opportunities Around Land Use and Automated Vehicles and Shared Mobility*. These topics will be evaluated by the Forum in coordination with the appropriate TRB Committees and staff to determine which topics can be expanded into more detailed research statements and proposals. Where possible, crossover to other Topical Papers has been identified to assist with the development of more robust and cross-issue research statements.

Subtopic	Research Opportunity	Crossover to Other Topics
4.1	Develop model land use regulations and policies based on AV deployment and use cases.	*None*
4.1	Analyze land uses that will be impacted by HAVs and related technology, including shared vehicles.	*None*
4.1	Analyze implications of an extended mixed fleet on land use and related policy.	*None*
4.1	Analyze the effect of HAVs on rural land use typologies including small urban communities.	*Planning*
4.1	Assess the impact of trends in e-commerce and telecommuting, as well as demographic and cultural dynamics in the wake of the COVID-19 pandemic as they relate to land use and AVs and shared mobility (including transit).	*Social Impacts*
4.1	Survey communities to establish a baseline on implementation of and management of land-use questions as it relates to • the curb, • shared rides, • shared vehicles, • microtransit, • micromobility, and • sidewalk robotic delivery vehicles.	*Social Impacts*
4.1	Correlate the impacts of AV technology on residential, office, and mixed land use to different levels and types of AV deployment including an analysis across time.	*None*
4.1	Investigate ways to assess how parking and AVs in various infrastructure uses affect car usage.	*Social Impacts*
4.1	Evaluate impacts of reduced parking over time including how a change in parking ratios may modify traveler behavior in the U.S. and support AVs and shared mobility.	*None*

Subtopic	Research Opportunity	Crossover to Other Topics
4.1	Analyze how management of the right of way to support the deployment of AVs and prioritizing the use of limited space impacts shared mobility and land use.	*Social Impacts*
4.1	Analyze new aspects of the curb, including new curb designs, allocation of curbside space, pricing of the curb, and new curbside technology.	*None*
4.1	Study an enforcement mechanism to manage growing competition for the ROW. Research could also address the safe use of ROW by both human and automated users.	*Social Impacts*
4.1	Study pricing of curb access for automated mobility including demand-based pricing.	*Social Impacts*
4.1	Develop a guide on curbside management for accessible pickup for passengers with disabilities.	*Equity & Accessibility, Transit*
4.2	Research the opportunities for land use in the context of the ADA to ensure AVs are compatible with existing accessibility requirements for entrance and egress and that evolving standards are proactively incorporated into building codes.	*Equity & Accessibility, Transit*
4.2	Investigate/model the impact of AVs and shared mobility from climate change, which directly impacts housing and land use decisions.	*Social Impacts*
4.3	Conduct case studies on car sharing in transit-oriented development	*None*
4.4	Create a curated knowledge management resource center featuring best practice guides, case studies, and policy tools around the adoption of V2X technology.	*Infrastructure*
4.4	Assess if more broadband and internet access will be needed to support connected AVs and/or related information collection.	*Data Sharing and Governance*

6 Appendix

A. Definition of Terms

ADA	Americans with Disabilities Act
ADS	Automated Driving System
AV	Automated Vehicle
EV	Electric Vehicle
FTA	Federal Transit Administration
HAV	Highly Automated Vehicle
LSAV	Low-Speed Automated Vehicle
MaaS	Mobility as a Service
NHTSA	National Highway Traffic Safety Administration
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
SAE	Society of Automotive Engineers
TNC	Transportation Network Company
USDOT	U.S. Department of Transportation
VMT	Vehicle Miles Traveled

B. References

Appleyard, Bruce, and William Riggs. "'Doing the Right Things' Rather than 'Doing Things Right': A Conceptual Transportation/Land Use Framework for Livability, Sustainability, and Equity in the Era of Driverless Cars," 2017.

Barth, Brian. "Curb Control." *Planning* 85, no. 6 (2019): 18–25.

Belcher, Scott, Edward Merlis, Justin McNew, and Morgan Wright. "Roadmap To Vehicle Connectivity," no. September (2018).

Brown, Michael, Eric Thorn and John Esposito. "A Review of Next Generation Communication Technology for Transportation Final Report," 2019.

"Chandler AZ Development Services Memo No. PZ18-024," n.d.

Cohen, Adam, and Susan Shaheen. "PAS Report 583: Planning for Shared Mobility," 2016, 110. www.planning.org/pas/index.htm.

Crute, Jeremy, William Riggs, Timothy S Chapin, and Lindsay Stevens. *Planning for Autonomous Mobility*, 2018. www.planning.org.

Dale-Johnson, David. "Preparing for Autonomous Vehicles: A Survey of Local Governments," no. November (2019).

Duvall, Tyler, Eric Hannon, Jared Katseff, Ben Safran, and Tyler Wallace. "A New Look at Autonomous Vehicle Infrastructure," 2019.

Federal Communications Commission. "The FCC's 5G FAST Plan." Federal Communications Commission, 2020.

———. “Use of the 5.850-5.925 GHz Band.” *Federal Register*, 2020.
Fehr and Peers. “San Francisco Curb Study,” 2018.
Harper, Corey D., Chris T. Hendrickson, and Constantine Samaras. “Exploring the Economic, Environmental, and Travel Implications of Changes in Parking Choices Due to Driverless Vehicles: An Agent-Based Simulation Approach.” *Journal of Urban Planning and Development* 144, no. 4 (2018).
Heineke, Kersten, Alexandre Menard, Freddie Sodergren, and Martin Wrulich. “Development in the Mobility Technology Ecosystem - How Can 5G Help?,” 2019.
Howell, Amanda, Nico Larco, Rebecca Lewis, and Becky Steckler. “New Mobility in the Right-Of-Way,” 2019.
Howell, Amanda, Huijun Tan, Anne Brown, Marc Scholssberg, Josh Karlin-Resnick, Rebecca Lewis, Marco Anderson, et al. “Multilevel Impacts of Emerging Technologies on City Form and Development,” 2020.
Intelligent Transportation Society of America. “Reply Comments of the Intelligent Transportation Society of America,” 2020.
ITF Corporate Partnership Board. “The Shared-Use City: Managing the Curb Corporate Partnership Board Report Corporate Partnership Board CPB,” 2018. www.itf-oecd.org.
Larson, William, and Weihua Zhao. “Self-Driving Cars and the City: Effects on Sprawl, Energy Consumption, and Housing Affordability.” *Regional Science and Urban Economics* 81, no. October 2019 (2020): 103484. https://doi.org/10.1016/j.regsciurbeco.2019.103484.
Lewis, Rebecca and Rebecca Steckler. “Emerging Technologies and Cities: Assessing the Impacts of New Mobility on Cities.” 2020.
Litman, Todd. “Autonomous Vehicle Implementation Predictions: Implications for Transport Planning,” 2020.
Lu, Zhongming, Rundong Du, Ellen Dunham-Jones, Haesun Park, and John Crittenden. “Data-Enabled Public Preferences Inform Integration of Autonomous Vehicles with Transit-Oriented Development in Atlanta.” *Cities* 63 (2017): 118–27. https://doi.org/10.1016/j.cities.2017.01.004.
Millard-Ball, Adam. “The Autonomous Vehicle Parking Problem.” *Transport Policy* 75, no. December 2018 (2019): 99–108. https://doi.org/10.1016/j.tranpol.2019.01.003.
Nourinejad, Mehdi, Sina Bahrami, and Matthew J. Roorda. “Designing Parking Facilities for Autonomous Vehicles.” *Transportation Research Part B: Methodological* 109 (2018): 110–27. https://doi.org/10.1016/j.trb.2017.12.017.
Regional Plan Association (RPA). “New Mobility: Autonomous Vehicles and the Region,” no. October (2017): 1–36. http://library.rpa.org/pdf/RPA-New-Mobility-Autonomous-Vehicles-and-the-Region.pdf.
Roe, Matthew, and Craig Toochek. “Curb Appeal: Curbside Management Strategies for Improving Transit Reliability,” no. November (2017): 1–12. https://nacto.org/wp-content/uploads/2017/11/NACTO-Curb-Appeal-Curbside-Management.pdf.
Rouse, David C., Jennifer Henaghan, Kelley Coyner, Lisa Nisenson, Jason Jordan, and American Planning Association. “Preparing Communities for Autonomous Vehicles,” 2018.
Schlossberg, Marc, William Riggs, Adam Millard-Ball, and Elizabeth Shay. “Rethinking the Street in an Era of Driverless Cars,” 2018.
Small Cell Forum, and 5G Americas. “Small Cell Siting: Regulatory and Deployment Considerations,” 2017.
Small Cell Forum and 5G Americas. “Small Cell Siting Challenges and Recommendations,” 2018.
Steckler, Becky. “Navigating New Mobility: Policy Approaches for Cities.” 2019.

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