NCHRP Project 20-113F

Preparing for Automated Vehicles and Shared Mobility: State-of-the-Research Topical Paper #7

IMPACTS OF AUTOMATED VEHICLES AND SHARED MOBILITY ON TRANSIT AND PARTNERSHIP OPPORTUNITIES

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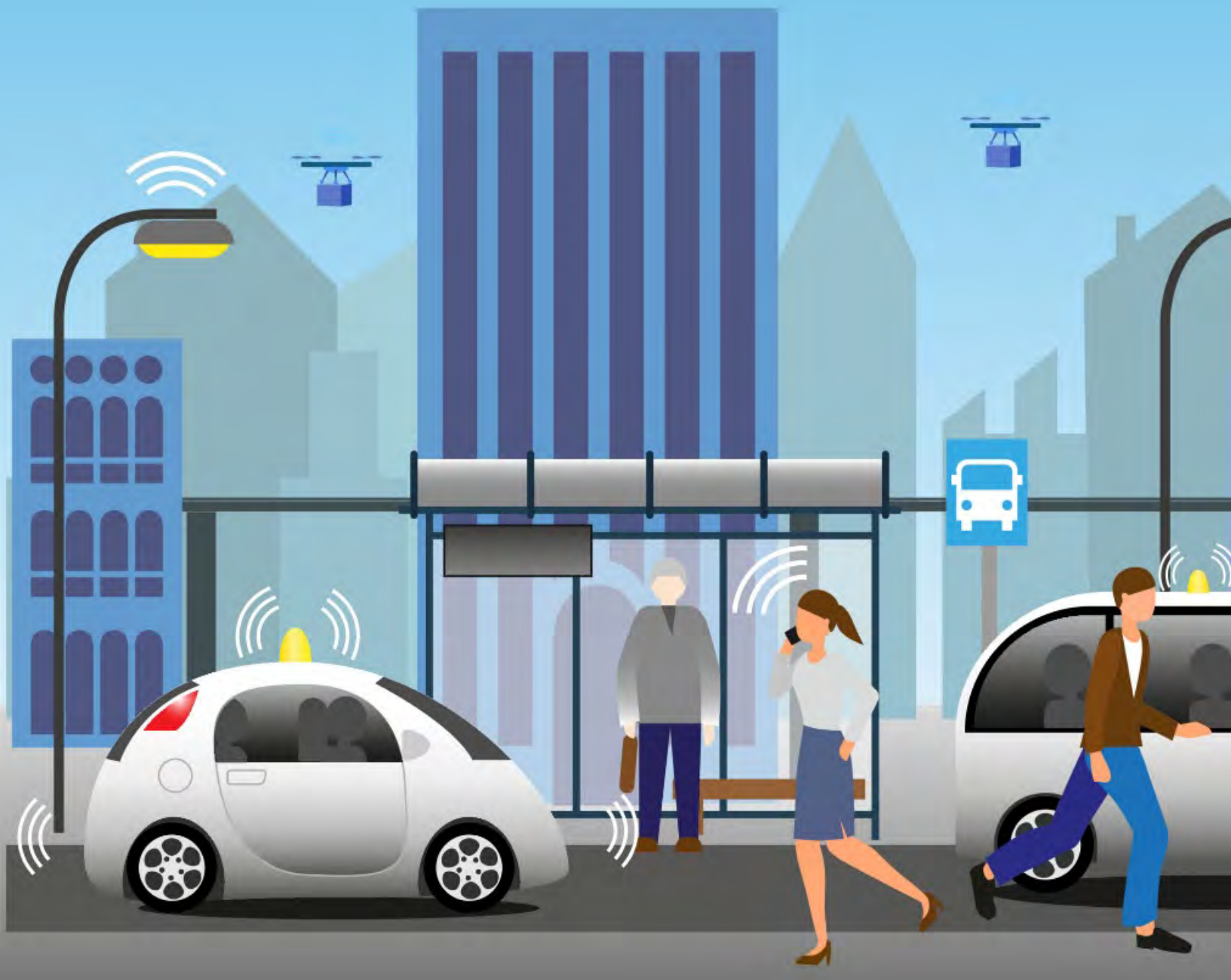
TRB AV/SM FORUM
AUTOMATED VEHICLES + SHARED MOBILITY

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 is 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 nine 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 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. Explore partnerships that complement and incentivize public transportation and shared mobility and that support first/last mile deployments, including ongoing trends towards mobility hubs and multi-connections; governance and infrastructure should be considered
2. Discuss perspectives on the meaning of “public transportation,” including definitions employed in federal, state, or other legislation
3. Evaluate first/last mile partnership opportunities and barriers
4. Complement previous research associated with equity and accessibility by considering the first/last 50 feet, in addition to the first/last 50 miles, to ensure existing transportation gaps and needs are filled, and not limited to urban environments
5. Evaluate app-based fare payment systems and opportunities and challenges associated with Mobility as a Service
6. Consider existing research around workforce implications around automation and transit, including opportunities for new roles and classifications for drivers or operators
7. Determine existing research around impacts of ADA requirements and considerations around universal design

3 Summary of Findings

The shared mobility landscape is changing, and AVs have a strong potential be a driver in solving existing transportation issues like first/last mile connections (including rural), gaps in service, and provision of better solutions for all individuals. Making this a reality will require vision and proactive planning to address the many unknowns including to create new definitions within the context of transportation funding, new governance structures to support evolving partnerships, and new solutions to existing transportation gaps. The research community, government, and the private sector wish to understand the opportunities for partnerships related to AVs and transit.

This Topical Paper provides a summary of research on opportunities for transit partnerships as they relate to shared mobility 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:

- **Partnerships with AV and other smart mobility service providers hold the potential for increasing shared mobility options and perhaps to increase connections to transit.** Partnerships between public agencies, private service providers, and funders such as human service agencies offer the opportunity to expand mobility options to underserved populations and mobility deserts. These partnerships have largely taken the form of sponsorship of a range of shared mobility services including shared rides, shared vehicles, and microtransit, all of which are being piloted with AVs. Initial reviews of demonstrations and pilots suggest that sponsors are motivated to provide these services to provide connections to transit services.

- **Early planning for mobility hubs at transit stations and centers includes provisions to support shared and individually-owned AVs.** This includes charging infrastructure, pick-up and drop-off areas, and, in some cases, dedicated lanes. Mobility hubs provide the infrastructure needed for forms of mobility beyond AVs. There are some partnerships evident in initial implementations of mobility hubs that have taken the form of design-build-operate-maintain public-private partnerships, or simpler arrangements such as memoranda of understanding for in-kind contributions.

- **“Public transportation” definitions in federal, state, and local law and regulation require updating to account for new partnership models and on-demand services.** These definitions typically determine eligibility for compliance with the Americans with Disabilities Act as well as applicability of a range of safety, operational, and governance requirements. Public transportation primarily focuses on fixed route service such as that provided by buses, ferries, or rail service. Leading research suggests a different set of definitions around public and private transit that turn largely on access to the service. Further examination of the integration of public and private transit in a common mobility ecosystem may not hinge on the definition of public transportation but could consider

alternative definitions that would facilitate adoption of shared AV services to complement public transit.

- **Use cases for shared AV services include first/last mile, fixed route, paratransit, and circulator services, each of which could expand the impact of transit and expand mobility in areas not served by transit.** Initial research indicates that on-demand private AVs could fill temporal or spatial gaps in transit service. The emerging literature suggests that a policy framework is required to ensure equitable access to AV services in a way that augments rather than detracts from transit services.

- **AV partnerships also present opportunities to connect on the first/last 50 miles of a journey, with particular focus on rural service.** Cost effective AV solutions for rural mobility gaps may rest in effectual use of subsidies. To address equity concerns, approaches also require moving beyond reliance on smart phones to tools like SMS text access, shared mobility access kiosks, and telephone concierge services.

- **Much of the impetus for Mobility as a Service applications is being driven in preparation for wider AV deployment.** MaaS is the integration of various transportation modes into a single mobility service that is accessible on demand. If implemented in an equitable and widespread manner, MaaS systems can be a powerful tool for integrating travel modes. However, many issues remain to be addressed including how to achieve full fare integration, equity, accommodation of the various federal benefit programs, and cooperation between public and private entities.

- **HAVs, once deployed in large numbers, will reduce the number of driver positions.** The body of research indicates that some of the current jobs will be replaced, while others will shift to new roles and different skill sets will be required. Various technical training programs will be needed to train safety operators and technicians. Additionally, considerations around labor agreements will need to be addressed.

4 Summary of Research Reviewed

The research reviewed included papers from academic research publications, federal agencies, and nonprofit organizations. This points to a cross-sector interest in maximizing transit's effectiveness through partnerships with AV and other shared mobility service providers. The following is a summary of the research reviewed.

4.1. Explore partnerships that complement and incentivize public transportation and shared mobility and that support first/last mile deployments, including ongoing trends towards mobility hubs and connections to inter-modal transit; governance and infrastructure should be considered

Cities have increasingly been turning to mobility hubs – places of connectivity where different transportation modes come together – to connect transit and other transportation modes. While the research does not yet document cases of AV integration into mobility hubs, existing literature on mobility hubs does have applications for future AV rollouts. In Minneapolis, a network of mobility hubs currently provides links between bus service, private bikeshare stations, and electric vehicle carshare services.[2] Mobility hubs outside the United States – in Belgium, Norway, and Singapore – integrate multiple modes with drop-off zones and electric vehicle charging infrastructure.[3] Many U.S. locations are in the planning process for mobility hubs. In Florida, Broward County has included mobility hubs in its 2035 long-range transportation plan and has published a detailed methodology for assessing candidate locations; this includes considerations for integrating ridehailing with the mobility hubs.[4] San Diego has also included a mobility hub network in its 2021 regional plan. Honolulu Area Rapid Transit has plans to specifically incorporate LSAVs into its future mobility hubs.[5]

4.1.1 Mobility Hubs

Cities have increasingly been turning to mobility hubs – places of connectivity where different transportation modes come together – to connect transit and other transportation modes. While the research does not yet document cases of AV integration into mobility hubs, but existing

[2] "Mobility Hubs Come to Lift in the Twin Cities," Shared Use Mobility Center, n.d., https://sharedusemobilitycenter.org/mobility-hubs-in-twin-cities/.
[3] Kelley Coyner, "Low-Speed Automated Vehicles (LSAVs) in Public Transportation," 2020, http://intranet.trb.org/TRBNet/ProjectEdit.asp?ProjectID=4438.
[4] "Revisit & Update, Mobility Hubs Program: Integrating Ride-Hailing with Mobility Hubs," 2018, http://www.browardmpo.org/images/4-BMPO-Ride-Hailing-Integration_FINAL_January_2018.pdf.
[5] SANDAG, "Mobility Hubs," San Diego Forward, n.d., https://www.sdforward.com/mobility-planning/mobilityhubs; Coyner, "Low-Speed Automated Vehicles (LSAVs) in Public Transportation."

literature on mobility hubs does have applications for future AV rollouts. In Minneapolis, a network of mobility hubs currently provides linkages between bus service, private bikeshare stations, and electric vehicle carshare services.[6] Many locations are in the planning process for mobility hubs. In Florida, Broward County has included mobility hubs in its 2035 long-range transportation plan and has published a detailed methodology for assessing candidate locations; this includes considerations for integrating ridehailing with the mobility hubs.[7] San Diego has also included a mobility hub network in its 2021 regional plan. Honolulu Area Rapid Transit has plans to specifically incorporate LSAVs into its future mobility hubs.[8]

4.1.2 Multimodal Connections

Private AV transit may provide key links for multimodal transportation. The City of Mountain View, California is planning an AV connection to the VTA light rail that will serve a business park, including Microsoft other businesses. The Rhode Island DOT's "Little Roady" project provides connections with a business park, the Amtrak Stations, and local bus transit. Several airports are piloting AV service between terminals and rental car facilities. In Arlington, Texas, AV options have provided connections to parking and commuter rail and are now expanding to connect with campus transportation and micromobility.[9]

Partnerships with TNCs can potentially be used as models for eventual AV deployment. Pierce County, Washington implemented a year-long pilot partnership with Lyft, ending December 31, 2019, to provide free rides in specific zones within its transit agency's service area. One zone provided connections to the Tacoma Dome Station multimodal facility, where users could access the Greyhound bus, light rail, commuter train, and Amtrak.[10] In California, as of 2019 San Mateo County plans to partner with TNCs to connect Caltrain stations and San Francisco International Airport.[11]

4.1.3 First/Last Mile Deployments

LSAV services have been successfully launched or are in the planning stages for first/last mile connections to transit and for a variety of other use cases. The Transportation Research Board's study of Low Speed Automated Vehicles in Public Transportation identified 70 pilots; all were some type of partnership between and among private and public entities. The report documents case studies on more than 20 of the projects, including multi-phase projects in North Carolina; Las Vegas, Nevada; and Arlington, Texas.[12] These types of projects are critical for extending the catchment areas of transit stations for high capacity bus and rail transit. The

[6] "Mobility Hubs Come to Lift in the Twin Cities."
[7] "Revisit & Update, Mobility Hubs Program: Integrating Ride-Hailing with Mobility Hubs."
[8] SANDAG, "Mobility Hubs"; Coyner, "Low-Speed Automated Vehicles (LSAVs) in Public Transportation."
[9] Coyner, "Low-Speed Automated Vehicles (LSAVs) in Public Transportation."
[10] Engineering National Academies of Sciences and Medicine, "Partnerships Between Transit Agencies and Transportation Network Companies," 2019.
[11] National Academies of Sciences and Medicine.
[12] National Academies of Sciences and Medicine, Coyner, "Low-Speed Automated Vehicles (LSAVs) in Public Transportation."

LSAV in Public Transit study includes a typology of use cases in transit, all of which might have first and last mile value. These include fixed route, A-B shuttles, circulators, and mobility on demand. Almost all the projects inventoried were operated and/or funded by two or more partners, including human service agencies, military installations, utility companies, convention bureaus, resorts, universities, and property owners. In addition, the study found that as vehicle and battery technology and capacity improve, AVs will become available for longer routes and expanded transportation value. A Singapore-based study simulating an integrated AV and public transportation system showed that preserving high demand bus routes while replacing low-demand routes with shared AVs would enhance service quality, occupy fewer road resources, be financially sustainable, and utilize transit services more efficiently.[13] Indeed, cities as diverse as Honolulu, Hawaii and Youngstown, Ohio are already planning projects that would expand transit coverage on low-service, low density routes.[14]

4.1.4 Infrastructure

Coyner (2020) notes in a review of LSAV case studies that infrastructural changes were made for many of the LSAV pilots to date. The most signification were the use of connected signal technology to aid LSAVs in making left hand turns safely as well as the provision for dedicated lanes. In addition, the study's practitioner's check list includes the following possible required infrastructure modifications:

- Paths such as sidewalks and bicycle trails
- Intersection improvements such as dedicated lanes
- Kiosks for information, ticketing, and mobility on demand tools
- Painted or temporary lane markings
- Signage noting AV operation and stops
- Temporary or permanent traffic signals and roadside units

4.1.5 Governance

Coyner (2020) noted that governance is important but largely overlooked when creating partnerships between public and private entities. Whether AV service is provided in partnership between public and private institutions or among multiple public agencies, collaboration is essential across management, oversight, and funding.[15] Public agencies retain their authority on safety and operations in the public right of way. The guidance reviewed stresses the need for clear expectations and roles when initiating agreements. Memoranda of understanding are

[13] Yu Shen, Hongmou Zhang, and Jinhua Zhao, "Integrating Shared Autonomous Vehicle in Public Transportation System: A Supply-Side Simulation of the First-Mile Service in Singapore," *Transportation Research Part A: Policy and Practice* 113 (2018): 125–36.
[14] Coyner, "Low-Speed Automated Vehicles (LSAVs) in Public Transportation."
[15] Coyner, "Low-Speed Automated Vehicles (LSAVs) in Public Transportation."

critical to integrate and streamline processes.[16] The guidance also emphasizes that even before partnerships are initiated, local governance can shape the course of these partnerships.

In addition to collaboration in management of shared service, local governments may also limit the operations of private transit. For example, the San Francisco Municipal Transportation Agency voted on a law that would ban private transit from replicating San Francisco Municipal Transportation Agency routes.[17]

4.1.6 Complementarity with Transit

AV service could also complement transit service. Available evidence comes from current TNC studies; however, these can be used as a case study for wider subscription-style AV adoption. First, these partnerships can increase transit use. A study by Hall, Palsson, and Price found that Uber increases transit ridership by 5% after two years; results varied based on location, with

[16] Susan Shaheen, Adam Cohen, and Elliot Martin, "The US Department of Transportation's Smart City Challenge and the Federal Transit Administration's Mobility on Demand Sandbox: Advancing Multimodal Mobility and Best Practices Workshop," *Transportation Research Circular*, no. E-C219 (2017).
[17] Allison Henry et al., "New Mobility Autonomous Vehicles and the Region," *Regional Plan Association (RPA), New-York*, 2017.

larger increases in larger cities and for smaller transit agencies.[18] However, Schaller notes that current surveys found that relatively few TNC trips are for the express purpose of connecting to public transit.[19] Indeed, a survey of 50 transit agencies found that 43% believed that TNCs will have a negative impact on transit systems in the next five years.[20]

The consensus of most research is that TNCs, and eventually AV service providers, need to complement transit routes, creating a more favorable environment for partnerships

Certain research finds that TNCs are a useful complement to transit by providing transportation options outside conventional or peak service hours. A five-city study noted that heaviest TNC use is during late night hours and weekends, when transit runs less frequently.[21] King, Conway, and Salon also noted geographical complementarity, as a high number of TNC trips to airports spoke to TNCs filling a gap in transit service to this destination.[22] Complementary public-private partnerships can achieve cost savings, particularly for late-night, call-and-ride, and paratransit services.[23] Subscription-based TNC services can also be used in place of fixed-route service. The town of Innisfil, Ontario found that heavily subsidizing Uber rides for citizens was not only less expensive than providing traditional service, but it also served significantly more residents than a proposed bus service would have.[24]

Coyner (2020) provides practitioner checklists that cover a number of partnership issues and provide templates for agreements and procurement documents.[25] Given that partnerships can benefit both transit agencies and private service providers, future research could provide guidance for successful cooperation between these different entities. This includes best practices for operationalizing partnerships in the realm of procurement, data sharing, and other areas.

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[18] Jonathan D Hall, Craig Palsson, and Joseph Price, "Is Uber a Substitute or Complement for Public Transit?," *Journal of Urban Economics* 108 (2018): 36–50.
[19] Bruce Schaller, "The New Automobility: Lyft, Uber and the Future of American Cities," 2018.
[20] Mengjie Han et al., "Understanding Transit Agency Perceptions about Transportation Network Companies, Shared Mobility, and Autonomous Transit: Lessons from the United States," *Transportation Research Record* 2673, no. 5 (2019): 95–108.
[21] Sharon Feigon and Colin Murphy, "Broadening Understanding of the Interplay among Public Transit, Shared Mobility, and Personal Automobiles," 2018; Shared-Use Mobility Center, "Shared Mobility and the Transformation of Public Transit," *American Public Transportation Association*, 2016; David A. King, Matthew Wigginton Conway, and Deborah Salon, "Do For-Hire Vehicles Provide First Mile/Last Mile Access to Transit?," *Transport Findings*, 2020, https://doi.org/https://doi.org/10.32866/001c.12872; Susan Shaheen and Nelson Chan, "Mobility and the Sharing Economy: Potential to Facilitate the First-and Last-Mile Public Transit Connections," *Built Environment* 42, no. 4 (2016): 573–88.
[22] David A. King, Matthew Wigginton Conway, and Deborah Salon, "Do For-Hire Vehicles Provide First Mile/Last Mile Access to Transit?," *Transportation Findings*, 2020, https://doi.org/10.32866/001c.12872.
[23] Feigon and Murphy, "Broadening Understanding of the Interplay among Public Transit, Shared Mobility, and Personal Automobiles."
[24] Matthias Sweet, Raktim Mitra, and Sarin Chemilian, "Innisfil Transit and Social Outcomes," 2020, https://dev.innisfil.ca/wp-content/uploads/2020/04/Innisfil-Transit-Social-Outcomes-Ryerson-University-Analysis.pdf.
[25] Coyner, "Low-Speed Automated Vehicles (LSAVs) in Public Transportation."

Related to this overall topic, the consensus of most research is that TNCs, and eventually AV service providers, need to complement transit routes, creating a more favorable environment for partnerships.

4.2. Discuss perspectives on the meaning of "public transportation," including definitions employed in federal, state, or other legislation

"Public transportation" definitions in federal, state, and local law and regulation do not account for emergence of the concept in private transit. These definitions typically govern determine eligibility for government, compliance with the Americans with Disabilities Act, as well as coverage of a range of safety, operational, and governance requirements**.** Public transportation primary focuses on fixed route service and leading research suggests at different set of definitions around public and private transit turning largely on access to the service.

4.2.1 Federal

Several federal definitions of public transportation exist. The FTA defines public transportation service as the operation of a vehicle providing general or special service to the public on a regular and continuing basis.[26] The Federal Public Transportation Program has a more specific definition. Here, public transportation is "regular, continuing shared-ride surface transportation services that are open to the general public or open to a segment of the general public defined by age, disability, or low income."[27] Excluded from this definition are services such as intercity passenger rail and bus service; charter bus and school bus service; and shuttles, such as courtesy service for patrons of an establishment or intra-facility shuttles. Language in the ADA that governs which services must meet its standards specifies that "public transportation services" are those provided by a public entity by bus, rail, or other means, "that [provide] the general public with general or special service, including charter service, on a regular and continuing basis."[28] Neither the FTA nor the Federal Public Transportation Program definitions require the service provider to be a public entity, meaning that for ADA purposes private services such as TNCs might potentially be considered public transportation and therefore accountable for meeting ADA standards. Indeed, the FTA notes that most AVs used in public transit will meet the definition of a "bus" as set forth in the ADA and will therefore be responsible for compliance[29] This was exemplified by a recent Department of Justice ruling that the University of Michigan must purchase wheelchair accessible AVs for its Mcity driverless shuttle

[26] "Interpretation of Definitions," n.d., https://www.transit.dot.gov/research-innovation/interpretations-definitions.
[27] William Mallett, "Federal Public Transportation Program: In BRief," 2020, https://fas.org/sgp/crs/misc/R42706.pdf.
[28] "Part 37 - Transportation Services for Individuals with Disabilities," n.d., https://www.transit.dot.gov/regulations-and-guidance/civil-rights-ada/part-37-transportation-services-individuals-disabilities.
[29] "Frequently Asked Questions: Transit Bus Automation Policy," 2019, https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/134506/transit-bus-automation-faqs_0.pdf.

program, as the shuttle runs a fixed route during business hours and is therefore subject to ADA requirements.[30]

4.2.2 State

As with the federal level, the state level also offers a myriad of public transportation definitions. A number of state definitions refer to "public" not in terms of the ownership of the system providing the service, but rather the access to the service. In Ohio, public transportation services are those that are available to people upon payment of a fare; they cannot be rescinded for exclusive use of any individual or group but must rather be open-door.[31] Oregon's definition is perhaps the broadest, including "any form of passenger transportation system, whether or not for hire, including but not limited to air, rail, other fixed guideway, bus, jitney, taxi and dial-a-ride passenger transportation systems within, between and outside of urban and urbanized areas."[32] This includes both air and intercity services, unlike the federal definition. Washington State defines public transportation differently in different contexts. At its most basic, public transportation is any form of transportation that is accessible to the public and that does not involve a single-occupancy motor vehicle.[33]

More research in this area would potentially support a standardized definition of public transportation that can be used at various regulatory levels. This has implications for funding opportunities and compliance issues for new mobility services such as AVs.

[30] Shannon M. Ackerman, "Letter of Resolution, D.J. No. 204-37-328, ADA Compliance Review of the University of Michigan's Driverless Shuttle Program," 2019.
[31] "Glossary of Public Transportation Terms," n.d., http://www.dot.state.oh.us/Divisions/Planning/Transit/Documents/Urban Transit Manual/Glossary.PDF.
[32] "Oregon Revised Statutes - Definitions for ORS 184.670 to 184.733."," n.d., https://www.oregonlaws.org/ors/184.675.
[33] "Washington State Public Transportation Plan," 2016, https://www.wsdot.com/sites/default/files/2019/10/15/PT-Report-WashingtonStatePublicTransportationPlan-2016.pdf.

4.3. Evaluate first/last mile partnership opportunities and barriers

4.3.1 Opportunities

Initiatives can increase mobility among people living in areas with limited transit access, such as some low-income neighborhoods, suburban areas, or rural areas

The research indicates that partnerships between public transit agencies and private service providers offer opportunities for first/last mile connections to transit. Such initiatives can increase mobility among people living in areas with limited transit access, such as some low-income neighborhoods, suburban areas, or rural areas.[34] They can also be used to improve transit access to certain destinations. In Atlanta, the Metropolitan Atlanta Rapid Transit Authority partnered with Uber and Lyft to provide discounted rides from transit stations to destinations such as the airport and Mercedes-Benz Stadium. As indicated above, first/last mile partnerships can be particularly beneficial during off-peak hours when transit service is infrequent or unavailable.[35] AVs are starting to be used for first/last mile connections, albeit at smaller scales. In the Netherlands, for example, ParkShuttle is being used to connect a business park to a nearby subway station.[36] Wen et al. have modeled scenarios for larger-scale AV integration with transit. Their study shows that encouraging ridesharing, allowing in-advance requests, and combining fares with transit would enable efficient and sustainable service integration.[37]

Aside from providing access to and from transit, first/last mile partnerships can improve efficiency for transit agencies. Florida's Pinellas Suncoast Transit Authority was able to remove low-ridership routes while improving transit access by subsidizing TNCs to bring users to stops connecting to major bus routes.[38] Shen, Zhang, and Zhao (2018) made the case that this can also be achieved with AVs. In their simulation based in Singapore, they showed that integrating AV service with public transit has the potential to enhance service quality while also using services more efficiently.[39] Public-private partnerships can also signify where public transit service might be expanded in the future if the transit agencies monitor demand for transit

[34] National Academies of Sciences and Medicine, "Partnerships Between Transit Agencies and Transportation Network Companies"; Johanna Zmud et al., "Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies," 2017.
[35] Sharon Feigon and Colin Murphy, *Shared Mobility and the Transformation of Public Transit*, 2016; King, Conway, and Salon, "Do For-Hire Vehicles Provide First Mile/Last Mile Access to Transit?," 2020.
[36] Joshua Cregger et al., "Low-Speed Automated Shuttles: State of the Practice," 2018.
[37] Jian Wen et al., "Transit-Oriented Autonomous Vehicle Operation with Integrated Demand-Supply Interaction," *Transportation Research Part C: Emerging Technologies* 97 (2018): 216–34.
[38] Henry et al., "New Mobility Autonomous Vehicles and the Region."
[39] Shen, Zhang, and Zhao, "Integrating Shared Autonomous Vehicle in Public Transportation System: A Supply-Side Simulation of the First-Mile Service in Singapore."

connections via TNC and use that as a basis for new services.[40]

4.3.2 Challenges

The research reveals that transit agencies can face a number of barriers when it comes to instituting public-private partnerships for first/last mile service. Regulatory and bureaucratic issues will naturally arise from bringing together entities with different operating systems. Formal partnerships often struggle to establish data sharing agreements between transit agencies and TNCs, although informal partnerships typically involve little to no data sharing.[41] Procurement processes can also pose a challenge as TNCs must meet procurement requirements, including competitive bidding thresholds.[42] It is important for entities to establish memoranda of understanding to integrate and streamline processes.[43] At the federal level, ride service providers must comply with federal legislation such as Buy America provisions, civil rights requirements, and the ADA.[44]

Aside from regulatory issues, public-private mobility partnerships have struggled to ensure equitable mobility service for those in need. For instance, strategies for marketing and serving unbanked populations must be considered even as service transitions to online and credit card access.[45] Provisions must also be made for incorporating income-eligible resident subsidies and dealing with equity issues around surge pricing in transit deserts.[46]

Other challenges are technological, and evaluation based. Fare integration systems must include commuter transportation benefits or subsidies. This can be difficult when dealing with transportation across jurisdictional lines.[47] Last, a lack of analysis of performance of previous partnerships serves as a barrier to new ones, as best practices and metrics for success are lacking.[48]

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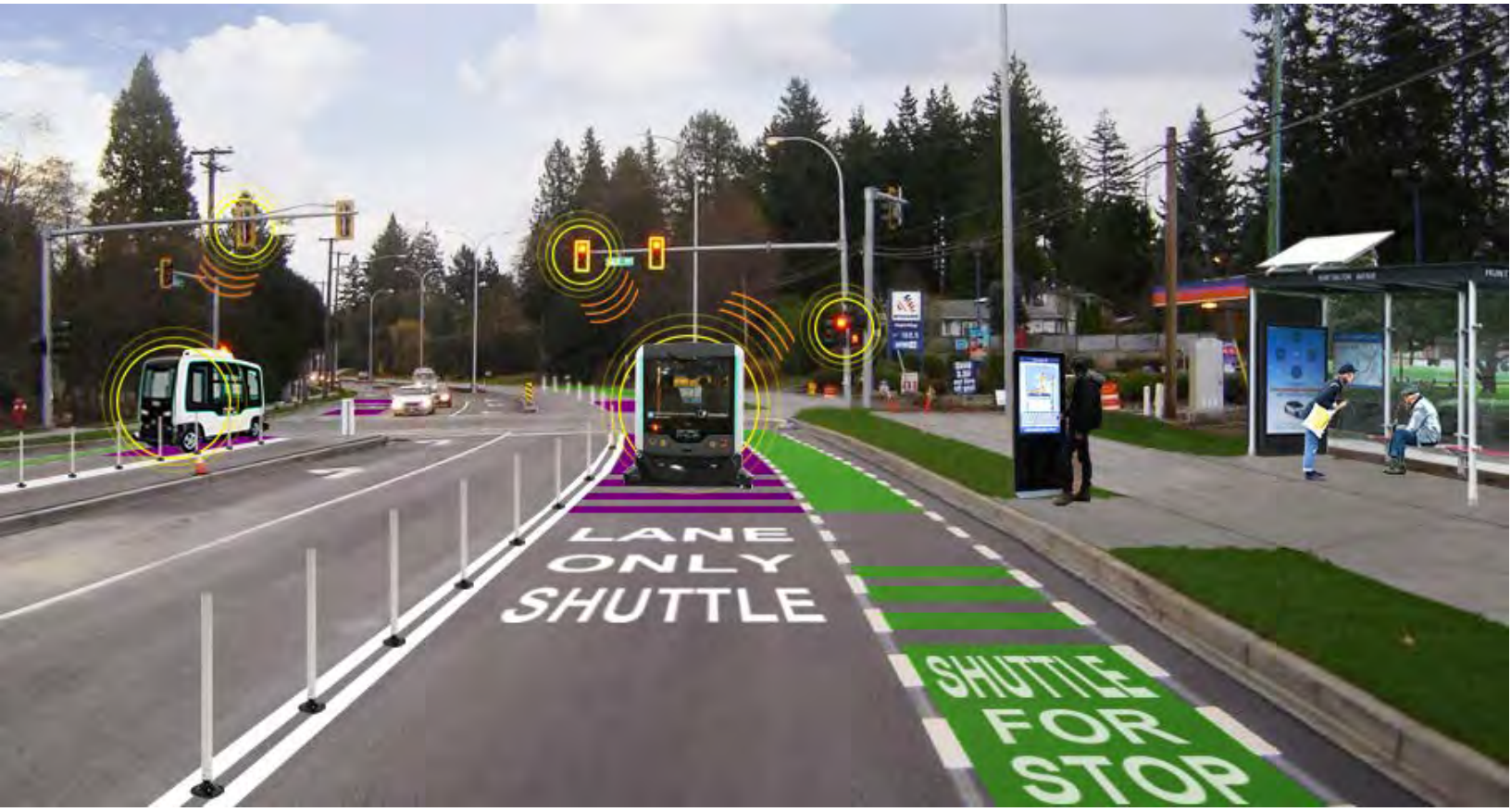
[40] Sharon Feigon, Colin Murphy, and Taylor McAdam, "Private Transit: Existing Services and Emerging Directions," 2018.
[41] National Academies of Sciences and Medicine, "Partnerships Between Transit Agencies and Transportation Network Companies."
[42] Jocelyn K Waite, "Legal Considerations in Evaluating Relationships between Transit Agencies and Ridesourcing Service Providers," 2018.
[43] Shaheen, Cohen, and Martin, "The US Department of Transportation's Smart City Challenge and the Federal Transit Administration's Mobility on Demand Sandbox: Advancing Multimodal Mobility and Best Practices Workshop."
[44] Feigon and Murphy, *Shared Mobility and the Transformation of Public Transit*; Waite, "Legal Considerations in Evaluating Relationships between Transit Agencies and Ridesourcing Service Providers."
[45] Shaheen, Cohen, and Martin, "The US Department of Transportation's Smart City Challenge and the Federal Transit Administration's Mobility on Demand Sandbox: Advancing Multimodal Mobility and Best Practices Workshop."
[46] Zmud et al., "Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies."
[47] Feigon and Murphy, *Shared Mobility and the Transformation of Public Transit*.
[48] Joseph Paul Schwieterman and Mallory Livingston, "A Review of Partnerships between Transportation Network Companies and Public Agencies in the United States," 2019.

The development of performance metrics for first/last mile partnerships is important and can be done by assessing metrics from current and previous partnerships. Additionally, implementation best practices around pricing and equity should be explored to make first/last mile services available more broadly.



4.4 Complement previous research associated with equity and accessibility by considering the first/last 50 feet, in addition to the first/last 50 miles, to ensure existing transportation gaps and needs are filled, and not limited to urban environments

It is important to consider first/last mile connection needs from the viewpoint of special user groups. Particularly, the research looks at accessibility considerations for the first and last 50 feet of a trip as well as the first and last 50 miles of trips that begin and end in rural areas. While much of this research focuses on shared mobility broadly, important lessons can be applied to AV service delivery.

4.4.1 First/Last 50 Feet

Public-private partnerships using smart mobility solutions such as AVs can be effective alternatives for paratransit. To be successful, one must consider the needs of users with a range of disabilities. Outside of vehicles, the built environment must be addressed to ensure that all can enjoy new mobility services. The Blueprint for Autonomous Urbanism notes that built environment features such as near-level curbs must be available to ensure accessible boarding.[49] This can be an issue when ridehailing or similar services do not have designated drop-off areas, as vehicle and curb heights are not standardized. Accessible sidewalks and bus stops are also vital for passengers to get to vehicles comfortably and safely. Bayless and Davidson's report notes the importance of accessible boarding area features such as wayfinding and signage, which are key to help users find mobility service locations.[50] The research stresses that the built environment must be considered so that people with various disabilities – including the blind, deaf, hard of hearing, and mobility impaired – can comfortably navigate to mobility services.[51] The forthcoming Best Practices in Coordination of Public Transit and Ride Sharing will include ADA accessibility considerations to guide future partnerships.[52]

To be successful, one must consider the needs of users with a range of disabilities

While paratransit services currently include attendants to assist people with disabilities, this concept must be reconsidered if AVs are to be used for this purpose, as these services could be potentially automated. Shaheen et al. suggest that attendants could either be retained to assist passengers, or passenger support could be automated in the absence of a driver.[53] The Alliance of Automobile Manufacturers write that human attendants will be required until a technology system enabling unassisted use is developed.[54] Regardless of the method, if the services fall within the federal definition, ADA requirements must be enforced in the provision of AV services to make these accessible to all users.

4.4.2 First/Last 50 Miles

Many rural areas face mobility challenges due to a lack of transit options. Pilot projects in places such as rural Japan have demonstrated that AVs can fill mobility gaps.[55] However, service delivery in low density areas is a challenge. An opportunity for more equitable access exists

[49] "Blueprint for Autonomous Urbanism – Second Edition," 2019, https://nacto.org/publication/bau2/.
[50] Steven H Bayless and Sara Davidson, "Driverless Cars and Accessibility: Designing the Future of Transportation for People with Disabilities," 2019.
[51] "Autonomous Vehicles: Driving Employment for People with Disabilities Information Gathering Session," 2018, https://autoalliance.org/wp-content/uploads/2019/05/ODEP_AVInfoGatheringReport2Final.pdf; Bayless and Davidson, "Driverless Cars and Accessibility: Designing the Future of Transportation for People with Disabilities."
[52] "Best Practices in Coordination of Public Transit and Ride Sharing [NCHRP 08-130]," 2019, https://rip.trb.org/view/1628595.
[53] Susan Shaheen et al., "Mobility on Demand: A Smart, Sustainable, and Equitable Future," *Transportation Research Circular*, no. E-C244 (2019).
[54] "AVs and Increased Accessibility Workshop Series Report," 2019, https://autoalliance.org/wp-content/uploads/2019/10/AVs-Accessibility-Workshop-Series-Report-16OCT2019.pdf.
[55] David J. Eaton, "Autonomous Rural Transportation Challenges and Opportunities in Iinan-Cho, Shimane, Japan," 2020, https://repositories.lib.utexas.edu/handle/2152/81242.

through subsidies or other financial incentives for mobility service providers to service less profitable areas. The Ohio Department of Transportation was awarded a grant by the USDOT in 2019 for a demonstration project that includes rural ridehailing using automated technology.[56] The research notes that subsidies are cost-effective, as they are often lower per ride than the cost of fixed-route service in low-density areas.[57] However, Goldsmith and Gardner reveal that incentives do not always compel TNCs to adequately serve underserved areas; the same may also be true for subscription-based AV services.[58] Rural areas may also lack the technology access necessary to easily access subscription-service AVs.

Policies can be put in place to ensure that services reach the unbanked and people without internet access. Shaheen et al. write that telephone concierge service, SMS text access, and shared mobility access kiosks can all be used by people without smartphones.[59] Few best practices currently exist for provision of services in rural areas. Shaheen, Cohen, and Martin note that sponsoring a "smart rural challenge" to encourage improvements could be a useful first step towards creating such best practices.[60] NCHRP research currently underway will also provide guidance in the form of an implementation guidebook for innovative applications to integrate public transportation in low-density areas using shared-use mobility services.[61]

Further research needs in this area might include universal design standards for AVs and best practices around built environment features to ensure accessibility. Best practices for rural service provision could inform future AV service to fill first/last 50-mile gaps.

4.5 Evaluate app-based fare payment systems and opportunities and challenges associated with Mobility as a Service

MaaS is the integration of various transportation modes into a single mobility service that is accessible on demand. MaaS offers increased convenience and access to multimodal transportation options. Different levels of fare integration and bundling options provide flexibility to users and can increase efficient mobility. However, MaaS implementation must overcome barriers at different levels of governance and must address unintended negative consequences. As we move into a proliferation of AVs, the topic of MaaS – while not specific to AVs – remains related. Shared AV services will require a MaaS access point.

[56] Coyner, "Low-Speed Automated Vehicles (LSAVs) in Public Transportation."
[57] Zmud et al., "Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies."
[58] Stephen Goldsmith and Betsy Gardner, "Prioritizing Public Value in the Changing Mobility Landscape," 2020.
[59] Susan Shaheen et al., "Travel Behavior: Shared Mobility and Transportation Equity," 2017.
[60] Shaheen, Cohen, and Martin, "The US Department of Transportation's Smart City Challenge and the Federal Transit Administration's Mobility on Demand Sandbox: Advancing Multimodal Mobility and Best Practices Workshop."
[61] "Best Practices in Coordination of Public Transit and Ride Sharing [NCHRP 08-130]."

4.5.1 Opportunities

The research in this area discusses that MaaS systems, if implemented in an equitable and widespread manner, offer an opportunity to make cities less congested, more inclusive, more environmentally friendly, and healthier.[62] By integrating other travel modes, it acts as a complement to private vehicle use, even if it does not necessarily lead to a reduction in vehicle ownership, as noted by Storme et al.[63] MaaS can incorporate a variety of services based on user preferences and need. Wright, Nelson, and Cottrill observe that this flexibility allows for tailoring to the needs of specific locations, whether urban, suburban, or rural.[64]

Kamargianni et al. describe how different types of service models can be used to implement MaaS.[65] Ticket and payment integration uses a single smart card or ticket tied to one account to access all modes taking part in the service. Mobility packages, meanwhile, can be available as pre-paid bundles of mobility services for a specific time or distance. Information and communication technologies integration uses a single app or website to access information about the various modes included in the service. Much variation exists within these types as well. Services can be commercially motivated or incorporate a public institution overlay.[66] Wong, Hensher, and Mulley propose a government-contracted model incorporating road pricing as an input to the MaaS package price. Lyons, Hammond, and McKay consider different types of MaaS as an evolutionary process and provide a framework to organize MaaS services into a hierarchy based on integration and user need.[67] In this framework, a truly evolved MaaS offers full integration across all travel modes with low cognitive effort required.

Researchers note the importance of determining customers' willingness to pay for a MaaS system. Guidon et al. note that high willingness to pay for certain bundled services can increase the profitability of a public transportation system, making MaaS attractive for both consumers and suppliers.[68] Other researchers state that education can be used to increase low willingness to pay, while ability to choose bundled services can also promote use of MaaS.[69] Caiati et al.'s study in the Netherlands found that the decision to subscribe to MaaS services and the choices

[62] C Linton and J BRAY, "MaaS Movement? Issues and Options on Mobility as a Service for City Region Transport Authorities," 2019.
[63] Tom Storme et al., "Limitations to the Car-Substitution Effect of MaaS. Findings from a Belgian Pilot Study," *Transportation Research Part A: Policy and Practice* 131 (2020): 196–205.
[64] Steve Wright, John D Nelson, and Caitlin D Cottrill, "MaaS for the Suburban Market: Incorporating Carpooling in the Mix," *Transportation Research Part A: Policy and Practice* 131 (2020): 206–18.
[65] Maria Kamargianni et al., "A Critical Review of New Mobility Services for Urban Transport," *Transportation Research Procedia* 14 (2016): 3294–3303.
[66] Yale Z Wong, David A Hensher, and Corinne Mulley, "Mobility as a Service (MaaS): Charting a Future Context," *Transportation Research Part A: Policy and Practice* 131 (2020): 5–19.
[67] Glenn Lyons, Paul Hammond, and Kate Mackay, "The Importance of User Perspective in the Evolution of MaaS," *Transportation Research Part A: Policy and Practice* 121 (2019): 22–36.
[68] Sergio Guidon et al., "Transportation Service Bundling–for Whose Benefit? Consumer Valuation of Pure Bundling in the Passenger Transportation Market," *Transportation Research Part A: Policy and Practice* 131 (2020): 91–106.
[69] Corinne Mulley et al., "Mobility as a Service in Community Transport in Australia: Can It Provide a Sustainable Future?," *Transportation Research Part A: Policy and Practice* 131 (2020): 107–22; Valeria Caiati, Soora Rasouli, and Harry Timmermans, "Bundling, Pricing Schemes and Extra Features Preferences for Mobility as a Service: Sequential Portfolio Choice Experiment," *Transportation Research Part A: Policy and Practice* 131 (2020): 123–48.

of which transportation modes to include varied based on socio-demographic and transportation-related characteristics.[70]

4.5.2 Challenges

Barriers to implementing MaaS exist at various levels of the transportation system – what Karlsson et al. refer to as macro, meso, and micro-level barriers.[71] Macro-level barriers include legislation as well as the lack of shared MaaS goals; meso-level barriers can be a lack of business models or assumed roles and responsibilities of involved parties; and micro-level barriers involve users' attitudes and habits regarding uptake of MaaS services. Full fare integration in the United States can be difficult given transit agencies' Title VI obligations and issues surrounding federal benefit programs. Also, as Feigon and Murphy make clear, pre-tax dollars cannot be used for services such as carsharing, ridehailing, or bikesharing under current Internal Revenue Service rules; this poses difficulties for integrating these or similar AV services with transit.[72] Cottrill notes that MaaS systems in Europe must comply with the recently enacted General Data Protection Regulation (GDPR), which codifies requirements around data privacy, consent, and protection.[73] There is no such national standard in the U.S. at this time; however, the State of California has enacted the California Consumer Privacy Act, which has been referred to as "GDPR light."[74]

As with first/last mile partnerships, implementation challenges can arise when public and private parties must cooperate. Polydoropoulou's investigation of the business perspective of MaaS found that cities' regulatory frameworks, the lack of standardization and openness in the application programming interfaces, and the need for transportation-related investments such as flexible transit ticketing systems all posed risks for MaaS implementation.[75]

User preferences can act as barriers to MaaS acceptance. Studies in Australia and the United Kingdom found that users who chose not to use MaaS services did so for reasons of convenience or efficiency, instead opting to use private vehicles.[76] Schikofsky, Dannewald, and Kowald note that such motivational deterrents could be addressed through marketing, product development, and policy measures to make MaaS more appealing to potential users.[77]

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[70] Caiati, Rasouli, and Timmermans, "Bundling, Pricing Schemes and Extra Features Preferences for Mobility as a Service: Sequential Portfolio Choice Experiment."
[71] I C M Karlsson et al., "Development and Implementation of Mobility-as-a-Service–A Qualitative Study of Barriers and Enabling Factors," *Transportation Research Part A: Policy and Practice* 131 (2020): 283–95.
[72] Feigon and Murphy, *Shared Mobility and the Transformation of Public Transit*.
[73] Caitlin D Cottrill, "MaaS Surveillance: Privacy Considerations in Mobility as a Service," *Transportation Research Part A: Policy and Practice* 131 (2020): 50–57.
[74] "California Consumer Privacy Act of 2018 [1798.100 - 1798.199]" (2019), http://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?division=3.&part=4.&lawCode=CIV&title=1.81.5.
[75] Amalia Polydoropoulou et al., "Prototype Business Models for Mobility-as-a-Service," *Transportation Research Part A: Policy and Practice* 131 (2020): 149–62.
[76] Chinh Q Ho, Corinne Mulley, and David A Hensher, "Public Preferences for Mobility as a Service: Insights from Stated Preference Surveys," *Transportation Research Part A: Policy and Practice* 131 (2020): 70–90.
[77] Jan Schikofsky, Till Dannewald, and Matthias Kowald, "Exploring Motivational Mechanisms behind the Intention to Adopt Mobility as a Service (MaaS): Insights from Germany," *Transportation Research Part A: Policy and Practice* 131 (2020): 296–312.

Aside from barriers to the rollout and use of MaaS, the implementation of MaaS systems can have negative, unanticipated implications for users. Pangbourne et al. note that the rise of MaaS could negatively affect the environment, health, and equity if not rolled out conscientiously.[78] For example, greenhouse gas emissions could increase if the use of MaaS encourages unnecessary, unshared TNC rides instead of transit or other, greener modes. User health could suffer if there is a modal shift away from active forms of transportation. Others could be left out of the system, as those who cannot afford services or lack access to the internet may find themselves with limited options.

To facilitate the rollout of MaaS systems, future research could address best practices around equity, regulation, and app operationalization. Studies of consumer willingness to pay would help develop desired service bundles to encourage buy-in to MaaS programs.

4.6 Consider existing research around workforce implications around automation and transit, including opportunities for new roles and classifications for drivers or operators

Workforce implications around AVs are a large concern for the driving industry as a whole and the transit workforce particularly. Research shows that the rollout of AVs will negatively impact current jobs in the driving industry; however, the net effect of new job creation is up for debate. Transit workers' union connections put them in a unique position to experience the implications of transit AVs.

4.6.1 AVs and Shifting Employment Roles

Deployment of smart mobility technology such as AVs could have a multifaceted effect on the transit workforce: while automated technology will threaten driving jobs, it can also lead to job creation in other fields.[79] A transit agency survey conducted by Han et al. found that 40% of those agencies state that their drivers are concerned about the impacts of automated technology.[80]

[78] Kate Pangbourne et al., "Questioning Mobility as a Service: Unanticipated Implications for Society and Governance," *Transportation Research Part A: Policy and Practice* 131 (2020): 35–49.
[79] Andrea Ricci, "Socioeconomic Impacts of Automated and Connected Vehicle: Summary of the Sixth EU–US Transportation Research Symposium," in *Transportation Research Board Conference Proceedings*, 2019; David N Beede, Regina Powers, and Cassandra Ingram, "The Employment Impact of Autonomous Vehicles," *Available at SSRN 3022818*, 2017.
[80] Han et al., "Understanding Transit Agency Perceptions about Transportation Network Companies, Shared Mobility, and Autonomous Transit: Lessons from the United States."

Yankelevich et al. estimated in 2018 that job losses in the driving sector – including transit, trucking, taxis, and other passenger transportation services – will number in the low hundreds of thousands during the next decade, with much of this anticipated displacement occurring in the latter half of the 2020s as AV adoption grows. Their report describes anticipated job losses and shifts in the passenger transportation industry, noting that certain passenger-facing jobs such as luxury transportation and paratransit will be less affected.[81] A 2017 study specifies that job losses could disproportionately affect African Americans, Hispanics, and certain geographic regions in which professional driving makes up a relatively large share of employment.[82] That study estimates that approximately 4 million jobs are likely to be lost, with occupations such as delivery and heavy truck drivers, bus drivers, and taxi and chauffeur drivers at greatest risk of job losses. However, Rouse et al.'s interview-based study found a lack of consensus among participants as to whether AVs would displace transit bus drivers.[83]

It is possible that transit drivers could experience role shifts as AV technology is adopted

It is possible that transit drivers could experience role shifts as AV technology is adopted. Some participants in Yankelevich et al.'s study suggested that if there was a shift to AV, transit employees would continue to operate automated buses as "ambassadors" or attendants to assist passengers.[84] Rouse et al. propose that driving jobs will likely be replaced by either lower-paying jobs such as concierge and inventory control positions or by higher skilled technology-related positions.[85] The USDOT's Strategic Transit Automation Research Plan includes provisions for a future assessment of automated transit labor impacts to study this topic in greater detail.[86]

4.6.2 Labor Union Implications

Unlike some other professions that may be impacted by AVs, public transit workers are normally supported by labor unions that will fight to preserve transit jobs. The AFL-CIO has called on the Department of Labor to consider policies to safeguard the transit workforce in relation to AVs.[87] Gettman et al. note that labor agreements may already constrain fully automated operations, as the Federal Transit Act Section 13c prohibits jobs from being taken away from public transit employees.[88]

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[81] Aleksandr Yankelevich et al., "Preparing the Workforce for Automated Vehicles" (The American Center for Mobility, Ypsilanti, MI, 2018).
[82] Algernon Austin, *Stick Shift: Autonomous Vehicles, Driving Jobs, and the Future of Work* (Center for Global Policy Solutions, 2017).
[83] David C Rouse et al., "Preparing Communities for Autonomous Vehicles," 2018.
[84] Yankelevich et al., "Preparing the Workforce for Automated Vehicles."
[85] Rouse et al., "Preparing Communities for Autonomous Vehicles."
[86] Elizabeth Machek et al., "Strategic Transit Automation Research Plan" (United States. Federal Transit Administration. Office of Research …, 2018).
[87] "Principles for the Transit Workforce in Automated Vehicle Legislation and Regulations," 2019, https://ttd.org/policy/principles-for-the-transit-workforce-in-automated-vehicle-legislation-and-regulations/.
[88] Douglas Gettman et al., "Impacts of Laws and Regulations on CV and AV Technology Introduction in Transit Operations," 2017.

Transit workers and their unions are in a unique position to have a voice in the rollout of AVs and automated transportation services. More research into employment transitions is needed to consider the implications of union contract regulations and how mitigations including retraining might be able to address a potential barrier to transit AVs.

4.7 Determine existing research around impacts of ADA requirements and considerations around universal design

ADA requirements are an important consideration for any public-private mobility partnerships. While transit agencies must comply with ADA regulations, at this time, direct applicability for private TNC providers surrounds where they meet the definition of public transit. Nevertheless, ADA requirements must be satisfied for any federally funded partnership with transit to be implemented. Transit services and private service providers, including new AV providers, all face challenges ensuring accessibility for their users. While initiatives and designs get closer to universal design standards, there remains a significant way to go to obtain full mobility accessibility.

4.7.1 Applicability of ADA Rules

ADA requirements can be a challenge to partnerships between transit agencies and new mobility service providers such as TNCs. Waite writes that transit agencies must comply with ADA regulations, and this obligation includes ensuring that any contracted services are also in compliance.[89] However, TNCs have claimed to be "technology companies" and as such not subject to ADA requirements. This issue remains unresolved in the courts, although several courts have previously rejected this argument in the context of employment litigation.[90] Accessibility features are not always mandated among traditional transportation service providers such as taxis. Bayless and Davidson note that the ADA contains exemptions for taxi companies on wheelchair accessibility rules, although some localities have introduced their own requirements.[91] The forthcoming NCHRP report on Best Practices in Coordination of Public Transit and Ride Sharing will provide more insight into this topic.[92]

The emergence of AVs has only added to the discussion around accessibility. Coyner (2020) states that there is currently no definition of an ADA-compliant LSAV, and none yet meet transit ADA-type standards.[93] However, AVs used in any capacity that falls within the ADA definition of public transit will need to comply with the ADA. Some city-driven efforts are underway to address accessibility around AVs. Arlington, VA required vehicles with ramps for their first AV

[89] Waite, "Legal Considerations in Evaluating Relationships between Transit Agencies and Ridesourcing Service Providers."
[90] Waite; Bayless and Davidson, "Driverless Cars and Accessibility: Designing the Future of Transportation for People with Disabilities."
[91] Bayless and Davidson, "Driverless Cars and Accessibility: Designing the Future of Transportation for People with Disabilities."
[92] "Best Practices in Coordination of Public Transit and Ride Sharing [NCHRP 08-130]."
[93] Coyner, "Low-Speed Automated Vehicles (LSAVs) in Public Transportation."

deployments, while the Jacksonville Transit Authority included wheelchair users in its assessment of LSAVs and accessibility.[94] At the national level, the FTA's Strategic Transit Automation Research Plan includes future demonstration projects for automated ADA paratransit.[95]

As AVs used for public transportation must be in compliance with the ADA, further research may be necessary to develop industry-wide standards for a fully accessible AV.

4.7.2 Challenges to Accessibility

Gettman et al. note that AV service providers will need to overcome a number of challenges to comply with the ADA.[96] Facilities will need to be designed for AV use and accessibility; this will be especially important for facilities built in the next 10 years. Important features to address include vehicle height for use with ramps, passenger access to platforms, as well as the means for boarding and securing passengers in the absence of a driver or attendant. The authors suggest that attendants will be needed for the foreseeable future to ensure ADA compliance.

4.7.3 Universal Design

Universal design is "the *design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design*.[97] This concept recognizes that different users have different needs and incorporates this into the design process.[98] While some progress has been made towards universal design in transit, especially among facilities and infrastructure built after the ADA's inception, research indicates that much room remains for improvements. The Universal Design Handbook includes guidance for mass transit, including terminal design, information resources, vehicle loading, and design.[99] Bitterman and Hess, meanwhile, provide universal design guidance specifically in the context of bus rapid transit systems.[100] Research has shown that incorporating universal design principles into public transit can improve service quality.[101] As AV designers also strive to meet universal

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[94] Coyner.
[95] Machek et al., "Strategic Transit Automation Research Plan."
[96] Gettman et al., "Impacts of Laws and Regulations on CV and AV Technology Introduction in Transit Operations."
[97] "Principles of Universal Design," United States Access Board, 1995, https://www.access-board.gov/guidelines-and-standards/communications-and-it/26-255-guidelines/825-principles-of-universal-design.
[98] Ben Pierce, Eric Plapper, and Jodi Rizek, "Accessible Transportation Technologies Research Initiative (ATTRI): User Needs Assessment: Stakeholder Engagement Report." (United States. Department of Transportation. Intelligent Transportation …, 2016).
[99] Edward Steinfeld, "Universal Design in Mass Transportation," *Universal Design Handbook. New York: McGraw Hill*, 2001.
[100] Alex Bitterman and Daniel Baldwin Hess, "Bus Rapid Transit Identity Meets Universal Design," *Disability & Society* 23, no. 5 (2008): 445–59.
[101] Aybike Ongel et al., "Public Transport Service Quality Improvement Using Universal Design Standards and Advanced Vehicle Technologies," in *2018 International Conference on Intelligent Autonomous Systems (ICoIAS)* (IEEE, 2018), 211–16; Natalia Martins Gonçalves, "Bus Rapid Transit: Level of Service Analysis of Pedestrian Itinerary and the BRT Station towards User-Friendly Accessibility and Universal Design," in *13th. Conference on Mobility and Transport for Elderly and Disable Persons. Proceedings... TRANSED*, 2012; Aaron Steinfeld et al., "Mobile Transit Information from Universal Design and Crowdsourcing," *Transportation Research Record* 2217, no. 1 (2011): 95–102.

design standards, synergies can be used to provide more accessible mobility services to all.[102] For example, the developer of the Denver 61AV Shuttle pilot installed ADA compliant bus stops with concrete pads for enhanced accessibility.[103]

[102] Darrell Etherington, "May Mobility Reveals Prototype of a Wheelchair-Accessible Autonomous Vehicle," TechCrunch, 2019; "Transforming Transportation for the World's Aging Population and People with Disabilities," IBM, 2018, https://www.ibm.com/blogs/age-and-ability/2017/01/06/transforming-transportation-for-the-worlds-aging-population-and-people-with-disabilities/.; "Lyft Partners with the National Federation of the Blind and Aptiv in Las Vegas," Lyft, Inc., 2020, https://www.lyft.com/blog/posts/lyft-aptiv-nfb-low-vision-riders.
[103] Coyner, "Low-Speed Automated Vehicles (LSAVs) in Public Transportation."

5 Further Research Opportunities

The suggestions below identify topics for future research to inform and focus the important discussion around *Impacts of Automated Vehicles and Shared Mobility on Transit and Partnership Opportunities*. 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
4.2	Investigate the impact of current, varied definitions of public transportation; develop and evaluate alternative approaches.	*Equity & Accessibility*
4.3	Assess ways in which AV and other shared services best complement and expand mobility services to underserved areas.	*Equity & Accessibility, Social Impacts, Data Sharing*
4.3	Develop a best practices guide for public-private partnerships including procurement models for fixed route and paratransit service, as well as for new technologies, data sharing, infrastructure readiness, and the like.	*None*
4.3	Create guides for cross-border subsidies across cities, fare integration, and creating sustainable shared mobility services.	*Equity & Accessibility*
4.3	Develop performance metrics for evaluating AV and shared mobility partnerships.	*None*
4.3	Assess ADS projects and human machine interface applications.	*Equity & Accessibility*
4.5	Evaluate models for MaaS that address transit-centric and universal MaaS, as well as MaaS implemented in Europe, including: • Fare subsidies across modes, digital access, and the unbanked. • App integration, operational best practices, and data ownership.	*Equity & Accessibility, Data Sharing*
4.6	Identify the timing of workforce impacts by work classification, demographics, and geography of widespread HAV deployment. Evaluate pilot efforts in training and develop a model for a labor-management partnership on provision of microtransit/AV service	*Social Impacts, Freight*
4.7	Conduct a literature synthesis on universal design for vehicles, facilities, and infrastructure.	*Equity and Accessibility*

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	US Department of Transportation
VMT	Vehicle Miles Traveled

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