NCHRP Project 20-113F

Preparing for Automated Vehicles and Shared Mobility: State-of-the-Research Topical Paper #4

MAXIMIZING POSITIVE SOCIAL IMPACTS OF AUTOMATED VEHICLES AND SHARED MOBILITY

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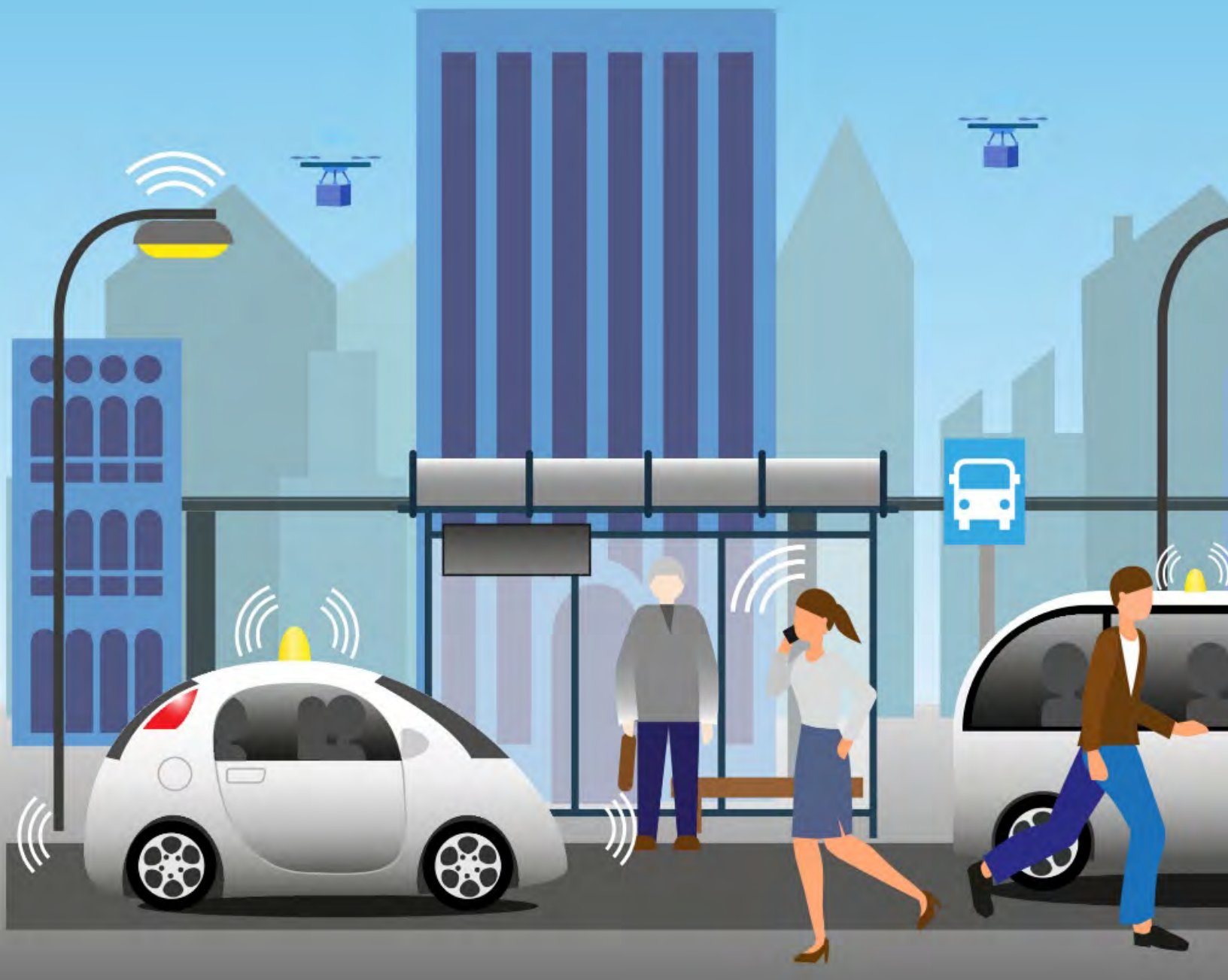
TRB AV/SM FORUM
AUTOMATED VEHICLES + SHARED MOBILITY

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 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. Provide realistic overview of opportunities and challenges associated with deployment of smart mobility strategies
2. Identify opportunities and challenges in assessing the positive/negative impacts of AVs and shared mobility
3. Identify collaborative approaches and public engagement strategies to minimize potential negative impacts of automated vehicles, including congestion, affordability, job loss, and increasing digital divide
4. Evaluate the roles of land use, parking, pricing, curb management, data, and other policy measures towards reducing the negative impacts and unintended consequences of AVs and shared mobility
5. Conceptualize and examine policy frameworks and levers to produce more accurate assessments of the value of transportation and incentivize more efficient transportation solutions, including from a livability and economic perspective

3 Summary of Findings

AVs and shared mobility strategies will have a profound impact on society if the technology can be scaled. These impacts are wide-reaching, ranging from environmental effects to employment and issues surrounding quality of life. There is a substantive debate on whether these impacts will be positive or negative; researchers predict varying outcomes largely depending on whether AVs are shared or personally-owned, used as single occupancy vehicles, or have electric or internal combustion engines. Based on the literature reviewed, the research community and private sector wish to understand the potential social impacts of AVs and strategies that can be used to maximize positive impacts.

This Topical Paper provides a summary of research on potential social impacts as they relate to shared mobility and AVs. Through reviewing the body of literature on impacts arising from HAVs within the context of the areas of focus noted above, several common themes emerge:

- **AVs powered by electricity and deployed in shared use models offer social benefits.** The body of literature identifies potential benefits that shared, electric AVs offer by reducing vehicle miles traveled per capita, congestion, and emissions. Researchers also note that if AVs are operated as single-occupancy vehicles or with internal combustion engines, they could compound congestion and worsen air quality and greenhouse gas emissions. The literature discusses whether AVs and increased shared mobility could free up time otherwise spent driving, or if AVs might extend commute times. Researchers also call for policy and programmatic approaches that require or incentivize shared service models and electrification.

- **Addressing concerns around job impacts is an area of discussion related to impacts of AVs.** The literature notes that the rise of AVs could cause job displacement, shifting roles, as well as new job creation over time. Leveraging existing research around job impacts to develop a more comprehensive plan for identifying likely areas of job losses and education programs is needed. Helping to ensure transitions to new AV-generated employment areas will present an important opportunity for future collaboration and research.

- **Policy frameworks should be aligned around measurable goals with respect to decreased VMT, electrification, and shared use, as well as equity outcomes.** The literature identified policy levers needed to achieve positive social impact. These levers or policies include funding that supports service to underserved communities and people with disabilities. Researchers further highlighted the value of participatory or collaborative engagement with people in impacted communities. As in other areas, policies should reflect both potential timelines and alternative scenarios for deployment.

- **Public engagement is recommended as a key in maximizing adoption and understanding opportunities to promote positive outcomes.** The literature emphasizes public engagement in preparing and planning for individual deployments and integration of AVs into the transportation system. Researchers observe this engagement should be around earning trust as well as around inclusion of those people

and communities that may not be active participants in the transportation planning process. Further, the literature notes that effective engagement requires resources and inclusive practices.

Additional research and outreach by the Forum will be needed to address these discussion trends. The high level of uncertainty surrounding the development and ultimate implementation of these new technologies provides strong challenges for transportation leaders.

4 Summary of Research Reviewed

The research reviewed included papers from academic journals, federal entities, and special interest groups. This variety of sources points to a cross-sector interest in maximizing the positive social impacts of AVs. The following is a summary of the research reviewed.

4.1 Provide realistic overview of opportunities and challenges associated with deployment of smart mobility strategies

The impact of smart mobility strategies can be a double-edged sword. As noted in the research to date, AVs are expected to lead to both job losses and job growth with variations across sectors. Depending on how they are rolled out – whether shared or single-occupancy, electrified or non-electric, – AVs have the potential to either positively impact the environment and quality of life or have negative repercussions. Most likely, the results will be some combination of positive and negative. Research primarily around SAE level 3 and higher AVs shows potential outcomes for varying deployment scenarios (see Table 1).

Table 1. Potential Positive and Negative Outcomes of AV Deployment

Possible Positive Outcomes	Possible Negative Outcomes
Economic	
New jobs in technology fields	Job losses such as taxi or truck drivers, replacement jobs with lower salaries and/or benefits
Increased access to jobs	Congestion reduces job access
Lower transportation costs from insurance and fuel	Potential rise of oligopolies and increased cost of transportation services
Economic growth from reduced vehicle crashes and potential increased commuter productivity	Longer commutes in distance and/or time

Environment

Electrification reduces transportation-related emissions	Lack of electrification and sharing increases transportation-related emissions
Sharing reduces VMT and congestion	Network travel[2] and lack of sharing increases VMT and congestion
Platooning and connected vehicle technology increase fuel efficiency and use of road space	Potential for disproportional noise, congestion, and pollution levels in disadvantaged communities
AVs complement greener travel modes	Potential preference for AVs over greener modes

Land Use

More land dedicated to other uses	Increased sprawl, potential reduced space for walking and biking

Social Equity

Increased mobility for the elderly, disabled, and those in transit-poor areas	Potential exclusion of those with disabilities, the unbanked, and people without internet
More free time for commuters and other travelers	Increased public health risks from shared vehicles

4.1.1 Jobs

Deployment of smart mobility strategies can lead to both job creation and threats to current jobs; while all levels of AVs can lead to job creation, more highly automated vehicles could lead to job displacements for current positions such as taxi and truck drivers.[3] Much of the current research on this topic notes this multifaceted effect. The Information and Communications Technology Council published a report identifying four types of job impacts in Canada.[4] Their analysis indicated that some jobs, such as drivers, will be phased out and eventually replaced. Others, such as mechanics, will need to be retrained, while professions such as police officers and emergency medical technicians might find their roles shifted. Still other sectors such as software engineers will see job growth. One study notes that while AVs might have significant economic benefits among a highly concentrated group of industries, such as shipping, transit, and technology, these benefits would negatively impact the workforce as many professional drivers will lose their jobs.[5] Yankelevich et al. (2018) estimate that job losses in the driving sector due to

[2] Relocation travel (i.e., empty TNC vehicle travel to pick up a new passenger)
[3] 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.
[4] A. Cutean, "Autonomous Vehicles and the Future of Work in Canada" (Ottawa, Canada, 2017), https://www.ictc-ctic.ca/wp-content/uploads/2018/01/ICTC_-Autonomous-Vehicles-and-The-Future-of-Work-in-Canada-1-1.pdf.
[5] "Future Environmental Net Assessment: Autonomous Vehicles," 2017, http://www.trb.org/Main/Blurbs/176291.aspx.

the growth of the HAV industry, including transit and truck drivers, will number in the low hundreds of thousands during the next decade, with much of this anticipated displacement occurring as AV adoptions grows in the latter half of the 2020s. The report describes anticipated job losses and shifts in the trucking and passenger transportation industries, noting that passenger-focused jobs such as luxury services and paratransit will be less affected. Combined with emerging jobs in technology fields and non-driving fields related to new mobility, the report suggests a brighter aggregate jobs outlook than suggested by other studies.[6] However, the emerging jobs will not necessarily directly benefit those whose jobs are displaced.

Another report focused on the medium- to long-term impacts of HAVs estimates that effects on the workforce could begin in the early 2030s. It concludes that at the peak impact period, sometime between 2045 and 2050, the increase in the national unemployment rate would be 0.06-0.13 percentage points.[7] This report argues that AVs will create new jobs that will, in time, replace jobs eliminated by automation and will increase access to existing jobs for some economically depressed regions. The Union of Concerned Scientists (2019) quantifies job access, suggesting that AVs as part of higher-occupancy pooled fleets would more than double the number of jobs accessible within a 45 minute commute in the Washington, DC area.[8] However, they state that without pooling, the resulting increased congestion would lead to a loss of 80% of this job access benefit.

A 2018 American Planning Association symposium on preparing communities for AVs notes other job barriers in addition to displacement. They indicate that these new jobs will either provide lower wage rates and fewer benefits, or will require additional training due to the necessary technology-related knowledge and skills.[9] A 2017 study specifies that AV-related job losses could disproportionately affect African Americans, Hispanics, and certain geographic regions in which professional driving makes up a relatively large share of employment.[10]

4.1.2 Economic Effects

Overall economic outlooks associated with the deployment of smart mobility strategies are generally less mixed than those directly focused on jobs. The summary of the sixth EU-U.S. Transportation Research Symposium, which focused on the socioeconomic impacts of AVs and connected vehicles, notes a variety of positive economic impacts. These include maximized productivity as HAVs free drivers from the act of driving; an increase in consumer purchasing power resulting from reduced transport costs; and a reorganization of supply chain logistics that could promote smaller and more locally-focused distribution, helping to eliminate food and retail deserts.[11] Potential challenges were noted in the freight industry, where negative impacts on

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[6] Aleksandr Yankelevich et al., "Preparing the Workforce for Automated Vehicles" (The American Center for Mobility, Ypsilanti, MI, 2018).
[7] W David Montgomery et al., "America's Workforce and the Self-Driving Future: Realizing Productivity Gains and Spurring Economic Growth," 2018.
[8] Richard Ezike et al., "Where Are Self-Driving Cars Taking Us?," 2019, https://www.ucsusa.org/resources/where-are-self-driving-cars-taking-us.
[9] David C Rouse et al., "Preparing Communities for Autonomous Vehicles," 2018.
[10] Algernon Austin, *Stick Shift: Autonomous Vehicles, Driving Jobs, and the Future of Work* (Center for Global Policy Solutions, 2017).
[11] Ricci, "Socioeconomic Impacts of Automated and Connected Vehicle: Summary of the Sixth EU–US Transportation Research Symposium."

competitiveness of small and independent trucking and distribution companies could spur the rise of oligopolies. A study on travel effects of HAVs found that their use could reduce costs from insurance and fuel, allowing this money to be put back into the economy in other ways.[12] Greenblatt and Shaheen also noted the potential money-saving effects of AVs, as lowered insurance costs coupled with the reduced cost of AV technology would benefit users.[13] Another study echoes these findings and states that HAVs could spur economic growth as a result of a number of effects of HAVs. These include a reduced toll from vehicle crashes, increased commuter productivity, and reduced dependence on oil assuming electrification of AVs.[14] Feen, Bin-Nun, and Panasci demonstrate positive potential economic effects on households, writing that access to a shared AV fleet could reduce costs up to $5,600 annually per household nationally and reduce the burden of transportation costs on millions of households, depending on business and pricing models to access AV transportation.[15]

4.1.3 Vehicle Miles Traveled, Congestion, and Emissions

Research on various smart mobility strategies show that deployment has the potential to either improve or exacerbate VMT, congestion, and emissions. Studies showing beneficial results tended to focus on ridesharing, especially using electric vehicles. On the contrary, access to personal AVs led to scenarios in which VMT, congestion, and/or emissions would increase.

A number of studies document the benefits of ridesharing to reduce the negative effects of transportation; these can be extended to new solutions such as AVs.[16] The benefits increase when vehicles are electrified.[17] Greenblatt and Shaheen cite the potential for on-demand technology coupled with shared AVs could reduce car ownership and overall VMT.[18] Leslie et al. (2018) note that fuel consumption, congestion, and air pollution would be reduced by AV platooning and a reduction of cold starts as AVs travel out of city centers to park. Benefits also stand to be gained from deployment of connected vehicles and connected AVs. Spulber et al. (2017) document that shared and connected AVs complement other modes of travel (such as transit) that reduce VMT, congestion, and emissions. Connected vehicle technology, some of

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[12] Caroline Rodier, "The Effects of Ride Hailing Services on Travel and Associated Greenhouse Gas Emissions," 2018.
[13] Jeffery B Greenblatt and Susan Shaheen, "Automated Vehicles, on-Demand Mobility, and Environmental Impacts," *Current Sustainable/Renewable Energy Reports* 2, no. 3 (2015): 74–81.
[14] Montgomery et al., "America's Workforce and the Self-Driving Future: Realizing Productivity Gains and Spurring Economic Growth."
[15] Gidon Feen, Amital Bin-Nun, and Anthony Panasci, "Fostering Economic Opportunity through Autonomous Vehicle Technology," 2020, https://secureenergy.org/wp-content/uploads/2020/07/Fostering-Economic-Opportunity-through-Autonomous-Vehicle-Technology.pdf.
[16] Ricci, "Socioeconomic Impacts of Automated and Connected Vehicle: Summary of the Sixth EU–US Transportation Research Symposium"; None None, "The Transforming Mobility Ecosystem: Enabling in Energy-Efficient Future" (EERE Publication and Product Library, 2017); Don Anair et al., "Ride-Hailing's Climate Risks," 2020, https://www.ucsusa.org/resources/ride-hailing-climate-risks; Susan Shaheen et al., "Mobility on Demand Operational Concept Report" (United States. Department of Transportation. Intelligent Transportation …, 2017); 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; T.S. Stephens et al., "Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles," 2016.
[17] Jacques Leslie et al., "Will Self-Driving Cars Usher in a Transportation Utopia or Dystopia?," 2018, http://e360.yale.edu/features/will-self-driving-cars-usher-in-a-transportation-utopia-or-dystopia; "Future Environmental Net Assessment: Autonomous Vehicles"; Johanna Zmud et al., "Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies," 2017.
[18] Greenblatt and Shaheen, "Automated Vehicles, on-Demand Mobility, and Environmental Impacts."

which is in use today, can increase efficiency through features such as eco-routing, adaptive cruise control, and platooning.[19] Safety benefits of connected and automated vehicles can also improve traffic conditions, as a decrease in collisions will decrease congestion.[20]

Meanwhile, the same technologies could result in increasing VMT, congestion, and emissions under various circumstances. Numerous studies show that AVs and TNCs, (also referred to as ridesourcing and ridehailing) could lead to more trips and increased VMT if they are not shared.[21] One study simulated a world of personal HAVs by giving subjects unlimited chauffeurs and noted that participants logged 76% more miles, took longer trips, and traveled more at night than they normally would.[22] Some of the increase in VMT would be the result of empty relocation and parking travel of level 3-5 AVs.[23] This will lead to increased emissions and energy use if AVs and TNC vehicles are not electrified.[24] Bauer et al. (2020) note that fleet electrification may be difficult to achieve due to a lack of charging infrastructure and long charging times; these barriers will need to be overcome to reap the emissions benefits of AV fleet electrification.[25] Additionally, others would come from increased vehicle trips that would otherwise have been taken using other modes, such as transit.[26] This increase in travel could

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[19] Yingying Yan et al., "An Empirical Study on Consumer Automobile Purchase Intentions Influenced by COVID-19," *Available at SSRN 3593963*, 2020; Zmud et al., "Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies"; Leslie et al., "Will Self-Driving Cars Usher in a Transportation Utopia or Dystopia?"; "Future Environmental Net Assessment: Autonomous Vehicles"; "NEXTCAR 2020 Annual Program Review," 2020, https://arpa-e.energy.gov/sites/default/files/0_NEXTCAR_AR_2020_final.pdf; Vicente Milanés and Steven E Shladover, "Modeling Cooperative and Autonomous Adaptive Cruise Control Dynamic Responses Using Experimental Data," *Transportation Research Part C: Emerging Technologies* 48 (2014): 285–300; Hao Liu et al., "Freeway Vehicle Fuel Efficiency Improvement via Cooperative Adaptive Cruise Control," *Journal of Intelligent Transportation Systems*, 2020, 1–13.

[20] Zmud et al., "Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies."

[21] Jeffrey Mervis et al., "Are We Going Too Fast on Driverless Cars?," *Science*, 2017, http://www.sciencemag.org/news/2017/12/are-we-going-too-fast-driverless-cars; Mustapha Harb et al., "Projecting Travelers into a World of Self-Driving Vehicles: Estimating Travel Behavior Implications via a Naturalistic Experiment," *Transportation* 45, no. 6 (2018): 1671–85; Rodier, "The Effects of Ride Hailing Services on Travel and Associated Greenhouse Gas Emissions"; Kelly Fleming and Mark R Singer, "Energy Implications of Current Travel and the Adoption of Automated Vehicles" (National Renewable Energy Lab.(NREL), Golden, CO (United States), 2019); None, "The Transforming Mobility Ecosystem: Enabling in Energy-Efficient Future"; William D Larson and Weihua Zhao, "Self-Driving Cars and the City: Long-Run Effects on Land Use, Welfare, and the Environment," *Welfare, and the Environment (October 13, 2017)*, 2017; Ezike et al., "Where Are Self-Driving Cars Taking Us?"

[22] Harb et al., "Projecting Travelers into a World of Self-Driving Vehicles: Estimating Travel Behavior Implications via a Naturalistic Experiment."

[23] Rodier, "The Effects of Ride Hailing Services on Travel and Associated Greenhouse Gas Emissions"; None, "The Transforming Mobility Ecosystem: Enabling in Energy-Efficient Future"; Center for Automotive Reseach, "Future Cities : Navigating the New Era of Mobility," *Center for Automotive Research. Retrieved from Http://Www. Cargroup. Org/Wpcontent/Uploads/2017/10/Future-Cities_Navigating-the-New-Era-of-Mobility. Pdf*, 2017, 1–40; Adam Millard-Ball, "The Autonomous Vehicle Parking Problem," *Transport Policy* 75 (2019): 99–108.

[24] Leslie et al., "Will Self-Driving Cars Usher in a Transportation Utopia or Dystopia?"; Fleming and Singer, "Energy Implications of Current Travel and the Adoption of Automated Vehicles"; Ezike et al., "Where Are Self-Driving Cars Taking Us?"; Stephens et al., "Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles"; "Insights into Future Mobility," 2019, http://energy.mit.edu/wp-content/uploads/2019/11/Insights-into-Future-Mobility.pdf.

[25] Gordon Bauer et al., "On-Demand Automotive Fleet Electrification Can Catalyze Global Transportation Decarbonization and Smart Urban Mobility," *Environmental Science & Technology*, 2020.

[26] None, "The Transforming Mobility Ecosystem: Enabling in Energy-Efficient Future"; Rodier, "The Effects of Ride Hailing Services on Travel and Associated Greenhouse Gas Emissions."

also lead to higher noise, congestion, and air pollution levels.[27] This could disproportionately affect disadvantaged communities, as demonstrated by an analysis in the Washington, DC area.[28]

4.1.4 Quality of Life

Deployment of smart mobility technology such as AVs can improve quality of life in several ways. First, HAVs can free up time for commuters and other travelers. Passengers can take advantage of liberation from driving by turning vehicles into moving offices, bedrooms, or dens, thereby eliminating time previously occupied at the wheel.[29] Reduced need for parking spaces would allow land to be dedicated to other uses, such as education, health, or recreation, that will further improve quality of life.[30] Less pavement needed by AVs could be used for more sidewalks and other amenities.[31] Populations that have previously experienced mobility barriers, such as the aging or disabled, could benefit from increased productivity and more mobility options, assuming that AVs are designed in an accessible way.[32] Smart mobility strategies can also improve mobility for people in areas that are poorly served by transit.[33] Shaheen, Cohen, and Martin write that AVs or other mobility services can provide key first- and last-mile connectivity and provide increased routes, travel speed, and reliability.[34] Lynberg notes that AVs and smart mobility strategies can increase efficiency and convenience, leading to time savings benefits.[35] Eaton describes the mobility opportunities that AVs could pose in a rural area of Japan,

Populations that have previously experienced mobility barriers, such as the aging or disabled, could benefit from increased productivity and more mobility options, assuming that AVs are designed in an accessible way

[27] Ricci, "Socioeconomic Impacts of Automated and Connected Vehicle: Summary of the Sixth EU–US Transportation Research Symposium."
[28] Ezike et al., "Where Are Self-Driving Cars Taking Us?"
[29] Leslie et al., "Will Self-Driving Cars Usher in a Transportation Utopia or Dystopia?"; Rodier, "The Effects of Ride Hailing Services on Travel and Associated Greenhouse Gas Emissions."
[30] "Ten Rules for Cities About Automated Vehicles," Congress for New Urbanism, 2017, https://www.cnu.org/publicsquare/2017/10/16/ten-rules-cities-about-automated-vehicles; None, "The Transforming Mobility Ecosystem: Enabling in Energy-Efficient Future"; Rouse et al., "Preparing Communities for Autonomous Vehicles."
[31] Rouse et al., "Preparing Communities for Autonomous Vehicles."
[32] "Future Environmental Net Assessment: Autonomous Vehicles."
[33] Ricci, "Socioeconomic Impacts of Automated and Connected Vehicle: Summary of the Sixth EU–US Transportation Research Symposium."
[34] 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).
[35] Matthew Lynberg, "Automated Vehicles for Safety," NHTSA, n.d.

where an aging population and few mobility options can make transportation difficult.[36]

On the other hand, if not deployed conscientiously, this technology could cause negative outcomes. Relinquishing the need to drive could encourage sprawl and ever-longer commute times as people choose to live farther from their places of work or other destinations.[37] The Congress for New Urbanism (2018) describes potential negative outcomes from privately-owned AVs contributing to congestion in their search for parking spaces.[38] Prioritizing safe AV flows could take space from walking, biking, and alternative modes of transportation, resulting in a negative feedback loop that encourages more driving, more congestion, and more air pollution, decreasing quality of life.[39] These effects would be felt differently; current inequities

[36] David J. Eaton, "Autonomous Rural Transportation Challenges and Opportunities in Iinan-Cho, Shimane, Japan," 2020, https://repositories.lib.utexas.edu/handle/2152/81242.
[37] "Ten Rules for Cities About Automated Vehicles"; "Future Environmental Net Assessment: Autonomous Vehicles"; Rouse et al., "Preparing Communities for Autonomous Vehicles."
[38] "Ten Rules for Cities About Automated Vehicles."
[39] Center for Automotive Reseach, "Future Cities : Navigating the New Era of Mobility."

such as uneven digital access and discriminatory practices such as “transportation redlining” could be exacerbated by new mobility technologies.[40]

The shift to smart mobility strategies such as AVs will not happen overnight. The research suggests that by working now to assess potential impacts and find best practices for technology that is beginning operation, planners and decision makers can ensure that society experiences a net positive effect from these technologies.

4.2 Identify opportunities and challenges in assessing the

positive/negative impacts of AVs and shared mobility

[40] Rouse et al., “Preparing Communities for Autonomous Vehicles.”

Critical to understanding the impacts of the rollout of AVs is having methodologies to assess these impacts. As AVs and smart mobility are still in the early stages of use, limited data exist to assess positive and negative impacts. However, studies on existing TNC models can be used to create benchmarks to identify opportunities and challenges for the deployment of AVs in subscription fleet-style format. While there are similarities between Section 4.1 and 4.2, Section 4.1 looks at the challenges and opportunities associated with AVs and shared mobility broadly. This Section 4.2 then focuses on the ways in which these outcomes are (or not) assessed in the existing research.

4.2.1 Jobs

Boarnet et al. (2017) provide evidence that first and last mile connections to transit increase access to jobs.[41] The authors studied the effects of various policy changes on two accessibility measures; they analyzed low-wage job access by transit within a 30-minute commute along with the number of potentially competing workers living in this range. Results of their study in the San Diego region showed that if transit riders walk to or from transit stops, low-wage job accessibility by car is almost 30 times larger than low-wage job accessibility by public transit. This implies that TNCs are a more effective way to increase job access than improving transit wait time or service headway. However, addressing issues around contracting, partnerships, and funding will be important factors should partnerships with AVs and transit move forward.

An evolving area of focus and synergy with mobility and innovation is the “gig” economy and opportunities for workforce needs in this domain.

4.2.2 VMT, Congestion & Emissions

Several studies have assessed the impact of TNCs and carsharing on VMT, congestion, and emissions. A 2019 study of electric TNC vehicles in California revealed that the emission benefits of electrifying a TNC vehicle are nearly three times greater than the benefits from electrifying a privately-owned vehicle.[42] A study of users of the carsharing service car2go in five North American cities found that greenhouse gas emissions were reduced from -4% to -18% due to use of the service and reduction of personal vehicles.[43] TNCs, too, were found to reduce personal vehicle ownership by 9% to 10%.[44] However, the same study notes that TNCs are associated with an increase in number of trips, a decrease in other modes of travel, and an increase in passenger-less travel, all of which contribute to increased VMT and emissions.[45] Several other studies reveal that TNCs can increase VMT and emissions in part from a reduction of trips by other potentially cleaner modes, such as public transit.[46] Stephens et. al.

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[41] Boarnet et al., “First/Last Mile Transit Access as an Equity Planning Issue.”

[42] Alan Jenn, “Emissions Benefits of Electric Vehicles in Uber and Lyft Services,” 2019.
[43] Elliot W Martin and Susan A Shaheen, “Greenhouse Gas Emission Impacts of Carsharing in North America,” *IEEE Transactions on Intelligent Transportation Systems* 12, no. 4 (2011): 1074–86.
[44] Rodier, “The Effects of Ride Hailing Services on Travel and Associated Greenhouse Gas Emissions.”
[45] Rodier.
[46] Melissa Balding et al., “Estimated TNC Share of VMT in Six US Metropolitan Regions (Revision 1),” *Fehr and Peers. Https://Drive. Google. Com/File/d/1FIUskVkj9lsAnWJQ6kLhAhNoVLjfFdx3/View*, 2019; Anair et al., “Ride-Hailing’s Climate Risks”; Bruce Schaller, “The New Automobility: Lyft, Uber and the Future of American Cities,” 2018; None, “The Transforming Mobility Ecosystem: Enabling in Energy-Efficient Future.”

use published literature to assess the energy impact of connected and automated vehicles.[47] As with the TNC studies, the report finds that use can lead to either an increase or decrease in energy consumption, depending on factors such as changes in travel patterns, fuel efficiency, and future adoption levels. Whether TNCs are electric vehicles or other clean energy sources is a factor as well.

There remains much potential for research to assess the impacts of AVs and shared mobility, whether through the lens of TNCs or by directly studying AVs as they are rolled out.

4.3 Identify collaborative approaches and public engagement strategies to minimize potential negative impacts of automated vehicles, including congestion, affordability, job loss. and increasing digital divide

In identifying the positive and negative impacts of smart mobility strategies, the research suggests planners and decision makers can begin to chart a path toward achieving ideal smart mobility visions. A common theme and finding of the research are the belief that potential negative impacts of smart mobility strategies can be mitigated through collaborations with private companies, transit authorities, and various government entities. This requires reconsideration of existing governance structures to promote such partnerships. Additionally, approaches to engage the community to ensure equitable outcomes are recommended.

4.3.1 Employment Outcomes

Approaches to mitigate potential job losses have come at the state, city, and union levels. These can vary based on whether jobs are directly or indirectly impacted by AVs (refer to Section 4.1.1). Toronto's 2019 draft "Automated Vehicle Tactical Plan" commits to improving workforce readiness for both AV industry jobs and to reskilling employees who lose jobs due to automation.[48] The AFL-CIO has called on the Department of Labor directly to consider policies to safeguard the transit workforce in relation to HAVs.[49] Some entities have sought to work with mobility technology companies to attract new jobs. In Michigan, the Michigan Economic Development Corporation is leveraging new mobility to create jobs by providing incentives for Waymo to site an assembly facility in the state.[50] The Province of Ontario, meanwhile, invested $80 million in an AV Innovation Network offering testing facilities, fostering industry connections, and providing research funding for promising technology.[51]

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[47] Thomas S. Stephens et al., "Assessing Energy Impacts of Connected and Automated Vehicles at the U.S. National Level - Preliminary Bounds and Proposed Methods," in *Road Vehicle Automation 5* (Springer Link, 2018), 105–15, https://link.springer.com/chapter/10.1007/978-3-319-94896-6_10#citeas.
[48] "Automated Vehicles Tactical Plan," 2019, https://www.toronto.ca/wp-content/uploads/2020/02/7ec4-TS_AV-Tactical-Plan_Technical-Report.pdf.
[49] "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/.
[50] Kathleen Achtenberg, "Business Expansions, Community Revitalization Actions Gain Michigan Strategic Fund Approval: Michigan Business," 2019, https://www.michiganbusiness.org/press-releases/2019/01/business-expansions-community-revitalization-actions-gain-michigan-strategic-fund-approval2/.
[51] "Autonomous Vehicle Innovation Network (AVIN)," AVIN, n.d., http://www.avinhub.ca.

4.3.2 Congestion & Air Quality

Negative effects on congestion and air quality can be mitigated by encouraging complementary use of shared AVs with other transportation modes. Integrating transportation services to allow for seamless trips can encourage use of cleaner modes of transportation.[52] For example, transit-supportive AVs deployed through new contractual mechanisms with private sector providers can result in congestion and air quality benefits.[53] Integrating active transportation facilities and infrastructure with AV service provision, such as mobility hubs, can also encourage complementary use of cleaner transportation modes.[54]

Collaborative approaches have the potential to increase coordination around reducing negative impacts from AVs and shared mobility

4.3.3 Collaborative Approaches

Successful approaches should involve and educate leaders at all levels of government.[55] A number of options for partnerships exist at the city level, such as experimenting with pilot projects, incorporating concepts from innovative mobility into public transit, giving grants or low-interest loans, or becoming a risk-sharing partner in a mobility program.[56] In San Jose, for example, the CIO developed a collaborative pilot process via roundtables and a Request for Information with the City's goals to ensure that new mobility positively impacted the community.[57] Similarly, public-private partnerships including connections between industry and research institutions can be used to identify and explore pressing AV research questions.[58] Engaging with stakeholders is key. Projects such as Arizona State University's Our Driverless Future promote deliberative forums to examine the advantages and disadvantages of different approaches.[59]

Collaborative approaches have the potential to increase coordination around reducing negative impacts from AVs and shared mobility. Funding partnerships for piloting collaborative approaches on the ground presents an important area for future research.

4.4 Evaluate the roles of land use, parking, pricing, curb management, data, and other policy measures towards reducing the negative impacts and unintended consequences of AVs and shared mobility

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[52] "Autonomous Vehicle Policy Framework Summit," 2018, http://www.transpogroup.com/assets/autonomousvehiclepolicyframeworksummit_finalproductreport.pdf.
[53] "Autonomous Vehicle Policy Framework Summit"; Zmud et al., "Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies."
[54] "Autonomous Vehicle Policy Framework Summit."
[55] "Autonomous Vehicle Policy Framework Summit."
[56] Center for Automotive Reseach, "Future Cities : Navigating the New Era of Mobility."
[57] "Issue Overview: Economic Development," n.d., https://www.hks.harvard.edu/sites/default/files/Taubman/AVPI/Economic Development Basic.pdf.
[58] "Issue Overview: Economic Development."
[59] "Driverless Vehicles: What Should Be at the Top of Our List?," 2019, https://cspo.org/wp-content/uploads/2019/01/Issue-Advisory-Driverless-Vehicles.pdf.

Aside from using collaborative approaches, negative impacts of smart mobility strategies can be regulated through several strategies. Taking a holistic approach to deployment and management, including merging land use and housing, can assist in addressing unintended consequences while improving mobility services.

4.4.1 Parking & Curb Management

AVs and shared mobility are likely to increase demand for curb space, whether for parking, drop-off, or deliveries. Research indicates this can be mitigated through parking and curb management policies such as eliminating minimum parking requirements, intelligently pricing curb spaces, and instituting parking cash-out strategies.[60] Congestion from shared mobility services can be addressed through regulation of parking and right-of-way access, whether by requiring paid access to loading zones, use of municipal requests for proposals for right-of-way-access, or otherwise designating parking or drop-off zones for private use.[61] Parking policies also have the ability to increase VMT through increased network travel of empty vehicles to remote lots; this is discussed further in Section 4.1.3. As of September 2020, NCHRP has put out a proposal to evaluate curbside management and develop a guidebook that addresses new mobility solutions, including AVs, being integrated into the transportation system.[62]

4.4.2 Pricing & Subsidies

Pricing tools can be used to encourage electrification and shared use of vehicles while also raising funds that can increase equity. Purchase of EVs is encouraged by providing subsidies or lowering AV taxes for EVs.[63] Promoting the use of zero-emission vehicles by drivers who work for TNCs is suggested in one source.[64] Recent information indicates that TNC service providers are currently transitioning towards encouraging EVs with tools such as incentives and discounts to increase the cost parity of these vehicles for their drivers.

A number of pricing strategies can encourage pooling among AVs and standard vehicles.[65] In the United States, some states have proposed lowering AV taxes for shared rides.[66]

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[60] Shruti Vaidyanathan, "Shaping Autonomous Vehicle Deployment to Meet Climate and Energy Goals: A Policy Toolkit for Cities," 2019; Center for Automotive Reseach, "Future Cities : Navigating the New Era of Mobility"; Zmud et al., "Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies."

[61] Susan Shaheen, Adam Cohen, and Ismail Zohdy, "Shared Mobility: Current Practices and Guiding Principles" (United States. Federal Highway Administration, 2016); Zmud et al., "Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies"; Center for Automotive Reseach, "Future Cities : Navigating the New Era of Mobility"; Susan Shaheen et al., "Shared Mobility Policy Playbook," 2019; Jeremy Crute et al., *Planning for Autonomous Mobility* (American Planning Association, 2018).

[62] "Dynamic Curbside Management: Keeping Pace with New and Emerging Mobility and Technology in the Public Right of Way," 2020, https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4868.

[63] Leslie et al., "Will Self-Driving Cars Usher in a Transportation Utopia or Dystopia?"; Center for Automotive Reseach, "Future Cities : Navigating the New Era of Mobility."

[64] Rodier, "The Effects of Ride Hailing Services on Travel and Associated Greenhouse Gas Emissions."

[65] Rodier; Ezike et al., "Where Are Self-Driving Cars Taking Us?"

[66] Leslie et al., "Will Self-Driving Cars Usher in a Transportation Utopia or Dystopia?"

Vaidyanathan (2019) proposes surcharging solo TNC rides to encourage sharing, while Zmud et al. (2017) propose subsidizing SAVs.

Road use pricing, per-mile fees, and congestion pricing can be used to discourage network travel, reduce VMT, and alleviate congestion.[67][68] As electrified vehicles will potentially render gas taxes obsolete over time, other means of pricing will need to be developed.[69] Fee systems can be based on several factors, such as time, distance, or energy consumption.[70] They could be progressively structured based on zone (e.g. rural vs. urban) or household income so that certain populations are not disproportionately burdened.[71] The challenge is making sure any new fee structures continue to support, promote, and incentivize new innovations, especially in ways that support the positive social outcomes discussed as part of this paper. This includes shared formats that avoid single occupancy trips.

The challenge is making sure any new fee structures continue to support, promote, and incentivize new innovations

4.4.3 Other Policy Measures

Other policy measures can encourage electrification and pooling and decrease emissions. In the United States, emissions standards target TNC vehicles to reduce overall emissions.[72] Massachusetts ensures electrification by requiring all AVs to be electric, while in China vehicle registration restrictions promote electrification among AVs and for TNC vehicles.[73] India has instituted targeted electrification efforts by focusing on high mileage commercial vehicles for electrification priority.[74] Purchase of EVs can also be encouraged by updating building codes to require wiring for EV charging stations.[75] The United States' comprehensive management plan for AV initiatives, AV 4.0, provides a broad policy overview to protect users and communities, promote efficient markets, and facilitate coordinated efforts in the development and deployment of AV technology.[76] At the city level, policies such as Portland, Oregon's Connected and

[67] Road use pricing refers to direct charges to use roads, such as tolls: this can include congestion pricing, or a surcharge on road use during periods of high demand. Per-mile fees, also called VMT fees or taxes, charges motorists based on how many miles they have traveled.
[68] Rodier, "The Effects of Ride Hailing Services on Travel and Associated Greenhouse Gas Emissions"; Zmud et al., "Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies"; Crute et al., *Planning for Autonomous Mobility*.
[69] Stephen Ratner, "Taxation of Autonomous Vehicles in Cities and States," *Stephen Ratner, Taxation of Autonomous Vehicles in Cities and States* 71 (2018).
[70] Millard-Ball, "The Autonomous Vehicle Parking Problem."
[71] Nicole DuPuis, Elias Stahl, and Brooks Rainwater, "The Future of Equity in Cities," 2017.
[72] Garrett Fitzgerald and Richard Lee, "Driving a Shared, Electric, Autonomous Mobility," 2019, https://rmi.org/insight/driving-a-shared-electric-autonomous-mobility-future/.
[73] Fitzgerald and Lee.
[74] Fitzgerald and Lee.
[75] Leslie et al., "Will Self-Driving Cars Usher in a Transportation Utopia or Dystopia?"
[76] "USDOT Comprehensive Management Plan for Automated Vehicle Initiatives," US Department of Transportation, n.d., https://www.transportation.gov/policy-initiatives/automated-vehicles/usdot-comprehensive-management-plan-automated-vehicle.

Automated Vehicle policy provides holistic guidance encompassing user safety, reduction of low-occupancy travel, and prioritization of electric vehicles.[77]

Policy measures can be used to mitigate the negative employment impacts of AVs and shared mobility. Austin (2017) proposes several recommendations such as automatic unemployment insurance, progressive basic income, and education and retraining. These measures would protect drivers or others who lose their jobs due to technology shifts but also proactively shift skills to match newly created jobs.

4.4.4 Transit Complementarity

One way to reduce negative effects of new mobility technology is to ensure complementarity, rather than replacement, with other options such as transit. This can be done by improving transit systems and making them more attractive to users.[78] Planning and payment integration across transportation modes can make multimodal trips more convenient.[79] On-demand, flexible route service, perhaps in partnership with smart mobility service providers, can also increase transit ridership and reduce single-occupancy vehicle trips by improving connections to transit and filling gaps in the transit system.[80] Funds raised from pricing regulations, as discussed above, can be used for these efforts.[81] Evidence of transit complementarity comes from current TNC studies; however, these can be used as a case study for wider subscription-style AV adoption. A study by Hall, Palsson, and Price found that Uber increases transit ridership by 5% after two years; results varied based on location, with larger increases in larger cities and for smaller transit agencies.[82] King, Conway, and Salon also suggested a connection between TNCs and transit, although this tended to be community-specific.[83] The Transportation Research Board's Shared Mobility and the Transformation of Public Transit report noted that survey respondents who used shared transportation modes were more likely to frequently use transit.[84]

Many localities have already enacted strategies to mitigate smart mobility's negative impacts, whether through the use of incentives or deterrents. Further research into best practices would serve as a guide for other entities as this technology continues to be rolled out.

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[77] "Connected and Automated Vehicles Policy," n.d., https://www.portlandoregon.gov/transportation/article/643814.
[78] Vaidyanathan, "Shaping Autonomous Vehicle Deployment to Meet Climate and Energy Goals: A Policy Toolkit for Cities"; Ezike et al., "Where Are Self-Driving Cars Taking Us?"
[79] Vaidyanathan, "Shaping Autonomous Vehicle Deployment to Meet Climate and Energy Goals: A Policy Toolkit for Cities"; "Blueprint for Autonomous Urbanism – Second Edition," 2019, https://nacto.org/publication/bau2/.
[80] Vaidyanathan, "Shaping Autonomous Vehicle Deployment to Meet Climate and Energy Goals: A Policy Toolkit for Cities"; "Blueprint for Autonomous Urbanism – Second Edition."
[81] "Blueprint for Autonomous Urbanism – Second Edition."
[82] 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.
[83] 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.
[84] Sharon Feigon and Colin Murphy, *Shared Mobility and the Transformation of Public Transit*, 2016.

4.5 Conceptualize and examine policy frameworks and levers to produce more accurate assessments of the value of transportation and incentivize more efficient transportation solutions, including from a livability and economic perspective

Previous studies have assessed the value of various transportation modes by looking at indicators including property values, tax revenues, and consumer spending. Understanding the value of transportation can help prioritize mobility solutions that are both economically beneficial and efficient. Data are key to this effort: data collection can help inform better planning, allocation of resources, and investments around AVs and smart mobility strategies.

4.5.1 Assess the Value of Transportation

While not directly applied to AVs, several research efforts have assessed the value of various transportation modes. A scoping review by Kornas et al. (2017) explored existing evidence regarding investments in active transportation. This evidence focuses on potential economic benefits of active transportation and notes either positive or neutral effects of active transportation infrastructure in the areas of tax revenues, property values, consumer spending, and employment.[85] Other studies have assessed the value of bikeshare or transit on property values.[86] All the studies note increasing property values associated with the presence of these

[85] Kathy Kornas et al., "Exploring Active Transportation Investments and Associated Benefits for Municipal Budgets: A Scoping Review," *Transport Reviews* 37, no. 4 (2017): 465–87.
[86] Konstantinos Pelechrinis et al., "Economic Impact and Policy Implications from Urban Shared Transportation: The Case of Pittsburgh's Shared Bike System," *PloS One* 12, no. 8 (2017): e0184092; Min Zhang and Barbara T H Yen,

transportation systems. Pelechrinis discusses negative impacts in terms of gentrification. Studies by Hamidi, Kittrell, and Ewing (2016) and Vessali (2012) show that high-density development is a factor in this property value increase. While most of these studies considered existing systems, Efthymiou and Antonious (2013) considered the effects of future transit infrastructure on property values. Environmental benefits can also be used to quantify the value of transportation modes.[87] Diez et al. (2018) provide a methodology to calculate a cost analysis for tons of carbon dioxide saved through implementation of a sustainable urban mobility plan.[88] Focusing on the city of Burgos in Spain, it calculates effectiveness ratios using available data on modal shifts and sustainable urban mobility plan investments.

4.5.2 Incentivize Efficient Transportation Solutions

Several tools have been created to incentivize more efficient transportation solutions. *Right-Sizing Transportation Investments: A Guidebook for Planning and Programming* provides guidance to assist state departments of transportation and other planning agencies to identify opportunities where greater social and economic value can be realized by repurposing, re-using, or fundamentally resizing existing transportation system assets.[89] López-Iglesias and Álvarez (2018) provide a case study to compare sustainable mobility alternatives in rural areas.[90] They developed a transportation model to obtain commuting patterns, means, and routes and evaluate environmental costs and integration indicators for future scenarios, ultimately identifying the option with higher benefits-to-cost. One study considers the use of externalized environmental and social costs, such as air pollution and physical activity level, in transportation appraisal frameworks for four countries. The countries have varying approaches to inclusion of these costs, with a general trend of underestimating the externalized costs of transportation investments.[91] Lastly, the Future Mobility Calculator can be used to assess the costs and benefits of shared, electric urban transportation options. Transit officials in Bogota, Colombia used the calculator to analyze a variety of transportation electrification scenarios to select the most efficient option.[92]

"The Impact of Bus Rapid Transit (BRT) on Land and Property Values: A Meta-Analysis," *Land Use Policy* 96 (2020): 104684; Shima Hamidi, Katherine Kittrell, and Reid Ewing, "Value of Transit as Reflected in US Single-Family Home Premiums: A Meta-Analysis," *Transportation Research Record* 2543, no. 1 (2016): 108–15; Zheng Li, "The Impact of Metro Accessibility on Residential Property Values: An Empirical Analysis," *Research in Transportation Economics* 70 (2018): 52–56; Kaveh V. Vessali, "Land Use Impacts of Rapid Transit: A Review of the Empirical Literature," *Berkeley Planning Journal*, 2012, https://doi.org/10.5070/bp311113054.

[87] Dimitrios Efthymiou and Constantinos Antoniou, "Measuring the Effects of Transportation Infrastructure Location on Real Estate Prices and Rents: Investigating the Current Impact of a Planned Metro Line," *EURO Journal on Transportation and Logistics*, 2013, https://doi.org/10.1007/s13676-013-0030-4.

[88] Jose Maria Diez et al., "Methodology for Assessing the Cost Effectiveness of Sustainable Urban Mobility Plans (SUMPs). The Case of the City of Burgos," *Journal of Transport Geography* 68 (2018): 22–30.

[89] Chandler Duncan et al., "Right-Sizing Transportation Investments: A Guidebook for Planning and Programming," 2020.

[90] Edelmiro López-Iglesias, David Peón, and Jorge Rodríguez-Álvarez, "Mobility Innovations for Sustainability and Cohesion of Rural Areas: A Transport Model and Public Investment Analysis for Valdeorras (Galicia, Spain)," *Journal of Cleaner Production* 172 (2018): 3520–34.

[91] N Dodge and R Chapman, "Framing Mobility Investment: A Review of the Inclusion of Environmental and Social Costs in Transport Appraisal Frameworks in Four Anglophone Countries," 2017.

[92] R Sclar et al., "The Future of Urban Mobility: The Case for Electric Bus Deployment in Bogotá, Colombia" (Coalition for Urban Transitions. London and Washington, DC. https …, 2020).

The research provides examples of practices that can be used to inform decision making around smart mobility deployment, including AVs, to ensure that technologies are deployed in an efficient and value-adding way.

4.6 Consider public and consumer acceptance of AV fleets and shared mobility, including consideration of potential public health concerns following the COVID-19 pandemic

Society cannot benefit from smart mobility strategies' potential positive impacts if consumers are not willing to take up this technology. Barriers to acceptance of new mobility solutions include safety concerns stemming from a lack of trust in AVs. More recently, public health concerns stemming from the COVID-19 pandemic have reduced shared transportation ridership more broadly. Research shows that consumer acceptance exists in a spectrum that varies, in some cases based on demographic groups[93].

4.6.1 Barriers to Acceptance

The literature documents mixed public perceptions of AVs and shared mobility: barriers to acceptance of this technology range from fear and distrust to existing pervasive car culture. Trust of automated technology is a significant barrier. A 2019 AAA survey found that 71% of respondents are afraid to ride in fully self-driving vehicles.[94] Reception to AV technology in more limited applications, such as low-speed shuttles with a short range or fully automated delivery vehicles, was more widespread. However, only 20% of respondents were comfortable with fully automated vehicles for more personal passengers such as loved ones. One study reported a gradual increase in the percentage of people comfortable with fully self-driving automation from 2016-2018; however, the percentage of people only comfortable with no automation or features that activate only in certain situations such as in an emergency also increased, indicating a polarizing trend.[95] Perceptions may vary based on whether respondents have interacted with AVs and the context in which they have done so, although the research does not consider this topic.

Barriers to acceptance of this technology range from fear and distrust to existing pervasive car culture

Acceptance of shared AVs is also hindered by concerns about giving up private vehicle ownership. In many countries, "car pride" and status of vehicle ownership sway preferences away from shared services.[96] A London survey showed that nearly half of respondents prefer to travel by car over any other form of transportation.[97] Additional concerns stem from using

[93] Chaiwoo Lee et al., "Consumer Comfort with Vehicle Automation: Changes over Time," 2019; Philipp Rode et al., "Towards New Urban Mobility: The Case of London and Berlin," 2015; Fleming and Singer, "Energy Implications of Current Travel and the Adoption of Automated Vehicles"; Patrícia S Lavieri et al., "Modeling Individual Preferences for Ownership and Sharing of Autonomous Vehicle Technologies," *Transportation Research Record* 2665, no. 1 (2017): 1–10.
[94] "Three in Four Americans Remain Afraid of Fully Self-Driving Vehicles," *AAA News Room*, 2019, https://newsroom.aaa.com/2019/03/americans-fear-self-driving-cars-survey/.
[95] Lee et al., "Consumer Comfort with Vehicle Automation: Changes over Time."
[96] "Insights into Future Mobility."
[97] Rode et al., "Towards New Urban Mobility: The Case of London and Berlin."

shared mobility services, as people experience fear of negative social interactions and safety concerns when using ridesharing, especially among women.[98]

Still other barriers can stem from a lack of accessible AVs for people needing special assistance. Several reports note that the lack of drivers in fully automated vehicles could hinder those needing assistance to board or otherwise navigate mobility services.[99] If fewer disabled and wheelchair-accessible services were available this would also negatively affect mobility: this is already seen with TNCs, where customers experience issues with reliability, estimated response times, and higher prices for wheelchair-accessible vehicles.[100] Hwang et al. write that, aside from in-vehicle requirements for disabled passengers, a lack of appropriate built environments such as level boarding platforms would add additional challenges for people navigating new mobility solutions.[101]

Comfort with mobility services varies based on several demographic characteristics. Younger, more urban populations tend to be more open to these new technologies.[102] While older adults generally express a willingness to use some levels of automation, one study shows that they are less interested in full autonomy than younger generations. Another study found that an increase in comfort with AVs is more pronounced among younger adults between ages 25-44.[103]

4.6.2 Increasing Trust

Increasing trust in automated and shared mobility is challenging but necessary for acceptance. The public will be much less accepting of crashes caused by software glitches or malfunctioning hardware than by human error.[104] Liability standards and vehicle monitoring protocols can be put in place to instill public confidence.[105] In terms of data, blockchain technology could potentially play a role in

Increasing trust in automated and shared mobility is challenging but necessary for acceptance

[98] Javier Morales Sarriera et al., "To Share or Not to Share: Investigating the Social Aspects of Dynamic Ridesharing," *Transportation Research Record* 2605, no. 1 (2017): 109–17.
[99] Rouse et al., "Preparing Communities for Autonomous Vehicles"; 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); Steven H Bayless and Sara Davidson, "Driverless Cars and Accessibility: Designing the Future of Transportation for People with Disabilities," 2019.
[100] Joanna Moody, Scott Middleton, and Jinhua Zhao, "Rider-to-Rider Discriminatory Attitudes and Ridesharing Behavior," *Transportation Research Part F: Traffic Psychology and Behaviour* 62 (2019): 258–73; "Still Left Behind," 2019, https://nylpi.org/wp-content/uploads/2019/05/Still-Left-Behind-Report—Updated.pdf.
[101] Jinuk Hwang et al., "A Focus Group Study on the Potential of Autonomous Vehicles as a Viable Transportation Option: Perspectives from People with Disabilities and Public Transit Agencies," *Transportation Research Part F: Traffic Psychology and Behaviour* 70 (2020): 260–74.
[102] Fleming and Singer, "Energy Implications of Current Travel and the Adoption of Automated Vehicles"; Lavieri et al., "Modeling Individual Preferences for Ownership and Sharing of Autonomous Vehicle Technologies."
[103] Lee et al., "Consumer Comfort with Vehicle Automation: Changes over Time."
[104] Mervis et al., "Are We Going Too Fast on Driverless Cars?"
[105] Fitzgerald and Lee, "Driving a Shared, Electric, Autonomous Mobility."

increasing security and trust.[106] Some analysts believe that gradually deploying AV technology sooner rather than later could help to win over the public, as regular interactions with advanced driver assistance systems could increase trust.[107] Lee et al. (2019) note that a misunderstanding among the public regarding the definition and availability of fully automated vehicles indicates a need for improved messaging and consumer education as well as clear messages from the industry.

Involving consumers is key to increasing their trust in AVs. Several projects have been undertaken to focus on outreach and public sentiment around driverless vehicles.[108] In London, the GATEway Project conducted trials to gather public feedback and gained valuable insight on design preferences and consumer concerns, such as the ability of AVs to read the behavior of other road users. In the United States, a AAA highly automated shuttle pilot in Las Vegas also focused on gathering public sentiment.[109] Research institutions have also launched programs such as the Massachusetts Institute of Technology's SMART Future Mobility and Arizona State University's Our Driverless Futures to consider users' preferences and concerns.[110] Other efforts have sought feedback on human behavior to better acclimate AVs to their movements; the University of California at San Diego's Autonomous Vehicle Laboratory conducts research to better understand the intent of other road users operating in proximity to AVs.[111] Addressing these issues can help increase public trust that AVs will be able to anticipate and properly respond to their surroundings.

4.6.3 Addressing Public Health Concerns

Recent considerations such as the COVID-19 pandemic must be considered to build acceptance for shared mobility services. This pandemic has made people wary of sharing transportation options and has led to increased automobile purchases.[112] Shared mobility service providers must ensure the safety of their services in a sometimes rapidly changing environment. The Federal Transit Agency is establishing guidance to ensure continued safety of passengers and employees during the COVID-19 pandemic.[113] Meanwhile, the American Public Transportation Association notes that the latest research supports safe use of public transportation during the pandemic, especially given safety precautions such as wearing

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[106] Ricci, "Socioeconomic Impacts of Automated and Connected Vehicle: Summary of the Sixth EU–US Transportation Research Symposium."
[107] "Three in Four Americans Remain Afraid of Fully Self-Driving Vehicles."
[108] K Fernández Medina and R Jenkins, "GATEway: Public Perceptions of a Last-Mile Driverless Shuttle," 2017; "Designing with People Inside a Driverless Vehicle: Workshop Report," 2018, https://gateway-project.org.uk/wp-content/uploads/2018/06/D3.2.8_RCA-Workshop-Trial-1-in-vehicle-report.pdf; "Sentiment Mapping Analysis Report," 2018, https://gateway-project.org.uk/wp-content/uploads/2018/06/D3.6-GATEway-Sentiment-mapping-Summary-report.pdf.
[109] "The Free AAA Self-Driving Shuttle," AAA, 2018, http://www.aaahoponlasvegas.com/.
[110] "About FM," SMART, n.d., https://smart.mit.edu/research/fm/about-fm; "Driverless Vehicles: What Should Be at the Top of Our List?"
[111] University of California at San Diego, "Autonomous Vehicle Laboratory," 2020, http://avl.ucsd.edu/; David Paz et al., "Lessons Learned from Deploying Autonomous Vehicles at UC San Diego," *EasyChair*, 2019, https://easychair.org/publications/preprint/GKgC.
[112] Yan et al., "An Empirical Study on Consumer Automobile Purchase Intentions Influenced by COVID-19."
[113] "FTA Safety Advisory," 2020, https://www.transit.dot.gov/sites/fta.dot.gov/files/2020-04/FTA-Safety-Advisory-20-01-COVID-19_0.pdf.

masks.[114] AV operators could find increased acceptance of uses such as supply delivery through recent efforts to support hospitals and in-need populations during the pandemic; however, as of September 2020, no research has been conducted to gauge any shifts in public perception resulting from these efforts.[115]Given rising public health concerns, best practices to promote safety and well-being using shared mobility services will also be important for consumer uptake of new technologies.

5 Further Research Opportunities

The suggestions below identify topics for future research to inform and focus the important discussion around *Maximizing Positive Social Impacts of Automated Vehicle Deployment 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 a synthesis of research on workforce development strategies, impacts of the "gig" economy in transportation, secondary economic impacts, and alternative investment strategies. Scope could include: • Workforce development: Return on financial investment, employee satisfaction, and efficacy in job placement, retraining in manufacturing including automotive • "Gig" economy: recent court actions regarding contractor versus employee status, health care and related benefits, work conditions, and relative earnings • Secondary impacts: economic impacts on related industries, businesses en route, and the like • Alternative community investment strategies	*Transit, Freight*
4.1	Compile case studies of AVs deployment in rural communities and identify best practices for closing the "digital divide" to facilitate enabling technology.	*Transit*

[114] "Public Transit Safety During the COVID-19 Pandemic," 2020, https://www.apta.com/wp-content/uploads/APTA-Brief-Safety-During-Pandemic-July-2020.pdf.

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Subtopic	Research Opportunity	Crossover to Other Topics
4.1	Develop a synthesis of research on the impact of AVs on property loss, morbidity, and mortality resulting from crashes.	*Equity & Accessibility*
4.1	Analyze economic effects of automation in transportation across socioeconomic and demographic categories.	*Equity & Accessibility*
4.3	Identify funding partnerships for strategies to mitigate negative impacts from AVs and shared mobility.	*Equity & Accessibility*
4.4	Create a resource for AV consumer education tools including public engagement.	*Safety, Equity & Accessibility*
4.4	Develop full suite of metrics for efficiency, safety, equity, personal mobility, access to jobs, health care, education, recreation, and health. Research should include model policies and case studies on data collection, sharing, management, and privacy.	*Equity & Accessibility* *Data Sharing and Governance*
4.6	Study whether the COVID-19 pandemic affects consumer acceptance of AVs, particularly within the subscription and shared mobility context	*Safety*
4.4	Evaluate policy tools such as road user pricing mechanisms and TNC surcharges for equity impacts and efficacy in encouraging use of ridesharing.	*Equity & Accessibility*
4.6.1	Align use of term “shared mobility” with deployment of AVs and determine whether delivery services can and should be considered “shared mobility” within context of automated deliveries.	*Freight*

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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