NCHRP Project 20-113F

Preparing for Automated Vehicles and Shared Mobility: State-of-the-Research Topical Paper #8

IMPLICATIONS FOR PLANNING AND MODELING

September 21, 2020

Transportation Research Board
500 5th Street NW
Washington, DC 20001
www.trb.org

Prepared by:

Stantec

ARA

For:

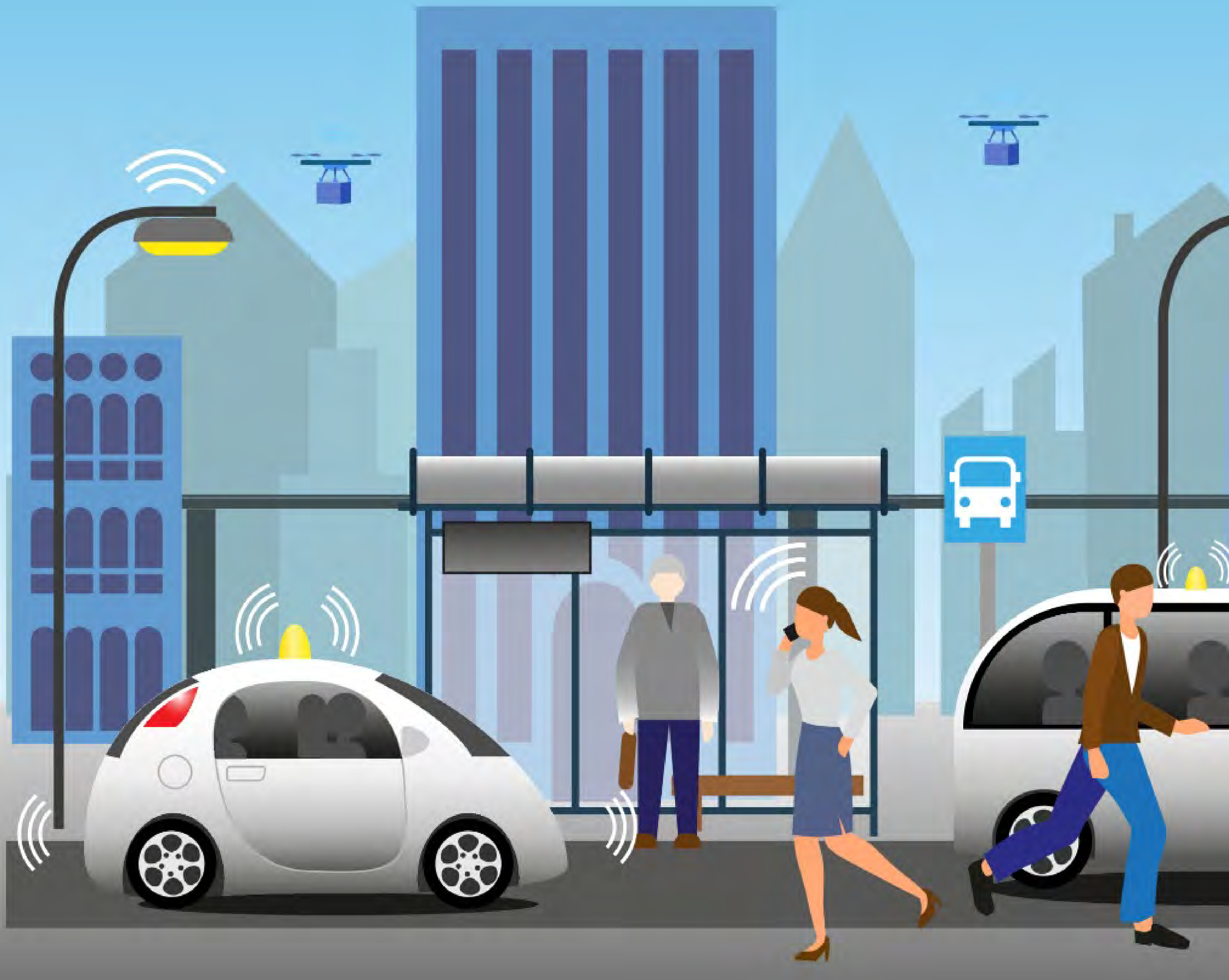
TRB AV/SM FORUM
AUTOMATED VEHICLES + SHARED MOBILITY

1 Introduction

1.1. Background

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

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



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

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

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

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

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

The goals of the Topical Papers are the following:

Snapshot of research completed under a particular topic area

Summary of research completed to date

Identification of gaps in research

Recommendations for additional research

1.2. Approach to Topical Paper Development

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

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

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

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

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

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

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

2 Paper Areas of Focus

This Topical Paper reviews research conducted and published as of July 10, 2020. In approaching this topic, the paper focuses on the following issue areas:

1. Highlight the current and ongoing research and deployment efforts, identify gaps in our current practice and knowledge, and present research problem statements associated with planning and modeling for the unknown
2. Identify critical information needed for planning and gaps in existing modeling activities
3. Expand on performance-based planning, and build on FHWA and NCHRP work in scenario planning, focusing on what the planning community needs to know, including technology convergence, likelihood of acceptance, and other factors
4. Build on ongoing research associated with testing and demonstration of automated vehicles and tracking projects receiving grants through Automated Driving System Demonstration Grants Program
5. Consider opportunities to build-in feedback mechanisms for demonstration projects connected to automated vehicles; identify tools that agencies will need to evaluate transportation projects and plans

3 Summary of Findings

The transportation community is regularly watching the development of advanced systems for HAVs and shared mobility. Increasingly, AV tests and new equipment are being used on U.S. public roadways. Recognizing this, state and local departments of transportation (DOTs) are interested in understanding what changes must (or should) be made to planning practice (Long Range Transportation Plan updates, specific modal plans, and other planning documentation) and in learning from existing demonstration projects.

Automated driving and shared mobility are considered to be the key leading influences and technologies that could bring major changes in personal mobility in the next two decades. Shared mobility already provides a new set of challenges for traditional planning and modeling activities. Since AVs are still primarily only in the testing phase, it is difficult to precisely anticipate actual outcomes and changes to the planning process. Nevertheless, the current state of AVs can be useful to roughly estimate likely magnitudes of impact across business practices and processes. These estimations about the extent and duration of changes can be inferred by answering the following two questions: “What are the potential changes in mobility?” and “To what extent are these changes synchronized with broader activities and practices in the community?”

Through reviewing the body of literature on planning and modeling considerations to accommodate AVs/HAVs within the context of the areas of focus noted above, several common themes emerge:

- **Including AV and shared mobility in long range transportation plans is not yet the norm, but the inclusion of these discussions is increasing dramatically.** The planning approach undertaken has an impact on the type of modeling that is appropriate. A metropolitan planning agency or DOT may decide, as a matter of planning policy, to adopt a range of strategies that best fit the long-range requirements of a region with respect to shared mobility and AVs. While the approach to developing these evaluation methods may differ between regions and states, all agencies have in common the need to develop new planning and modeling processes that include AVs in the transportation environment.

- **Planning for uncertainty is an area that remains under development.** The traditional approaches to infrastructure planning, using historical data and land use patterns and projections, coupled with expected trip generators are no longer a reliable approach to conveying information to plan for an uncertain future – there remains a substantial amount of effort associated with understanding the sensitivities of these substantial shifts and transportations. Assumptions based planning and robust decision making dominate the discussions.

- **Modeling for “Zero Occupancy” or other characteristics for AVs needs emphasis.** Modeling tools can be developed to address the short-, mid-, and long-term impacts on travel behavior that conditions set forth (various occupancies or other expectations). However, across all of these time frames, changes necessitated by shared uses and automation are evident. With automation, a trip does not begin and end in the same way. In the short term, many existing planning and modeling tools will suffice, as travel behavior changes will not be significant. Initial changes will be a gradual increase in the use of new modes, such as TNCs or e-scooters, improved driver assistance systems, and perhaps potential new types of access and egress options for public transportation systems. This changes as time passes and markets develop.

- **Market acceptance remains the critical unknown force for modeling and planning.** Much of the research in this series identifies the expectations for market acceptance and penetration. Planning and modeling are also highly influenced by the slope of the curve for consumer acceptance. 2040 - 2050 long-range plans can be realistic targets for substantial numbers of operating AVs. Changes due to COVID-19 could substantially change the way that shared mobility options expand. At present, there is little research available although many teams have begun to ask these research questions.

- **Incorporating new modes into traditional models remains challenging.** Overall, we still see that at this time, trip-based models developed as aggregate models of population and employment in a region with disaggregate measures of transportation supply do not readily include shared mobility options.

- **Other models share similar weaknesses in presenting AVs and shared mobility.** Activity-based and dynamic traffic assignment models developed to include persons and firms as a *function* of transportation supply and strategic models developed as disaggregate models of persons and firms in a region with *aggregate measures* of transportation supply exist, but are not widely utilized.

- **Demonstration programs provide meaningful lessons, but the knowledge transfer elements of these demonstrations are burdened by the substantial acceleration of new and improved services and technologies.** The demonstration programs and accompanying funding provide extensive ability to learn from test cases. The demonstrations, however, often are quickly outpaced by technology. As such, the information may not be advancing the state of the practice as much as desired or expected in the demonstration development.

4 Summary of Research Reviewed

Our research effort included review of papers and reports developed by individual university transportation centers in the United States, FHWA studies, published papers in academic journals, state-sponsored initiatives, corporate research and development work, and NCHRP-sponsored research. This variety of research points to a wide range of opinions. While there is much research on the social and economic[2] impacts of automated driving, discussion on planning or modeling impacts is more limited.

The convergence of AVs and shared mobility, including the growth of TNCs, offers a number of interesting opportunities to refine planning practices. Clearly, the deployment of automated technology in private automobiles increases mobility choices for those who may be unable to drive, such as young people, the elderly, and persons with disabilities. It could provide longer commute times and improve job sheds for urban areas. It could make substantial changes to goods movement and location of commercial and industrial facilities. Additional information on goods movement is considered in the Freight white paper. Another key outcome could be expanded mode choices and better managed travel demand by reducing the use of single occupant vehicles (at the same time, there could be an increased number of low or no occupancy trips).[3]

AVs and shared mobility also bring forward several approaches to the overall discussion on transportation policy.[4] These studies vary in their findings on technological progress, market acceptance, requirements on the public sector, and planning generally. The variety of efforts demonstrate a range of optimistic and pessimistic projections for the future.[5] Zmud (2019) and others developed a framework for planning for AV. This planning and forecasting framework includes data, planning contexts, modeling, adoption timelines, and communication of uncertainty.[6]

---

[2] Johnsen, Annika & Strand, Niklas & Andersson, Jan & Patten, Christopher & Kraetsch, Clemens & Takman, Johanna. (2017). Literature review on the acceptance and road safety, ethical, legal, social and economic implications of automated vehicles.

[3] Litman, T. 2015. “Autonomous Vehicle Implementation Predictions: Implications for Transport Planning.” Transportation Research Board 94th Annual Meeting. Washington, DC, U.S. 15p.

[4] Litman, T. (2013, August 17). *Autonomous Vehicle Implementation Predictions: Implications for Transport Planning.* Retrieved from Victoria Transport Policy Institute: http://www.vtpi.org/avip.pdf

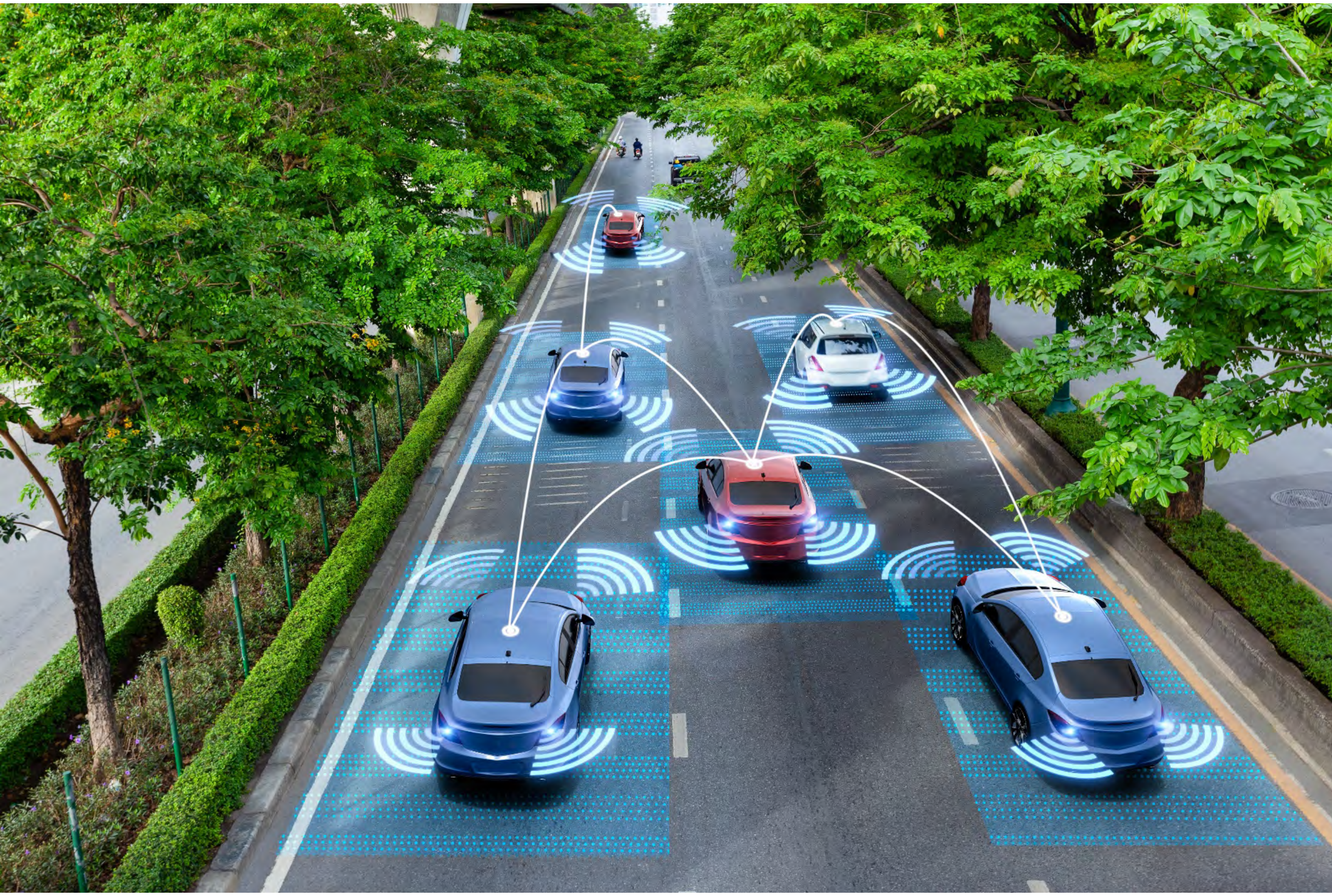
[5] Kornhauser, Alain. 2020.

[6] National Academies of Sciences, Engineering, and Medicine 2018. Updating Regional Transportation Planning and Modeling Tools to Address Impacts of Connected and Automated Vehicles, Volume 1: Executive Summary. Washington, DC: The National Academies Press. https://doi.org/10.17226/25319

4.1. Planning and Modeling for the Unknown

4.1.1 Dealing with Uncertainty through Scenario Planning

Planners and modelers are concerned with long-range forecasting of travel and related consequences in urban regions.[7] While we cannot know for certain what the total impacts of new AV technologies will be on our transportation system, the surrounding communities, industries, and the labor market, such uncertainty does not relieve the need to plan for said impacts. Planning for such ambiguities using scenario planning is an effective means to prepare for alternative uncertain futures.[8] For decades, the USDOT, private companies, academic



[7] National Academies of Sciences, Engineering, and Medicine 2018. Updating Regional Transportation Planning and Modeling Tools to Address Impacts of Connected and Automated Vehicles, Volume 1: Executive Summary. Washington, DC: The National Academies Press. https://doi.org/10.17226/25319.
[8] Williams, Kristine. Planning Implications for Automated Vehicles. Tampa Hillsborough Expressway Authority. 2016.

institutions, and automobile manufacturers have researched and tested vehicles that sense the environment around them, operate independently, and/or communicate directly with other vehicles and with infrastructure.[9] This approach, set in an increasingly shared set of economic activities and intertwined with advances in machine learning, machine vision, optics, and other sensors, has enabled new vehicle technology.

At a minimum these changes for mobility are already altering the operational characteristics of vehicle transportation. At their fullest potential, these technologies effectively disrupt many aspects of modern life, bringing economic, environmental, and societal changes that warrant immense effort and preparation. Scenario planning allows for the multiple paths that the uncertain future holds. It also provides an opportunity for the community to identify key needs and expected options. A menu-based approach is often used to identify key next steps in the planning process following the directed scenario-based efforts.[10]

Scenarios can also influence the expectation for traditional uses of vehicles. When fully automated vehicles are permitted on the roadways, the fundamental nature of vehicle trips will change. Vehicles can travel empty to preposition themselves where they are needed. Parents could let cars drive their children to school and soccer practice. Public transportation, taxi, limousine, and trucking industries will likely undergo major transformations. The current model of individual auto ownership is also likely to experience significant shifts.[11]

The existence of non-AVs in the general fleet becomes a problem for system operations in scenario based planning because AVs can be controlled by route and operational functions while competing for roadway maneuvering space with human-driven vehicles that are unpredictable in their behavior.[12] Modeling and planning tools need to address this important phase of market penetration and must be able to present problems related to having mixed fleets of AVs and non-AVs. In the longer term, the technology will be pervasive and will require a complete set of new assumptions about urban form, land use, parking requirements, and other indirect impacts in addition to the direct impacts on travel behavior and choice. Using scenario planning methods allow for these new assumptions to be played out. The modeling of vehicle fleets (delivery vehicles, taxis, or similar purposed vehicles) has received increased attention as the most likely beneficiaries of automation advances.[13] Efficiency gains may be small individually, but are magnified dramatically by increased market penetration and population gains in the overall count of vehicles.

Benchmarking has also emerged as a key mechanism for establishing scenarios. Establishing scenarios based on high, medium, and low benchmarks for market acceptance create varying

---

[9] National Academies of Sciences, Engineering, and Medicine 2018. Updating Regional Transportation Planning and Modeling Tools to Address Impacts of Connected and Automated Vehicles, Volume 1: Executive Summary. Washington, DC: The National Academies Press. https://doi.org/10.17226/25319.
[10] MIT- information presented to Shared Mobility and AV Forum, Washington, DC. January 24-25, 2020.
[11] Lutin, J. K.-L. (2013, July). *The Revolutionary Development of Self-Driving Vehicles and Implications for the Transportation Engineering Profession.*
[1212] Zmud, Johanna, et al. "Research to examine behavioral responses to automated vehicles." Road Vehicle Automation 5. Springer, Cham, 2019. 53-67.
[13] Greenwald, Judith M., and Alain Kornhauser. "It’s up to us: Policies to improve climate outcomes from automated vehicles." Energy Policy 127 (2019): 445-451.

needs for planning changes across shared use and automated vehicles.[14] The use of benchmarking also allows comparisons among agencies for accommodating new technology in its planning practices.

Among the many unknowns related to AVs is the impact of this technology on the location decisions for households and businesses. Telework and access to broadband also influence these decisions. The convergence of these advances could substantially change mode choice and residential location decisions. Given that AVs allow all riders to be productive, or at least engaged, while traveling, there is the possibility that the technology will promote further decentralization and sprawl.[15]

Among the many unknowns related to AVs is the impact of this technology on the location decisions for households and businesses

Given this framework of various influences, market characteristics, and highly unpredictable responses, scenario planning approach is expected to bring the best modeling and analysis methods to bear.[16]

4.1.2 Closing Observations

With respect to planning and modeling for the unknown, there remains a great deal of interest in use and application of scenario-based planning. The expectation is that agencies use these scenario baselines and benchmarking has emerged as a preferred practice.

4.2. Critical information needed for planning and gaps in existing modeling activities

4.2.1 Zero Occupancy

Among the primary gaps in modeling knowledge at present is a better understanding of inserting Zero Occupancy and staging facilities in the trip-based planning process. Models are being modified to accommodate such movements, but at present, little research has clearly shown how to best model these movements. Quantification, like with planning for uncertainty, remains difficult to achieve.

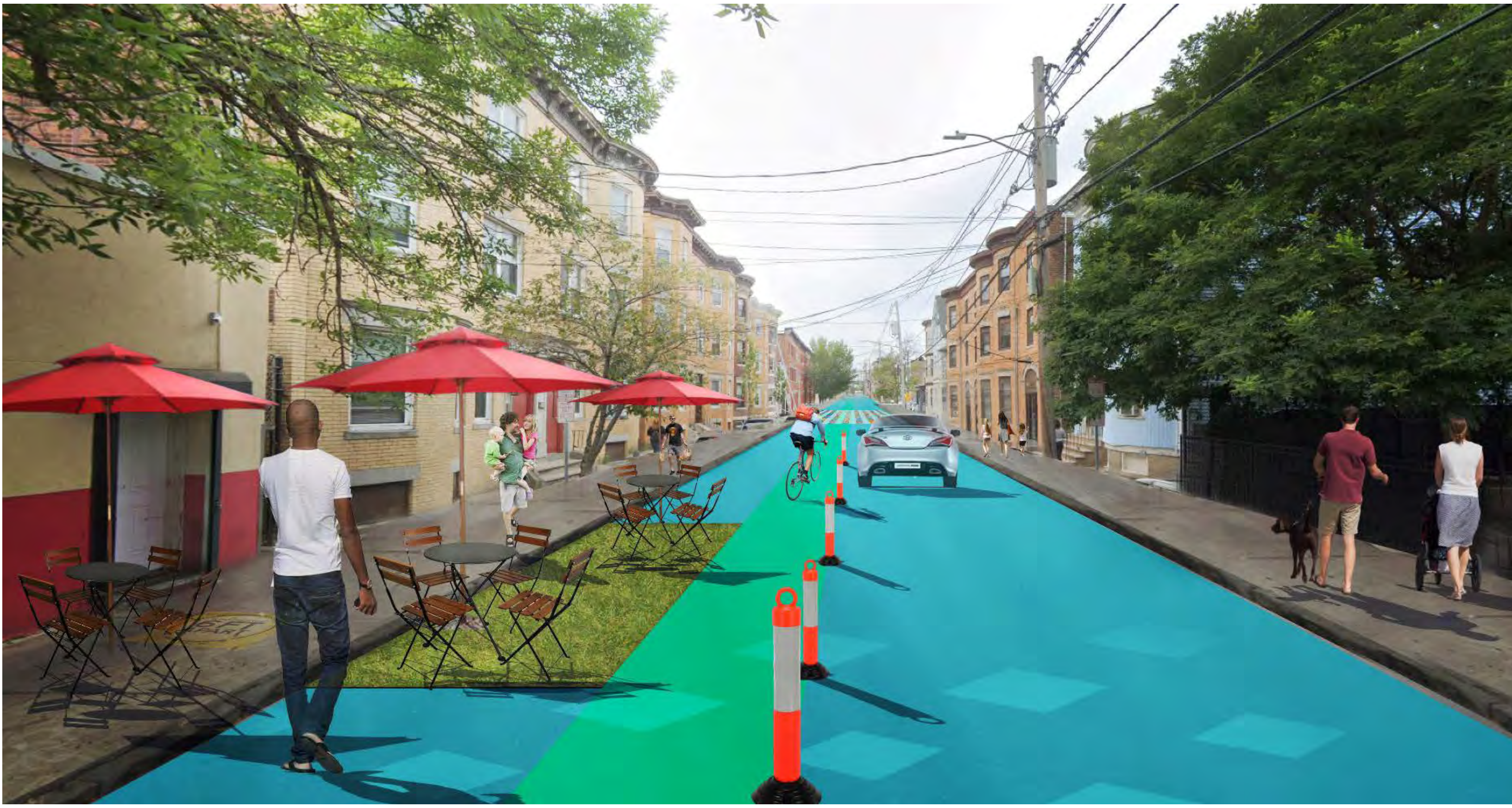
4.2.2 Use of Existing Tools

There have been a number of studies on land use impacts of automation and shared mobility. Some include extended commutes and longer trip lengths. More urban expansion has been cited by several authors. University of Maryland researchers examined existing integrated land use and transportation models to demonstrate how researchers can examine the possibilities of

---

[14] Zmud, J. P., N. Reed, "Synthesis of the Socioeconomic Impacts of Connected and Automated Vehicles and Shared Mobility," *Socioeconomics Impacts of Automated and Connected Vehicles: Summary or the Sixth EU-U.S. Transportation Research Symposium*, Transportation Research Board, 2019.
[15] Stevens, Lindsay. Will autonomous vehicles promote urban sprawl?
[16] Redd, L and Jensen, M. Autonomous Vehicles and Planning. Whitepaper.2017.

the new technology using existing tools.[17] Lavieri and others developed a comprehensive model system of AV adoption using data in the Puget Sound, Washington, Regional Travel Study.[18] Several data models have been developed to ingest a variety of information from these existing tools.[19]



4.2.3 Model Assumptions

Historically, existing transportation-related models look at different aspects of the transportation system (travel demand, traffic flows, emissions, etc.) independently. Models can in turn, be used to forecast the adoption of AV technologies, which provide gauges to help forecast the effects of AVs under alternative future scenarios.

Soteropoulos et al. reviewed 37 modeling studies on the implications of AVs for travel behavior and land use published between 2013 and 2018.[20] This comprehensive review showed that AVs

---

[17] Engelbert, Daniel. Modeling The Land Use Impacts Of Autonomous Vehicles. 2017.

[18] Lavieri PS, Garikapati VM, Bhat CR, Pendyala RM, Astroza S, Dias FF. Modeling Individual Preferences for Ownership and Sharing of Autonomous Vehicle Technologies. Transportation Research Record. 2017;2665(1):1-10. doi:10.3141/2665-01

[19] Bhat, C. R. A New Generalized Heterogeneous Data Model (GHDM) to Jointly Model Mixed Types of Dependent Variables. Transportation Research Part B: Methodological, Vol. 79, 2015, pp. 50–77. https://doi.org/10.1016/j.trb.2015.05.017.

[20] Soteropoulos

were expected to increase VMT, decrease the share of public transport and active modes, reduce the need for parking spaces and increase population in suburban and rural regions. Soteropoulos concluded that these outcomes from the 37 studies appeared to be highly sensitive to model assumptions. Assumptions about the AVs' business model (i.e. private vs. shared AVs) and changes in the value of time provided substantial variation in how many vehicles were in the observable network at a given time.

Another key differentiator identified in the literature refers to predictive and exploratory modeling differences. Predictive modeling works to unlock the expected outcomes of new technologies while the exploratory modeling helps to develop scenarios. Both are highly sensitive to the assumptions brought to the model from the start. [21]

Researchers in the Department of Energy's Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility Consortium used the POLARIS agent-based transportation systems simulator[22] for analysis on mixed fleets. POLARIS is a high-performance, open-source agent-based modeling framework that can simulate large-scale transportation systems. POLARIS features an integrated travel demand, network flow and traffic assignment model in which multiple key aspects of travel decisions (activity planning, route choice, and tactical-level driving decisions) are presented. POLARIS models individual decision making at long-term, mid-term and within-day time frames for the various decisions that are represented. The SMART team significantly updated POLARIS to determine optimal levels of vehicle sharing when the vehicle is allowed to reposition itself.[23] The model assumes that households with a fixed number of fully automated vehicles (all household vehicles are assumed to be AVs for those willing to pay) are able to schedule the vehicle pickups in such a way to minimize total household costs. The team also integrated vehicle platooning algorithms.

Assumptions about changes in capacity (higher roadway capacity due to shorter following distance or decreased lane widths) and the operating characteristics of shared AVs (e.g. waiting time, dispatching model, relocation of vehicles) strongly influenced the model results.[24] Soteropoulus found that a scenario dominated by private AVs was generally associated with more miles traveled, less public transport and active modes use, more vehicles to serve travel demand and thus more parking spaces, and a highly dispersed urban form compared to a shared AVs context with more modest decreases in value of time. These researchers recommend more research on generalized travel costs and the perception of travel time in the (shared) AVs era to inform future models. Ideally these surveys should explore such preferences among different socio-demographic groups and use cases of AVs (e.g. different

[21] RAND. 2014. Autonomous Vehicle Technology: A Guide for Policymakers. Santa Monica: RAND Corporation Transportation, Space, and Technology Program

[22] Auld, Joshua, Michael Hope, Hubert Ley, Bo Xu, Kuilin Zhang, and Vadim Sokolov. "Modelling Framework for Regional Integrated Simulation of Transportation Network and Activity-Based Demand (Polaris)." 2013.

[23] US Department of Energy, SMART Mobility Connected and Automated Vehicles Capstone Report, July 2020. https://www.energy.gov/sites/prod/files/2020/08/f77/SMART-CAVS_Capstone_07.22.20.pdf

[24] Smith, B. W., & Svensson, J. (2015). Automated and Autonomous Driving: Regulation under Uncertainty. Transportation Research Board Annual Conference

sizes of AVs), taking also into account likely developments such as the possibility for social-emotional matching of passengers in shared AV contexts.[25]

Model assumptions also provide an opportunity to draw upon uncertainties in the planning process.[26] Riggs, Boswell, and Guerra offer planners a framework to appropriately respond to the uncertainty of automated vehicles: appropriately designing roadway capacity and lessen the risk of 'stranded assets' and considering the role of multimodal planning actions in light of autonomy.[27]

With respect to planning and modeling for uncertainty, there are many ongoing and recently completed research topics. The most cited are use of scenario-based plans and the careful attention to assumptions used in the research findings. These two research areas (scenario-based planning and use of clear assumptions) dominate planning for uncertainty. While the assumptions chosen dominate the discussion on model outcomes, planners and modelers should provide a range of expected outcomes as a preferred practice. Potential ranges of outcomes – e.g. pessimistic, baseline, optimistic – would help provide planners with more complete information.

Transportation planning implications of advanced data management for scenario-based planning are numerous. For example:

- planners and government agencies will need to coordinate with the industry to identify the types of data needed for planning purposes and ensure that vehicle and infrastructure hardware and software are properly coordinated and designed to aggregate and convey that data;
- the ability to measure performance and responses to various planning interventions will increase dramatically as real time information on travel behavior becomes available, leading to a more strategic approach to transportation planning and advanced mobility management capabilities; and
- real time transportation data feeding into traffic management centers will enable far more efficient use of the existing transportation system and provide drivers with a number of conveniences, including the ability to avoid congestion and locate destinations or services.

4.3. Performance-based planning, and build on FHWA and NCHRP work in scenario planning, focusing on what the planning community needs to know, including technology convergence, likelihood of acceptance, and other factors

[25] Dimitris Milakis (2019) Long-term implications of automated vehicles: an introduction, Transport Reviews, 39:1, 1-8, DOI: 10.1080/01441647.2019.1545286
[26] Fagnant, D. J., & Kockelman, K. M. (2014). The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. Transportation Research Part C: Emerging Technologies, 40, 1–13.
[27] Riggs, William, Boswell, Michael, and Guerra Erick. Autonomous Vehicles, Uncertainty And The Planning Policy Response. 2017.

FHWA's push for performance-based planning provides a framework for AVs and shared mobility. An "agile" process with short phases, allows for frequent re-assessment and adaptation. It will be critical to ensure that the infrastructure that is planned and constructed is seamlessly coordinated with the technological advancements of automated vehicles.

The combination of smart sensors embedded in transportation infrastructure and automated vehicles raises a clear opportunity for future planning – the opportunity for vehicles and infrastructure to communicate in real time and provide performance based data and information.[28] Sensors will allow the potential for large amounts of rich data from vehicle sensors, roadside units and other electronic sources to be used in a variety of ways. There are unresolved issues of privacy associated with sensor development, testing, and data collection, maintenance, and storage.

Legacy et al. have explored the role of urban and transport planning in the deployment of AVs through a review of relevant literature in geography, planning and transport journals and in semi-structured interviews with public sector planners in the Australian context.[29] They identified three perspectives of AV research following Kębłowski and Bassens (2018) typology (i.e. the neoclassical, the sustainability and the political economy perspective). They concluded that AVs are not necessarily expected to provide answers to old problems like inequitable access, climate change and fragmentation of physical landscapes. They added that scholarly research is still far from offering a holistic and systematic understanding of AV implications for urban forms.

Other research has found that AV adoption drops with increasing (and therefore more expensive) trip length; a reflection of consumer cost economics.[30] Some research indicates the number of cars per household could drop by 43 percent in a shared AV scenario.[31] Shared AVs offer a potential solution to parking and other urban problems that presently stem from widespread individual car ownership. Those unable to drive (i.e. those who are disabled and/or elderly) could then access vehicles to travel directly to their destinations.

The responses from public sector planners revealed an understanding of the need for regulatory and planning intervention (especially at early stages of AV development) to ensure that the deployment of AVs will not come in conflict with existing social and environmental targets. Yet public sector planners have difficulties in identifying their role in shaping the AV deployment path within a complex public and private governance context. Planners seem to adopt instead a more reactionary position reflecting a "watch and wait" approach[32], which according to the authors create risks for the social and environmental sustainability of cities. The authors call for more research on the development of a "cohesive and coherent critical theoretical and

[28] Harper, C. D., Hendrickson, C. T., Samaras, C. Cost and benefit estimates of partially-automated vehicle collision avoidance technologies. Accident Analysis & Prevention, 95, 104–115. 2016
[29] Legacy, Crystal, et al. "Planning the driverless city." Transport reviews 39.1 (2019): 84-102.
[30] Boston Consulting Group. Reshaping Urban Mobility with Autonomous Vehicles Lessons from the City of Boston. June 2018.
[31] University of Michigan Transportation Research Institute, "Driverless Vehicles: Fewer Cars, More Miles," University of Michigan, 2015.
[32] Guerra, E. (2016). Planning for cars that drive themselves: Metropolitan planning organizations, regional transportation plans, and autonomous vehicles. Journal of Planning Education and Research, 36(2), 210–224. doi: 10.1177/0739456X15613591

conceptual framework" facilitating reconciliation between AVs deployment and public purpose planning.

4.4 Timing, Phasing and Long-Range Planning Cycles

To plan for AVs and shared mobility, planners will need a clearer picture as to the timing and phasing of the technology

To plan for AVs and shared mobility, planners will need a clearer picture as to the timing and phasing of the technology.[33] Yet considerable controversy has ensued as to the actual timing for deployment of AVs, and competing technologies add to the uncertainty. Predictions vary depending on levels of deployment.

Industry projections tend to be equally confusing yet confident, although there is recognition that "due to several challenges, highly-automated driving will enter the market gradually[34] …." Analysis by the Victoria Transport Policy Institute stated that most predictions are "wildly optimistic", and even if self-driving vehicles actually are available in 2020-2021, they will have a high price premium, making full market saturation not likely until 2060.[35] That analysis assumes two key issues will slow market saturation – historic vehicle fleet turnover rates and the initial high costs of new technology.

An important consideration is that planning cycles are generally consistent due to Federal requirements. Metropolitan Planning Organization and the state DOTs are presently preparing long-range transportation plans through the years 2040- 2050. According to the guidelines, the use of 5- and 10-year periods increases flexibility and reduces the need to "fine tune" project priorities. This allows for adjustments based on emerging technology.

It may be appropriate to begin considering the potential implications of AVs in later phases of the current long-range planning cycle. For example, one might include a scenario in the final ten years of the plan that anticipates different levels of deployment or alternative regional applications that support long-range transportation planning objectives, safety and operational performance measures and performance targets. Example scenarios could include a variety of potential applications, such as recapturing existing arterial capacity through AVs and smart infrastructure, or road trains of platooning trucks on dedicated lanes for more efficient movement of freight.

---

[33] Meyer, Gereon, and Susan Shaheen, eds. Disrupting Mobility: Impacts of Sharing Economy and Innovative Transportation on Cities. Springer, 2017.
[34] Coelingh, Erik, et al. "Collision warning with auto brake: a real-life safety perspective." Innovations for Safety: Opportunities and Challenges (2007).
[35] Litman, Todd. "Autonomous vehicle implementation predictions: Implications for transport planning." (2020).

The SMART Mobility Consortium also identified several interactions between manufacturer research and development, VMT accumulation for insurance underwriting, time for regulatory approval, vehicle costs to consumers and achieving economies of scale as part of the challenges for timing and phasing. The study also investigated influential factors for AV adoption and energy consumption sensitivities. These included strong influencers such as consumer preference, time valuation and technology costs; others include vehicle powertrain types and fuel economy, proportion of time freed by a particular AV concept, willingness to pool, road congestion, and amount of deadheading (i.e., extra travel performed by ride-hailing vehicles in between passenger-carrying trips).[36] While much of the additional literature on automated vehicles and shared mobility on travel behavior and the environment is still developing, researchers have also suggested that use of shared automated vehicles could reduce transportation costs and energy usage reaching as much as a 55% reduction in energy use and approximately a 90% reduction in greenhouse gas (GHG) emissions.[37]

The Department of Energy's Modeling Workflow Development, Implementation, and Results Capstone Report evaluated new transportation technologies such as connectivity, automation, sharing, and electrification through multi-level systems analysis that captured interactions between these technologies. Through an integration approach of multiple models across different levels of fidelity and scale, the effort yields insights about the influence of new mobility and vehicle technologies at the system level.[38] At the individual vehicle level, detailed models were created to represent powertrain component technologies and control algorithms across powertrain and vehicle classes. This was used with multi-vehicle models to evaluate the impact of connectivity (e.g., vehicle to infrastructure), and to quantify the potential energy benefits. These inputs were further extended to micro-simulation models to quantify the impact of those new controls on traffic flow, based on specific travel patterns and traffic levels. Finally, larger mesoscopic transportation system models were used to model travel behavior at the city or regional scale, and to assess the impact of new transportation technologies on the larger transportation system. This approach proved novel in its ability to develop common scenarios for planning.

Vehicle ownership models also greatly influence the potential planning related outcomes for AVs. Replacement of traditional trip types with automated ones allows for more trips being served.[39] This research also found that the lower values on travel time (accommodating other functions while in travel) helps enhance avoid congestion.

---

[36] US Department of Energy, SMART Mobility Connected and Automated Vehicles Capstone Report, July 2020. https://www.energy.gov/sites/prod/files/2020/08/f77/SMART-CAVS_Capstone_07.22.20.pdf

[37] Shaheen, Susan PhD & Bouzaghrane, Mohamed Amine, 2019. "Mobility and Energy Impacts of Shared Automated Vehicles: a Review of Recent Literature," Institute of Transportation Studies, Research Reports, Working Papers, Proceedings qt5g29c7pp, Institute of Transportation Studies, UC Berkeley.

[38] US Department of Energy, SMART Mobility Modeling Workflow Development, Implementation, and Results, https://www.energy.gov/sites/prod/files/2020/08/f77/SMART-Workflow_Capstone_07.28.20.pdf.

[39] de Almeida Correia, G. H. , and van Arem, B. . Solving the User Optimum Privately Owned Automated Vehicles Assignment Problem (UO-POAVAP): A Model to Explore the Impacts of Self-Driving Vehicles on Urban Mobility. Transportation Research Part B: Methodological, Vol. 87, 2016, pp. 64–88. https://doi.org/10.1016/j.trb.2016.03.002.

4.5 Consider opportunities to build-in feedback mechanisms for demonstration projects connected to automated vehicles; identify tools that agencies will need to evaluate transportation projects and plans

Changes in ownership, organizational structure and operation of transport infrastructures might appear when the share of fully automated vehicles (level 4 or 5) increases considerably in the vehicle fleet. A shared fleet of AVs—in combination with public transportation—could sustain current levels of mobility using only 10 percent of the vehicles currently on the road today.[40] Understanding the infrastructure sequencing needs is essential for the development of a well-designed rollout of new technologies for transportation.[41] Changes to right of way management practices, parking requirements, curb setbacks, and other elements could include a segmentation of the road network, operation and maintenance by private organizations and the emergence of transportation providers that could guarantee trip quality, regardless of the travel mode.[42]

Understanding the infrastructure sequencing needs is essential for the development of a well-designed rollout of new technologies for transportation

The Department of Energy has released a series of white papers highlighting the findings of their SMART Mobility Consortium referenced earlier that identify several enhancements to simulation and modeling tools to reproduce scenarios. Existing models were enhanced by developing new algorithms to reproduce complicated interactions of automated vehicles and manually-driven vehicles in multi-lane controlled access highway segments.[43] Particularly, the addition of this lane-changing algorithm provides a modeling framework to realistically depict car-following and lane-changing behaviors in mixed traffic. With this effort, models are can reproduce the traffic dynamics that are likely to appear in multilane highways. In addition, the SMART modeling framework can describe the behaviors of automated vehicles under specific operational strategies relevant for improving overall traffic flow and fuel consumption.

---

[40] International Transport Forum, “Urban Mobility System Upgrade,” 2015.
[41] Mervis, Jeffrey, Gretchen Vogel, Jennifer Couzin-Frankel May, Ann Gibbons-May, Meredith Wadman, Jon Cohen, Warren Cornwall, et al. “Are We Going Too Fast on Driverless Cars?” Science, December 14, 2017.
[42] Van Arem, Bart, and Cyprian A. Smits. An exploration of the development of automated vehicle guidance systems. No. 97/NV/294. 1997.
[43] Liu, Hao, Xingan David Kan, Steven E. Shladover, Xiao-Yun Lu, and Robert E. Ferlis. "Modeling impacts of cooperative adaptive cruise control on mixed traffic flow in multi-lane freeway facilities." Transportation Research Part C: Emerging Technologies 95 (2018): 261-279

In addition to this work, there appears to be some desire for priority treatments for transit operations, truck platooning, and general segregated lanes for AV technologies. Fagnant and Kockelman outlined approaches for considering shared mobility options as they relate to automation.[44] In this work, the authors provide both cost and environmental savings associated with the move to automated vehicles in a shared use format. The SMART consortium platooning work also demonstrates the fuel efficiency of said interactions.

Fleet transition and mixed fleet planning and modeling continue to provide challenges for planners

Fleet transition and mixed fleet planning and modeling continue to provide challenges for planners. Several researchers have recommended that vehicle fleets, including e-taxis[45], provide rich opportunities for early adoption of AV technologies. Safety issues associated with a mix of automated and non-automated vehicles, including expected behaviors, have often been noted as a key concern for policy makers. Some research has been initiated to evaluate mixed fleets, including work on heavy trucks integrated into fleet operations with conventional trucks.[46] Speed variability decreases with increasing AV penetration.[47] Additional research has also shown how incrementally transitioning the fleet to AVs influences safety.[48] For example, low transition rates result in an increase in conflicts at signalized intersections but a decrease at priority-controlled intersections.

---

[44] Fagnant, D., & Kockelman, K. (2014). The Future of Fully Automated Vehicles: Opportunities for Vehicle- and Ride-Sharing, With Cost and Emissions Savings. Austin, Texas: Center for Transportation Research University of Texas at Austin

[45] Kornhauser & Orf .Serving the Nation's Personal Mobility Needs with the Casual Sharing of autonomous Taxis & Today's Urban Rail, Amtrak and Air Transport Systems, 467F16 Class, Feb 2017 or Uncongested Mobility for All: A Proposal for an Area Wide Autonomous Taxi System in New Jersey,, J. Zachariah, J. Gao, A. Kornhauser, T. Mufti, July 2013

[46] https://www.fleetforward.com/355628/vtti-to-study-autonomous-trucks-in-mixed-fleets

[47] Banerjee, S.S., Jha, S., Cyriac, J., Kalbarczyk, Z.T., Iyer, R.K., Year. Hands off the wheel in autonomous vehicles?: A systems perspective on over a million miles of field data. 48th Annual IEEE/IFIP International Conference on Dependable Systems and Networks (DSN), 2020, pp. 586-597.

[48] Virdi N, Grzybowska H, Waller ST, Dixit V. A safety assessment of mixed fleets with Connected and Autonomous Vehicles using the Surrogate Safety Assessment Module. Accident; Analysis and Prevention. 2019 Oct;131:95-111. DOI: 10.1016/j.aap.2019.06.001.

5 Further Research Opportunities

The suggestions below identify topics for future research to inform and focus the important discussion around *Implication for Planning and Modeling*. 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	Further development of scenario planning tools and methods. Powerful methods for scenario analysis are sorely needed for understanding and planning for the advent and future of AV. Several methods are currently in use, such as a fairly standard form of scenario analysis where plausible, coherent scenarios are listed, and analysts formulate a range of strategies accordingly. The complexity of some arenas, however, such as the potential futures for AV, demand more rigor than traditional methods. Past plans have proven to be generally off by orders of magnitude. The use and development of these tools is crucial for better preparedness for mobility in the future. The extensive variability from future impacts leads to substantial challenges in the planning community. The ability to develop some set group of potential scenarios and their overall impacts will be valuable. An additional element of improved scenario planning would be the development of scenario planning and modeling of specific policy options to determine the most likely effective interventions as certain AV technology develops further. This could include pilot programs or other policy interventions that advance coincident with technology improvements.	*Social Impacts*
4.2	Generalized travel costs and the perception of travel time in the (shared) AVs era to inform future models. Ideally these surveys should explore such preferences among different socio-demographic groups and use cases of AVs (e.g. different sizes of AVs), taking also into account likely developments such as the possibility for social-emotional matching of passengers in shared AV contexts.	*Social Impacts*
4.2.	Developing consistent modeling tools. Consistency among modeling tools and outcomes remains somewhat problematic for the transportation community. The ability to effectively model zero occupancy trips or even destination based shared mobility options has been based on assumptions that can be overly optimistic. The impact on goods movement and facility location is not well known at this point. The continued work in planning for new industrial locations and freight movements would provide planners with additional strategies for scenario development and land use planning.	*None*

Subtopic	Research Opportunity	Crossover to Other Topics
4.4	Modeling for significant changes in the economy and emerging challenges. The far-reaching impact on the economy – including changes to use of drivers, facility location, residential land use, and similar items provides for a need to better explore questions of where and how we travel. n a post-COVID environment there also will be opportunities to improve modeling to understand new travel patterns and experiences associated with the advancement of AV and shared mobility technologies. Other questions remain on what specific the issues could create significant impacts, including disaster response challenges when shared mobility cannot keep up with sudden demand, and long-term effects from COVID such as significant increase in telecommuting and telework? How will these changes affect planning for AV and shared mobility uses?	*Social Impacts*
4.5	Modeling and Planning for Urban and Rural Settings. There are substantial differences between the modeling and planning techniques that are appropriate at both urban and rural levels. These differences include everything from reliance on existing capacity information to trip purpose, intent, and length. Vehicle types and road conditions (including infrastructure design, signage, speed controls, and similar information) need to be explored in these varied settings. At present, planners do not have access to scenarios for rural advances in AV usage or potential usage.	*None*
4.5	There is a need to better understand the introduction of AVs to the vehicle fleet and its related safety and operational challenges. Among the potential topics needing further study: • What is the expected duration of the mixed fleet environments? • Are there particular modeling or simulation techniques that should be standardized as part of the long-term planning process? • What will be the impact of gradual transitions of the fleet for freight and goods movement? Will land use changes follow at a gradual pace?	*Land Use*

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
SMART	Systems and Modeling for Accelerated Research in Transportation (US Department of Energy)
USDOT	US Department of Transportation
VMT	Vehicle Miles Traveled

B. References

Auld, Joshua, Michael Hope, Hubert Ley, Bo Xu, Kuilin Zhang, and Vadim Sokolov. "Modelling

Banerjee, S.S., Jha, S., Cyriac, J., Kalbarczyk, Z.T., Iyer, R.K., Year. Hands off the wheel in autonomous vehicles?: A systems perspective on over a million miles of field data. 48th Annual IEEE/IFIP International Conference on Dependable Systems and Networks (DSN), 2020, pp. 586-597.

Barbour, Natalia, Nikhil Menon, Yu Zhang, and Fred Mannering. "Shared automated vehicles: A statistical analysis of consumer use likelihoods and concerns." Transport Policy 80 (2019): 86-93.

Bhat, C. R. A New Generalized Heterogeneous Data Model (GHDM) to Jointly Model Mixed Types of Dependent Variables. Transportation Research Part B: Methodological, Vol. 79, 2015, pp. 50–77. https://doi.org/10.1016/j.trb.2015.05.017.

Boston Consulting Group. Reshaping Urban Mobility with Autonomous Vehicles Lessons from the City of Boston. June 2018.

Buckley, Lisa, Sherrie-Anne Kaye, and Anuj K. Pradhan. "Psychosocial factors associated with intended use of automated vehicles: A simulated driving study." Accident Analysis & Prevention 115 (2018): 202-208.

Childress, Suzanne, Brice Nichols, Billy Charlton, and Stefan Coe. "Using an activity-based model to explore the potential impacts of automated vehicles." Transportation Research Record 2493, no. 1 (2015): 99-106.

Cohen, Tom, and Clémence Cavoli. "Automated vehicles: exploring possible consequences of government (non) intervention for congestion and accessibility." *Transport reviews* 39, no. 1 (2019): 129-151.

Coelingh, Erik, et al. "Collision warning with auto brake: a real-life safety perspective." Innovations for Safety: Opportunities and Challenges (2007).

Dannemiller, Katherine A., Aupal Mondal, Katherine E. Asmussen, and Chandra R. Bhat. "Investigating Autonomous Vehicle Impacts on Individual Activity-Travel Behavior."

de Almeida Correia, G. H. , and van Arem, B. . Solving the User Optimum Privately Owned Automated Vehicles Assignment Problem (UO-POAVAP): A Model to Explore the Impacts of Self-Driving Vehicles on Urban Mobility. Transportation Research Part B: Methodological, Vol. 87, 2016, pp. 64–88. https://doi.org/10.1016/j.trb.2016.03.002.

Denaro, Robert P., J. O. H. A. N. N. A. Zmud, Steven Shladover, Bryant Walker Smith, and Jane Lappin. "Automated vehicle technology." King Coal Highway 292 (2014): 19-24.

Diels, Cyriel, Tugra Erol, Milena Kukova, Joscha Wasser, Maciej Cieslak, William Payre, Abhijai Miglani, Neil Mansfield, Simon Hodder, and Jelte Bos. "Designing for comfort in shared and automated vehicles (SAV): a conceptual framework." (2017).

Dimitris Milakis (2019) Long-term implications of automated vehicles: an introduction, Transport Reviews, 39:1, 1-8, DOI: 10.1080/01441647.2019.1545286

Eilbert, Andrew, Lauren Jackson, George Noel, and Scott Smith. "A Framework for Evaluating Energy and Emission Impacts of Connected and Automated Vehicles through Traffic Microsimulations." Transportation Research Board (2018).

Engelbert, Daniel. Modeling The Land Use Impacts Of Autonomous Vehicles. 2017.

Fagnant, D. J., & Kockelman, K. M. (2014). The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. Transportation Research Part C: Emerging Technologies, 40, 1–13.

Fagnant, D., & Kockelman, K. (2014). The Future of Fully Automated Vehicles: Opportunities for Vehicle- and Ride-Sharing, With Cost and Emissions Savings. Austin, Texas: Center for Transportation Research University of Texas at Austin

Fishelson, James. Who owns the data: privatization and secrecy in shared mobility and Vehicle automation.

Framework for Regional Integrated Simulation of Transportation Network and Activity-Based Demand (Polaris)." 2013.

González-González, Esther, Soledad Nogués, and Dominic Stead. "Automated vehicles and the city of tomorrow: A backcasting approach." Cities 94 (2019): 153-160.

González, David, Joshué Pérez, Vicente Milanés, and Fawzi Nashashibi. "A review of motion planning techniques for automated vehicles." IEEE Transactions on Intelligent Transportation Systems 17, no. 4 (2015): 1135-1145.

Greenblatt, Jeffery B., and Susan Shaheen. "Automated vehicles, on-demand mobility, and environmental impacts." Current sustainable/renewable energy reports 2, no. 3 (2015): 74-81.

Greenwald, Judith M., and Alain Kornhauser. "It's up to us: Policies to improve climate outcomes from automated vehicles." Energy Policy 127 (2019): 445-451.

Guerra, E. (2016). Planning for cars that drive themselves: Metropolitan planning organizations, regional transportation plans, and autonomous vehicles. Journal of Planning Education and Research, 36(2), 210–224. doi: 10.1177/0739456X15613591

Gurumurthy, Krishna Murthy, Kara M. Kockelman, and Michele D. Simoni. "Benefits and costs of ride-sharing in shared automated vehicles across austin, texas: Opportunities for congestion pricing." Transportation Research Record 2673, no. 6 (2019): 548-556.

Hardman, Scott, Rosaria Berliner, and Gil Tal. "Who will be the early adopters of automated vehicles? Insights from a survey of electric vehicle owners in the United States." Transportation research part D: transport and environment 71 (2019): 248-264.

Harper, C. D., Hendrickson, C. T., Samaras, C. Cost and benefit estimates of partially-automated vehicle collision avoidance technologies. Accident Analysis & Prevention, 95, 104–115. 2016

International Transport Forum, "Urban Mobility System Upgrade," 2015.

Johnsen, Annika & Strand, Niklas & Andersson, Jan & Patten, Christopher & Kraetsch, Clemens & Takman, Johanna. (2017). Literature review on the acceptance and road safety, ethical, legal, social and economic implications of automated vehicles.

Klischat, Moritz, Octav Dragoi, Mostafa Eissa, and Matthias Althoff. "Coupling sumo with a motion planning framework for automated vehicles." In SUMO User Conference. 2019.

Kockelman, Kara, Paul Avery, Prateek Bansal, Stephen D. Boyles, Pavle Bujanovic, Tejas Choudhary, Lewis Clements et al. Implications of connected and automated vehicles on the safety and operations of roadway networks: a final report. No. FHWA/TX-16/0-6849-1. 2016.

Kornhauser & Orf .Serving the Nation's Personal Mobility Needs with the Casual Sharing of autonomous Taxis & Today's Urban Rail, Amtrak and Air Transport Systems, 467F16 Class, Feb 2017 or Uncongested Mobility for All: A Proposal for an Area Wide Autonomous Taxi System in New Jersey,, J. Zachariah, J. Gao, A. Kornhauser, T. Mufti, July 2013

Kornhauser, Alain L. "A Perspective on the New Federal Automated Vehicles Policy." (2016).

Kortum, Katherine, and Mark Norman. "National Academies–TRB Forum on Preparing for Automated Vehicles and Shared Mobility." Transportation Research Circular E-C234 (2018).

Lavieri PS, Garikapati VM, Bhat CR, Pendyala RM, Astroza S, Dias FF. Modeling Individual Preferences for Ownership and Sharing of Autonomous Vehicle Technologies. Transportation Research Record. 2017;2665(1):1-10. doi:10.3141/2665-01

Lavieri, Patrícia S., Venu M. Garikapati, Chandra R. Bhat, Ram M. Pendyala, Sebastian Astroza, and Felipe F. Dias. "Modeling individual preferences for ownership and sharing of autonomous vehicle technologies." Transportation research record 2665, no. 1 (2017): 1-10.

Lavieri, Patrícia S., and Chandra R. Bhat. "Modeling individuals' willingness to share trips with strangers in an autonomous vehicle future." Transportation research part A: policy and practice 124 (2019): 242-261.

Legacy, Crystal, et al. "Planning the driverless city." Transport reviews 39.1 (2019): 84-102.

Litman, T. 2015. "Autonomous Vehicle Implementation Predictions: Implications for Transport Planning." Transportation Research Board 94th Annual Meeting. Washington, DC, U.S. 15p.

Litman, T. (2013, August 17). Autonomous Vehicle Implementation Predictions: Implications for Transport Planning. Retrieved from Victoria Transport Policy Institute: http://www.vtpi.org/avip.pdf

Litman, Todd. "Autonomous vehicle implementation predictions: Implications for transport planning." (2020).

Liu, Hao, Xingan David Kan, Steven E. Shladover, Xiao-Yun Lu, and Robert E. Ferlis. "Modeling impacts of cooperative adaptive cruise control on mixed traffic flow in multi-lane freeway facilities." Transportation Research Part C: Emerging Technologies 95 (2018): 261-279

Liljamo, Timo, Heikki Liimatainen, and Markus Pöllänen. "Attitudes and concerns on automated vehicles." Transportation research part F: traffic psychology and behaviour 59 (2018): 24-44.

Lutin, Jerome M., F. ITE, and Alain L. Kornhauser. "The revolutionary development of self-driving vehicles and implications for the transportation engineering profession." Cell 215 (2013): 630-4125.

Lutin, Jerome M., and Alain L. Kornhauser. "Application of autonomous driving technology to transit—functional capabilities for safety and capacity." *Transportation Research Record, paper* 14-0207 (2014).

Massachusetts Institute of Technology. MIT- information presented to Shared Mobility and AV Forum, Washington, DC. January 24-25, 2020.

McMahon, Donn H., J. Karl Hedrick, and Steven E. Shladover. "Vehicle modelling and control for automated highway systems." In 1990 American Control Conference, pp. 297-303. IEEE, 1990.

Mervis, Jeffrey, Gretchen Vogel, Jennifer Couzin-Frankel May, Ann Gibbons-May, Meredith Wadman, Jon Cohen, Warren Cornwall, et al. "Are We Going Too Fast on Driverless Cars?" Science, December 14, 2017.

Meyer, Gereon, and Susan Shaheen, eds. Disrupting Mobility: Impacts of Sharing Economy and Innovative Transportation on Cities. Springer, 2017.

Milanés, Vicente, 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.

National Academies of Sciences, Engineering, and Medicine 2018. Updating Regional Transportation Planning and Modeling Tools to Address Impacts of Connected and Automated Vehicles, Volume 1: Executive Summary. Washington, DC: The National Academies Press. https://doi.org/10.17226/25319

Piao, Jinan, Mike McDonald, Nick Hounsell, Matthieu Graindorge, Tatiana Graindorge, and Nicolas Malhene. "Public views towards implementation of automated vehicles in urban areas." Transportation research procedia 14, no. 0 (2016): 2168-2177.

RAND. 2014. Autonomous Vehicle Technology: A Guide for Policymakers. Santa Monica:RAND Corporation Transportation, Space, and Technology Program

Redd, L and Jensen, M. Autonomous Vehicles and Planning. Whitepaper.2017.

Riggs, William, Boswell, Michael, and Guerra Erick. Autonomous Vehicles, Uncertainty And The Planning Policy Response. 2017.

Sener, Ipek N., Johanna Zmud, and Thomas Williams. "Measures of baseline intent to use automated vehicles: A case study of Texas cities." Transportation research part F: traffic psychology and behaviour 62 (2019): 66-77.

Shaheen, Susan. "Shared mobility: the potential of ridehailing and pooling." In Three revolutions, pp. 55-76. Island Press, Washington, DC, 2018.

Shaheen, Susan A. "Mobility and the sharing economy." Transport Policy 51, no. Supplement C (2016): 141-142.

Shaheen, Susan PhD & Bouzaghrane, Mohamed Amine, 2019. "Mobility and Energy Impacts of Shared Automated Vehicles: a Review of Recent Literature," Institute of Transportation Studies, Research Reports, Working Papers, Proceedings qt5g29c7pp, Institute of Transportation Studies, UC Berkeley.

Shladover, Steven E. "Connected and automated vehicle systems: Introduction and overview." Journal of Intelligent Transportation Systems 22, no. 3 (2018): 190-200.

Shladover, Steven E. "Cooperative (rather than autonomous) vehicle-highway automation systems." IEEE Intelligent Transportation Systems Magazine 1, no. 1 (2009): 10-19.

Smith, B. W., & Svensson, J. (2015). Automated and Autonomous Driving: Regulation under

Snelder, Maaike, Isabel Wilmink, Jeroen van der Gun, Hendrik Jan Bergveld, Parvin Hoseini, and Bart van Arem. "Mobility impacts of automated driving and shared mobility." European Journal of Transport and Infrastructure Research 19, no. 4 (2019).

Soteropoulos, Aggelos, Martin Berger, and Francesco Ciari. "Impacts of automated vehicles on travel behaviour and land use: an international review of modelling studies." Transport reviews 39.1 (2019): 29-49.Stevens, Lindsay. Will autonomous vehicles promote urban sprawl?

Soteropoulos, Aggelos, et al. "Automated drivability: Toward an assessment of the spatial deployment of level 4 automated vehicles." Transportation Research Part A: Policy and Practice 136 (2020): 64-84.

Sprei, Frances. "Disrupting mobility." Energy Research & Social Science 37 (2018): 238-242.

Stead, Dominic, and Bhavana Vaddadi. "Automated vehicles and how they may affect urban form: A review of recent scenario studies." *Cities* 92 (2019): 125-133.

Stocker, Adam, and Susan Shaheen. "Shared automated vehicles: Review of business models." International Transport Forum Discussion Paper, 2017.

Stocker, Adam, and Susan Shaheen. "Shared automated mobility: early exploration and potential impacts." In Road Vehicle Automation 4, pp. 125-139. Springer, Cham, 2018.

Transportation Research Board. Summary or the Sixth EU-U.S. Transportation Research Symposium, National Academies of Sciences and Engineering, 2019.

University of Michigan Transportation Research Institute, "Driverless Vehicles: Fewer Cars, More Miles," University of Michigan, 2015.

US Department of Energy, SMART Mobility Connected and Automated Vehicles Capstone Report, July 2020. https://www.energy.gov/sites/prod/files/2020/08/f77/SMART-CAVS_Capstone_07.22.20.pdf

US Department of Energy, SMART Mobility Modeling Workflow Development, Implementation, and Results, https://www.energy.gov/sites/prod/files/2020/08/f77/SMART-Workflow_Capstone_07.28.20.pdf.

Ulbrich, Simon, and Markus Maurer. "Towards tactical lane change behavior planning for automated vehicles." In 2015 IEEE 18th International Conference on Intelligent Transportation Systems, pp. 989-995. IEEE, 2015.

Van Arem, Bart, and Cyprian A. Smits. An exploration of the development of automated vehicle guidance systems. No. 97/NV/294. 1997.

Virdi N, Grzybowska H, Waller ST, Dixit V. A safety assessment of mixed fleets with Connected and Autonomous Vehicles using the Surrogate Safety Assessment Module. Accident; Analysis and Prevention. 2019 Oct;131:95-111. DOI: 10.1016/j.aap.2019.06.001.

Wagner, Jason, Trey Baker, Ginger Goodin, and John Maddox. Automated vehicles: Policy implications scoping study. No. SWUTC/14/600451-00029-1. Southwest Region University Transportation Center, Texas A & M Transportation Institute, Texas A & M University, 2014.

Williams, Kristine. Planning Implications for Automated Vehicles. Tampa Hillsborough Expressway Authority. 2016.

Yang, Da, Shiyu Zheng, Cheng Wen, Peter J. Jin, and Bin Ran. "A dynamic lane-changing trajectory planning model for automated vehicles." Transportation Research Part C: Emerging Technologies 95 (2018): 228-247.

Zhao, Yong, and Kara M. Kockelman. "Anticipating the regional impacts of connected and automated vehicle travel in Austin, Texas." Journal of Urban Planning and Development 144, no. 4 (2018): 04018032.

Zmud, Johanna, et al. "Research to examine behavioral responses to automated vehicles." Road Vehicle Automation 5. Springer, Cham, 2019. 53-67.

Zmud, J. P., N. Reed, “Synthesis of the Socioeconomic Impacts of Connected and Automated Vehicles and Shared Mobility,” Socioeconomics Impacts of Automated and Connected Vehicles:

Zmud, Johanna, Tom Williams, Maren Outwater, Mark Bradley, Nidhi Kalra, and Shelley Row. *Updating Regional Transportation Planning and Modeling Tools to Address Impacts of Connected and Automated Vehicles, Volume 1: Executive Summary*. No. Project 20-102 (09). 2018.

Zmud, Johanna, Felipe Dias, Patricia Lavieri, Chandra Bhat, Ram Pendyala, Yoram Shiftan, Maren Outwater, and Barbara Lenz. "Research to examine behavioral responses to automated vehicles." In *Road Vehicle Automation 5*, pp. 53-67. Springer, Cham, 2019.

Zmud, Johanna, Ginger Goodin, Maarit Moran, Nidhi Kalra, and Eric Thorn. "Advancing automated and connected vehicles: policy and planning strategies for state and local transportation agencies." (2017).

https://www.fleetforward.com/355628/vtti-to-study-autonomous-trucks-in-mixed-fleets

C. Acknowledgments

The research team for the nine Topical Papers was led by Stantec with Applied Research Associates serving as a subcontractor. In the role as Principal Investigator, Kelley Coyner served as an adviser to the research and development of the Topical Papers. The project team consisted of the following members:

Principal Research Manager: Greg Rodriguez, Stantec, Mobility Policy Principal
Principal Research Coordinator: Pamela Bailey-Campbell, Stantec, Senior Transportation Strategic Advisor
ARA Research Lead: Jason Bittner, Principal and Practice Area Lead
Researcher: Jennifer Shriber, Stantec, Transportation Planner
Researcher: Sophia Constantine, Stantec, Researcher
Principal Investigator: Kelley Coyner, Innovation4Mobility