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This report summarizes proceedings of an Automated Vehicle (AV) modeling peer exchange sponsored by the Federal Highway Administration (FHWA) and hosted by the Maricopa Association of Governments in Phoenix, AZ, on June 27, 2019. The purpose of the peer exchange was to discuss the potential impacts of emerging technologies, such as AVs, on the long-range transportation planning process. Five peers from metropolitan planning organizations across the country participated to share their experiences and perspectives. The event was sponsored by FHWA through its Transportation Planning Capacity Building Program, led in partnership with the Federal Transit Administration.

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Transportation Planning Capacity Building (TPCB) Peer Program

Automated Vehicle Modeling Peer Exchange

A TPCB Peer Exchange Event

Location: Phoenix, Arizona

Date: June 27, 2019

Host Agency: Maricopa Association of Governments

Peer Agencies: Mid-America Regional Council
North Central Texas Council of Governments
Sacramento Area Council of Governments
San Diego Association of Governments

Federal Agency: Federal Highway Administration

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Executive Summary

This report highlights noteworthy practices and discussions shared during a one-day peer exchange on Automated Vehicle (AV) modeling, held June 27, 2019, in Phoenix, Arizona, and hosted by the Maricopa Association of Governments. The Federal Highway Administration (FHWA) sponsored the peer exchange through its Transportation Planning Capacity Building (TPCB) Peer Program, which is run jointly with the Federal Transit Administration. The program promotes knowledge transfer on transportation planning topics through peer learning opportunities. Contact information for the FHWA representatives involved in peer exchange planning as well as the peer exchange peers and presenters is included in Appendix A: Key Contacts of this report.

With increasing interest in AVs and the potential impacts they stand to have on the Nation's transportation network, many transportation agencies, including Metropolitan Planning Organizations (MPOs), are actively exploring ways to address AV modeling considerations in the long-range transportation planning process. The peer exchange brought together five MPOs to discuss their approaches to AV modeling. Insights shared during the peer exchange do not necessarily reflect the opinions of FHWA.

The following MPO representatives served as the peers for the event:

- **Bruce Griesenbeck**, Data and Analysis Manager, Sacramento Area Council of Governments (SACOG) (Sacramento, CA);
- **Vladimir Livshits**, Ph.D., Director of Transportation Technologies, Maricopa Association of Governments (MAG) (Phoenix, AZ);
- **Arash Mirzaei**, Transportation System Modeling Manager, North Central Texas Council of Governments (NCTCOG) (Arlington, TX);
- **Wu Sun**, Ph.D., Principal Researcher and Modeler, San Diego Association of Governments (SANDAG) (San Diego, CA); and
- **Eileen Yang**, Transportation Modeling Manager, Mid-America Regional Council (MARC) (Kansas City, MO).

The peers presented information about their agencies' AV modeling activities and the context in which they are doing modeling. The peers also participated in discussions throughout the peer exchange on a variety of topics, including (1) managing risk and uncertainty in modeling; (2) communicating model results; and (3) modeling information gaps and resource needs.

The presentations and discussion resulted in key takeaways, including:

- There is tremendous uncertainty about the impacts AVs will have on future transportation systems. Behavioral travel models are among the few tools that may provide useful mechanisms for conceptualization of the effect of these technologies.
- Using models can allow for more informed decisionmaking, recognizing that models provide insights and not answers. Every model has underlying assumptions and data. Models are a way to quantify the future and can provide a consistent set of metrics to explore scenarios reflecting various assumptions (e.g., land use, socioeconomic data, etc.).

- Scenario testing can make the most of AV modeling compared to other more specific forecasting techniques due to the approach's flexibility in exploring outcomes of multiple, varied futures.
- Organizing estimates of "uncertainty" factors in the modeling chain by category of assumptions could help MPO modelers better understand how the factors relate and potentially impact each other.
- Presenting model results and related information should include consequential assumptions about the model and external inputs. This method of communication provides a meaningful context for interpretation of the model results. In addition, it is important to keep the target audience in mind so that the model's underlying assumptions and data can be communicated effectively.
- Data interpretation is the foundation of travel modeling and is a significant skillset needed for modeling professionals. New data, new applications, and new data management approaches are emerging from AVs and other new technologies.

Overview of the Peer Exchange

Goals of the Peer Exchange

FHWA organized the peer exchange to bring together MPO technical modelers who are leaders in the field of AV modeling to discuss how they are addressing AV modeling considerations in the long-range transportation planning process. FHWA sponsored the peer exchange through its TPCB Peer Program.

FHWA designed the peer exchange to benchmark current practices among MPO technical modelers in modeling AV and identify near-term actions to address existing challenges and knowledge gaps. As the peers participating in the peer exchange all had deep modeling experience, FHWA additionally sought to obtain their ideas on key considerations, challenges, and opportunities for future resources to further address AV modeling in the long-range transportation planning process

Participating Peers

The peer exchange included five peer MPO representatives, all of whom have extensive experience in modeling and are now thinking about AV modeling considerations. The five peer agencies were MAG, MARC, NCTCOG, SACOG, and SANDAG.

Format of the Event

MAG hosted the one-day peer exchange in Phoenix, Arizona, on June 27, 2019. The five peer presenters, FHWA staff, and other partners, including the Arizona Department of Transportation, attended the workshop. A full list of attendees is available in Appendix B: Event Participants of this report.

The peers first shared information about their agencies' approach to AV modeling and the context in which they are doing modeling. The subsequent discussion was then organized around the topics of (1) managing risk and uncertainty in modeling; (2) communicating model results; and (3) modeling information gaps and resource needs.

The agenda for the peer exchange is provided in Appendix C: Peer Exchange Agenda of this report.

Presentation Highlights

Welcome and Introduction

Jeremy Raw, Community Planner with the FHWA Office of Planning, Karla Petty, FHWA Arizona Division Administrator, and Eric Anderson, MAG Executive Director, opened the peer exchange. The FHWA Office of Planning is interested in learning from MPOs that have metropolitan transportation plans (MTPs) that reference the emergence of AVs. Mr. Raw raised that there is tremendous uncertainty around this emergence.

Executive Director Anderson emphasized that models do not give answers; rather, they provide insights. MPOs and other transportation agencies and stakeholders look to the models to give insight into how different decisions might impact the world in which we live. Models are tools to help us sift through theories and methodologies; they do not have the answers. This theme of "models providing insights, not answers" would carry through the rest of the peer exchange.

Division Administrator Petty discussed that Arizona is a leader in the field of AV testing and MAG is at the forefront of AV modeling. Several AV companies are testing their technologies in Arizona and in the MAG region. There are automated trucks driving on the State's freeway systems and within the community. Ms. Petty noted that there are many questions and unknowns surrounding AVs and recognized peer exchange participants for focusing on these uncertainties. She reiterated the importance of using models to allow for informed decisionmaking and highlighted the potential value of AVs in improving roadway safety.

Purpose of Peer Exchange

Several web-based meetings among the peers and facilitated by FHWA preceded the peer exchange. These "virtual" meetings allowed for the peers to share information with each other and what they hoped to gain from the peer exchange.

One of the goals of the peer exchange was to discuss what MPOs can reasonably do in light of the uncertainty in modeling AVs in their long-range transportation planning process and how they might go about this modeling. For example, MPOs traditionally have used models, in part, to build scenarios around land use conditions and not usually around changes in trip purposes or travel behavior.[1] The growth of AVs potentially creates a situation where "core" assumptions once thought not to change become potentially more likely to change (e.g., changes in travel behavior, goods movement). Mr. Raw noted that models can inform how the world *might* work in the future but not about how it *will* work.

As part of the MTP development, MPOs work with their stakeholders to envision where a community is headed and identify goals for the future. MPO modelers are responsible for processing this information through models based on different sets of assumptions. Decisionmakers often use the results of the models to help inform their decisionmaking. Explaining and understanding these assumptions can be challenging, particularly as the model is not the end of asking questions but rather the beginning to help find answers.

[1] The peer exchange specifically focused on specific travel demand modeling considerations, as opposed to broader scenario planning considerations. Additional information on scenario planning is available on the FHWA Scenario Planning website at: https://www.fhwa.dot.gov/planning/scenario_and_visualization/scenario_planning/.

Report on Recent Events and Resources

Jeremy Raw of the FHWA Office of Planning, along with Scott Smith, Ph.D., of the U.S. Department of Transportation Volpe National Transportation Systems Center (U.S. DOT Volpe Center), discussed how the peer exchange tied into other recent events on related topics, including:

- **University of California, Davis (UC Davis) Workshop on AV Modeling:** The meeting, hosted by UC Davis in April 2019, and funded in part by the California Air Resources Board, focused on the impacts that AVs stand to have on current travel demand forecasting tools and potential ways to update these tools in light of new, disruptive technologies. Conclusions from this event, which was attended by Jeremy Raw (FHWA) and two of the peers, Vladimir Livshits and Arash Mirzaei, reached conclusions similar to the peer exchange: that there is insufficient information to forecast with any confidence how AVs will perform, and that the key concerns for now are how to explore possible alternative scenarios reflecting possible important shifts in travel behavior and system operation, and how to gather and interpret data about those shifts as new technologies emerge.

- **FHWA Peer Review on Robust Decisionmaking (RDM) under Deep Uncertainty**: On June 13-14 2019, prior to the AV Modeling peer exchange, FHWA hosted a separate peer review on RDM.[2] The peer review included participants from the California Department of Transportation, Culver City, FHWA, MAG, Metropolitan Transportation Council, Oregon Department of Transportation, Puget Sound Regional Council, RAND, SACOG, SANDAG, Southern California Association of Governments, and the U.S. DOT Volpe Center. The peer review focused specifically on SACOG's use of the Travel Model Improvement Program-Exploratory Analysis and Modeling Tool (TMIP-EMAT) to examine the greenhouse gas and mobility impacts of their long-range plan under several scenarios.

- **Transportation Research Board (TRB) Planning Applications Conference**: On June 2-5, 2019, TRB hosted its biennial Planning Applications Conference, which showcases new and innovative techniques and methods in transportation planning. Several AV Modeling peer exchange participants attended this conference. The conference was not specifically focused on AV but included several sessions and discussions on how to represent scenarios and assumptions effectively for AV modeling as well as how to plan when there is great uncertainty about possible future outcomes.

Throughout their presentation, Mr. Raw and Dr. Smith opened up discussion to the audience, as several peer exchange participants also participated in these meetings. Participants noted the following key themes resulting from the RDM event in particular:

- RDM involves the consideration of "wicked problems[3]," where stakeholders do not agree on the formulation of the problem, or on the likelihood of various scenarios. The goal in such an environment then becomes gaining agreement on the actions and not the predictions. You are

[2] RDM focuses on four primary concepts: 1) decision analysis (the structuring of decisions and tradeoffs); 2) stress testing (deliberately trying to break plans, so that they can be improved; 3) scenarios (identifying multiple plausible world views); and 4) exploratory modeling (running many models quickly to explore possible differences in outcomes).

[3] Rittel, H. W. J.; M. M. Webber (1973). *Dilemmas in a General Theory of Planning.* Policy Sciences. 4 (2): 155–169.

trying to get agreement from stakeholders on what actions should be taken today to improve the likelihood of "good" outcomes in the future.

- In taking an RDM approach, the first step is to frame the decision. What are the biggest uncertainties? The next step is to stress-test strategies over a wide range of futures; this will involve running thousands of scenarios. Identifying the most important factors—not solely the most uncertain factors—is crucial; if the "wrong" assumptions are used, the whole process will be impacted. Using insights from this modeling can help an agency figure out how to refine its strategies or make it less likely that it will miss its goals in the future. One key finding from SACOG's RDM pilot was that current MTPs may be vulnerable to exogenous assumptions (e.g., fuel prices, economic growth). If these assumptions are incorrect, it can result in an agency missing its goals. The RDM process instead helps agencies focus on the "load-bearing" uncertainties.
- There is a need to look at transportation plan development differently. The RDM process takes risk management and analysis and puts it into planning practice. The process of bringing to life implicit assumptions should be standard under conditions of extreme uncertainty, whether through scenarios, RDM, meta-models, etc. Federal regulations and conformity analysis still require point forecasts, but plans also need to address this uncertainty. Models are tools to help incorporate risk management more strategically into transportation plans.

Peer Approaches to AV Modeling

Each of the MPO peers shared presentations about their AV modeling activities and perspectives on future opportunities and challenges (Figure 1). The following summarizes key points of these presentations.

Figure 1: Participants listen during a peer's presentation.
Source: U.S. DOT Volpe Center

Sacramento Area Council of Governments

Bruce Griesenbeck
Data and Analysis Manager
Sacramento, CA

SACOG is the designated MPO for the six-county Sacramento region. The vast majority of land area in the SACOG region is rural, forested, or agricultural; only a small portion is urbanized. Approximately 2.4 million residents live in the region. SACOG is currently finalizing its next MTP/Sustainable Communities Strategy (MTP/SCS), which will have a horizon year of 2040. The plan is anticipated for adoption in 2020. Mr. Griesenbeck focused his presentation on SACOG's approach to estimating the potential impacts of AVs and Transportation Network Companies (TNCs) using an activity-based travel demand model (ABM) in the development of MTP/SCS scenarios. Through its efforts, SACOG sought to test if its ABM could capably and credibly forecast AV/TNC demand. The MPO also conducted a separate scenario-based risk analysis to investigate possible other future actions that the region could potentially pursue.

The SACOG ABM uses DAYSIM as its software base. Resource Systems Group, Inc. provided SACOG with updated DAYSIM software, including scenario-testing functions for an auto ownership element where households can own either conventional vehicles or AVs as well as a "paid rideshare" or TNC element where rideshare is one of the mode choices within the model. The AV/TNC functionality in DAYSIM serves as a scenario-testing model, rather than as a predictive model.

Mr. Griesenbeck discussed that the assumptions built into the ABM can vary its outcomes. For example, one assumption is that the adoption rate of AV will likely be higher for higher income households, younger households, and households that are farther away from the city center. Another assumption is that a household choosing to own an AV is likely to own fewer non-AV vehicles. However, AV ownership may provide a possible incentive to households to reconsider how many other vehicles are in the household.

On the TNC side, Mr. Griesenbeck noted that there are constants to set the overall use of rideshare as a mode. However, he raised that one of the uncertaintites is not solely how people will value their time traveling but what they will be doing in AVs. For example, AVs could be considered as meeting places themselves rather than as a mode of transportation to a destination. How people value time may not necessarily demonstrate the full extent of how people's activities might change and how they might behave within an AV.

Through its scenario testing, SACOG used three scenarios established initially by UC Davis:

- Business-as-usual, which considers no significant use of electrification or automation (e.g., using transportation in the same way as today);
- 2 Revolutions (2R), in which electrification and automation, but not shared mobility, are widely used; and
- 3 Revolutions (3R), in which electrification, automation, and shared mobility are all present.[4]

In its initial results, SACOG found that the 2R scenario potentially generated new VMT, while the 3R scenario had the potential for some reduction of VMT. Transit was also impacted in the scenarios, as

[4] For additional information, visit: https://its.ucdavis.edu/blog-post/how-to-combine-three-revolutions-in-transportation-for-maximum-benefit-worldwide/. In the 2R scenario, the vehicles themselves are anticipated to change, but behavioral changes are less significant. In the 3R scenarios, there are significant changes to the vehicles and traveler behavior.

more travelers turned to TNCs. Mr. Griesenbeck noted that there are limitations to the modeling and scenario testing. There is no explicit representation of the supply side, or vehicle side, of AVs, and "deadheads" (i.e., repositioning AVs without passengers) are not part of the scenario testing. Until the supply side is represented, Mr. Griesenbeck noted that additional research could be a way to make scenarios "smarter" and more connected. With scenario testing, MPO modelers provide the inputs and assumptions, so the models can be limited in their results. As a next step, SACOG is exploring how to account for deadhead travel for TNCs in its models.

Maricopa Association of Governments

Vladimir Livshits, Ph.D.
Director of Transportation Technologies and Services
Phoenix, AZ

MAG is a Council of Governments that serves as the regional planning agency for the metropolitan Phoenix area. The region is approximately 16,000 square miles, with approximately 4.8 million residents. The region is home to about 68 percent of the State's population and 72 percent of employment. Maricopa County, which is included in the MAG region, is one of the fastest growing counties in the country in terms of population growth.

MAG develops and maintains socioeconomic forecasts and models and uses Arizona's Socioeconomic Modeling and Reporting Toolbox (AZ-SMART) for its modeling activities. The AZ-SMART model system is a highly customized version of the UrbanSim modeling system for the MAG region. These forecasts and models provide the main inputs for the transportation models. This year, MAG plans to more tightly integrate and automate its land use model with the transportation forecasting models.

MAG's transportation models include a four-step travel demand model (TDM), an ABM, and several Dynamic Traffic Assignment (DTA) models that use TransModeler and DynusT. The four-step TDM is the MAG's official regional model; however, the agency plans to switch to the ABM as the official model in the near future. MAG is currently working to update and calibrate both the four-step model and the ABM. In December 2018, MAG conducted a peer review of the models to obtain feedback from peer MPOs, transportation agencies, consultants, and academia on the model updates. MAG is also exploring updates to the supply side inputs of the models. Through its updates, MAG has been coordinating closely with other agencies, including the Ohio Department of Transportation and SANDAG, to incorporate and share information and best practices. Beyond the four-step, ABM, and DTA models, MAG also developed a behavior-based freight model, using funding provided from the Second Strategic Highway Research Program (SHRP2), specifically the SHRP2 C20 Freight Demand Modeling and Data Improvement Implementation Assistance Program.

In updating the ABM, MAG incorporated car allocation submodels (in the carTrack module) specifically essential for modeling household-owned AVs and their routing with associated empty ZOV (Zero-Occupancy Vehicle) trips.

In addition, MAG incorporated feedback loops into the travel activities, so if travel cannot be made, the model goes back to activity scheduling. These updates were incorporated through the Individual Schedule Adjustment Module (ISAM). With these changes, MAG's ABM transitions towards an agent-based model with individual tracking of vehicles throughout the modeling process.

Like SACOG, MAG recognizes that there are implicit assumptions to the models and that model results can be questionable. In testing scenarios, MAG found that AVs may lead to increases in VMT and have impacts on air quality performance and transit use. However, these findings are are based upon a number of underlying assumptions such as capacity assumptions and AV penetration rates.

As next steps, MAG plans to continue its model updates, including the integration of vehicle fleet composition model (including electric vehicles) and the integration with DTA. MAG is also incorporating sensitivity analysis and looking at elasticities. MAG continues to seek new, innovative approaches for its modeling activities and identify possible activities for the future, such as further investigating microsimulation for supply and demand sides.

San Diego Association of Governments

Wu Sun, Ph.D.
Principal Researcher and Modeler
San Diego, CA

Dr. Sun discussed SANDAG's approach to modeling AVs in the long-range transportation planning process. As a California MPO, SANDAG, like SACOG, must prepare a MTP/SCS every four years.[5] SANDAG plans to take a new approach for its upcoming RTP/SCS. While SANDAG is preparing its 2020 RTP in order to meet Federal requirements, it is also developing a 2021 version, known as the "Regional Plan" (RP), which will integrate the RTP and its Regional Comprehensive Plan and include treatment of Connected/Automated Vehicle (C/AV) and other emerging technologies.

The 2021 RP anticipates five key strategies, or what the plan calls, "5 Big Moves":

1. *Complete Corridors*, which focuses on establishing a complete transportation system for all roadway users to improve safety, capacity, and efficiency;
2. *Transit Leap*, which looks to strengthen transit services through high-capacity, high-speed, and high-frequency options;
3. *Mobility Hubs*, which brings together multiple travel options, including shared mobility services and bicycle and pedestrian infrastructure, to facilitate travel to destinations;
4. *Flexible Fleets*, which considers new micromobility forms and rideshare; and
5. *Next Operating System*, which addresses data flow and communications to make the transportation system work more smoothly.

To represent some these "big moves" in modeling, SANDAG established four emerging technology categories, all of which feed into its model: 1) C/AV and shared C/AV; 2) TNC; 3) High-speed transit service; and 4) micromobility. Dr. Sun used the remainder of his presentation to discuss SANDAG's model specifically and how SANDAG is including C/AV in the model.

[5] SANDAG refers to its MTP as a "Regional Transportation Plan" (RTP). Thus, the term "RTP" is used throughout the summary of the SANDAG presentation.

SANDAG uses an ABM for its modeling activities, which it first developed in 2013 ("ABM1"). SANDAG has continued to refine the model over time (Figure 2: Evolution of SANDAG's ABM from 2013 to present. SANDAG is currently using an updated version of the ABM ("ABM2"), which was completed in June 2018 and is used for the 2020 RTP. A third iteration ("ABM2+") is also in development to support the 2021 RP.

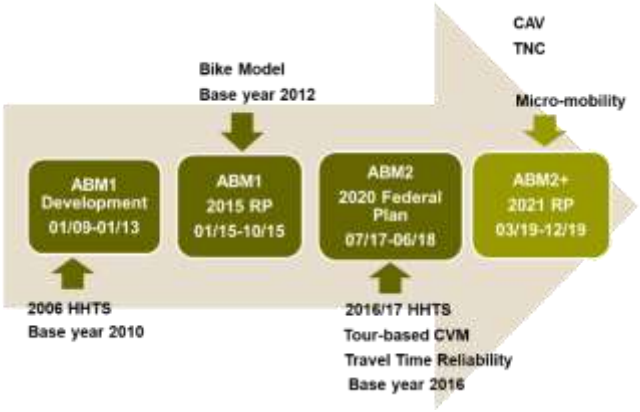

Figure 2: Evolution of SANDAG's ABM from 2013 to present.
Source: SANDAG

SANDAG's ABM includes various model components to incorporate C/AV, including:

- Auto ownership (number of conventional vehicles or AVs)
- Vehicle type choice (households that own at least one of each type of vehicle [HV and AV] have a choice of which vehicle to use for each tour, taking into account not only when auto is the chosen mode but also when evaluating other modal options [walk, bike, transit, etc.])
- Mode choice (behavioral changes unknown, but model incorporates an expanded auto travel market and flexible modifiers to test the possible impacts of AVs)

On the supply side, SANDAG is working on highway assignment and capacity improvements to integrate into the model. SANDAG is considering whether to add AVs to the vehicle flow using special Passenger Car Equivalent (PCE) factors or to assign AVs separately. SANDAG is also testing capacity improvements, which may vary depending on AV penetration rates depending on whether driving environments include both conventional vehicles and AVs or solely AVs. In addition, SANDAG is looking into the potential impacts of shared AVs, which could reduce VMT significantly. Other model features underway include assigning passengers to hotspots, incorporating stops for potential electric vehicle charging, and extending AV routing to a single TNC.

Dr. Sun noted that the challenges SANDAG sees in AV modeling include the limited observed data of this new technology and the great uncertainty it brings on how travel behavior will change. He raised that scenario testing is a more supportive tool in this environment over traditional single-point forecasts. Scenario testing allows for multiple runs with various parameters, which can be helpful when having so many assumptions. Given the complexity of the scenarios and model runs, it can also be difficult to communicate information clearly and in an approachable manner to others not as familiar with travel demand modeling.

To address these challenges, SANDAG established a Technical Advisory Committee to obtain input from peer MPO modelers on its modeling activities and learn from others about innovative practices in the field. SANDAG is also finalizing its ABM2 for the 2020 RTP and refining the ABM2+ for the 2021 RP. SANDAG anticipates beginning work on the next iteration of the ABM in 2020, to be known as "ABM3."

Mid-America Regional Council

Eileen Yang
Transportation Modeling Manager
Kansas City, MO

Ms. Yang focused her presentation on MARC's approach to modeling uncertainty, discussing MARC's current model, its scenario building activities, and anticipated future efforts.

MARC uses a four-step TDM, based on Inro's Emme software. The MARC model is an enhanced four-step trip-based model that focuses on daily travel patterns.[6] The model includes many enhancements that have recently been improved and augmented, such as an auto availability model with household income and household size sub-models, improved trip distribution procedures to include destination choice formulations, enhanced time-of-day component to model 24 hour daily slices, and the Kansas City International Airport as a special generator. The model supports transportation modeling for the MARC region, which covers eight counties and two million residents across Greater Kansas City, MO.

For its upcoming 2050 MTP, MARC applied a scenario planning process. MARC completed a pilot anlysis early this year, which generated two land use and four transportation scenarios (Figure 3).[7] MARC also considered the impacts to the transportation system if AVs were to have full penetration into the vehicle fleet by 2050. MARC conducted additional scenario modeling to analyze these potential impacts. Ms. Yang discussed that measuring this type of deep uncertainty can be challenging and is based on very uncertain assumptions. She noted that one key element is to reframe the questions the models help answer. For example, rather than asking, "What will happen?," the models can help address, "What should we do today to most effectively manage the range of events that might happen?"[8]

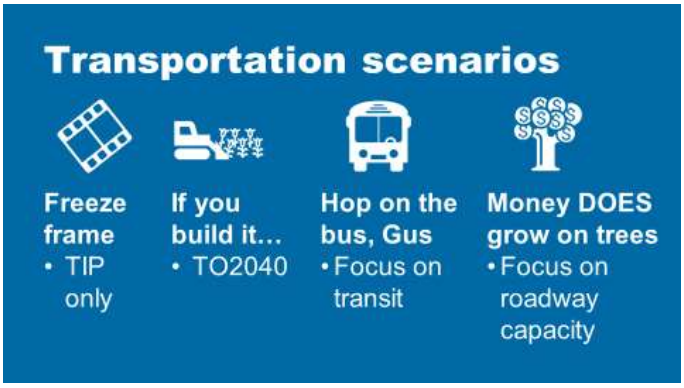

Figure 3: MARC's four transportation scenarios.
Source: MARC

[6] A typical four-step travel demand model focuses on: 1) trip generation; 2) trip distribution; 3) mode choice; and 4) trip assignment (See the online Travel Forecasting Resource: http://tfresource.org/Category:Trip-based_models.)

[7] The scenarios are as follows:

Land Use Scenarios

- "Let It Ride": This scenario is the trend growth scenario/traditional land use forecast. By 2050, MARC anticipates 30 percent population growth and 50 percent job growth within the region.
- "Take the Wheel": This is the focused growth land use scenario, which assumes 60 percent population growth and 80 percent job growth within the region.

Transportation Scenarios

- "Freeze Frame": This is the future "no build" scenario in which population and employment grow, but no further investments are made to the transportation system beyond what is included in the 2018-2022 Transportation Improvement Program.
- "If You Build It…": This scenario assumes population and employment growth and the funding of all projects identified in MARC's current MTP, *Transportation Outlook 2040*.
- "Hop on the Bus, Gus": This scenario assumes population and employment growth and increased investment in transit.
- "Money DOES Grow on Trees": This scenario assumes population and employment growth and has no financial constraints, focusing primarily on increased roadway capacity.

[8] This perspective is offered through TRB's National Cooperative Highway Research Program (NCHRP) Research Report 896: *Updating Regional Transportation Planning and Modeling Tools to Address Impacts of Connected and Automated Vehicles*. MARC relied on this report as a resource in designing its effort. For additional information on the NCHRP Research Report 896, please visit: http://www.trb.org/Publications/Blurbs/178393.aspx.

Given the wide range of uncertainties, MARC consciously decided to select five changeable variables in its modeling test runs. Through this exercise, MARC hoped to learn more about the relationship between model parameters and the model output. It is anticipated that AVs will be present in the future, but the impacts they will potentially have remain uncertain. The five variables MARC elected to focus on were: 1) capacity increase (freeway and expressway); 2) auto vehicle operation cost; 3) parking cost; 4) vehicle occupancy; and 5) zero-occupancy trips.

After conducting the model test runs, MARC coordinated with local partners, consultants, and stakeholders to discuss the original scenarios developed. Through this coordination, MARC decided to develop additional "Utopian" (a fleet-based AV ownership model) and "Dystopian" (an individually owned AV ownership model) scenarios to further test the extremes of assumptions, identified in part through a working group established for the scenario planning effort. One of the challenges MARC then faced was translating the feedback from the working group into the model; however, the MPO was able to accommodate these inputs by using assumptions about model parameters.

MARC is currently finalizing its approach for the scenarios and anticipates beginning additional stakeholder discussions around the scenarios later in 2019. The next step will be to obtain feedback on the approach, particularly on the "Fleet Based"and the "Individual AV ownership" scenarios, to determine the best next steps forward.

North Central Texas Council of Governments

Arash Mirzaei, P.E.
Transportation System Modeling Manager
Arlington, TX

Mr. Mirzaei's presentation focused on an C/AV modeling effort led by NCTCOG, in collaboration with the University of Texas at Austin Center for Transportation Research, through its University Partnership Program. NCTCOG serves as the council of governments for 16 counties within the North Central Texas region, which includes the cities of Dallas and Fort Worth.

NCTCOG has a four-step model that it develops and updates in house. In integrating C/AV considerations into the model, NCTCOG sought to engage academics and thus established the partnership with the Center for Transportation Research. The project is in its third year, for which NCTCOG provides $75,000 each year.

The goals of the project were to:

1. *Understand future technologies.* Mr. Mirzaei discussed that the landscape in which transportation agencies are trying to plan is constantly changing. However, while so many uncertainties exist, it is important to focus on the key ones that mattter in order to bring these into modeling tools.
2. *Implement model changes.* NCTCOG is working to update its model to incorporate potential C/AV impacts. In addition to model changes, changes in the decisionmaking process are also occurring.
3. *Develop possible scenarios*. In identifying scenarios, NCTCOG looked to envision possible futures for the North Central Texas region. As part of this exercise, NCTCOG hoped to better determine possible timelines for adoption/transition and when action may be needed.

Mr. Mirzaei discussed NCTCOG's approach to incorporating AVs into its model, focusing on the traditional model elements of trip generation, trip distribution, mode choice, and assignment (Figure 4: NCTCOG's approach for incorporating AVs into its four-step model.

- The NCTCOG model models trips generated by household and not by individual; the agency further divides households into those with access to AVs and those without. NCTCOG based the adoption of AVs on market segmentation, considering the potential number of conventional vehicles and AVs owned. Mr. Mirzaei noted that, through the project's research, NCTCOG was not able to find reliable trends and thus treated vehicle ownership as an exogenous variable. NCTCOG considered its analysis to be scenario-based rather than predictive.
- For trip distribution, NCTCOG elected to go with generalized cost after testing various factors.
- NCTCOG focused on ride-hailing and AV-based modes for mode choice, thinking about the overall attractiveness for each, wait times, and, similar to SACOG and SANDAG, in-vehicle travel time.
- For trip assignment, NCTCOG considered the PCEs of C/AVs, so that it could have greater control over market segment assumptions.

Mr. Mirzaei discussed the challenge of modeling the aforementioned details in a reasonable manner. NCTCOG used scenario testing to explore the impacts of the model's assumptions. NCTCOG developed a range of scenarios, focusing on characteristics such as workplace trip changes, capacity enhancement, new "driver" populations, average vehicle occupancy, and automated freight delivery. Mr. Mirzaei noted that NCTCOG, through its efforts, has realized that the accessibility potentially offered by AVs could also provide an economic value that is not necessarily part of the transportation model at the current time.

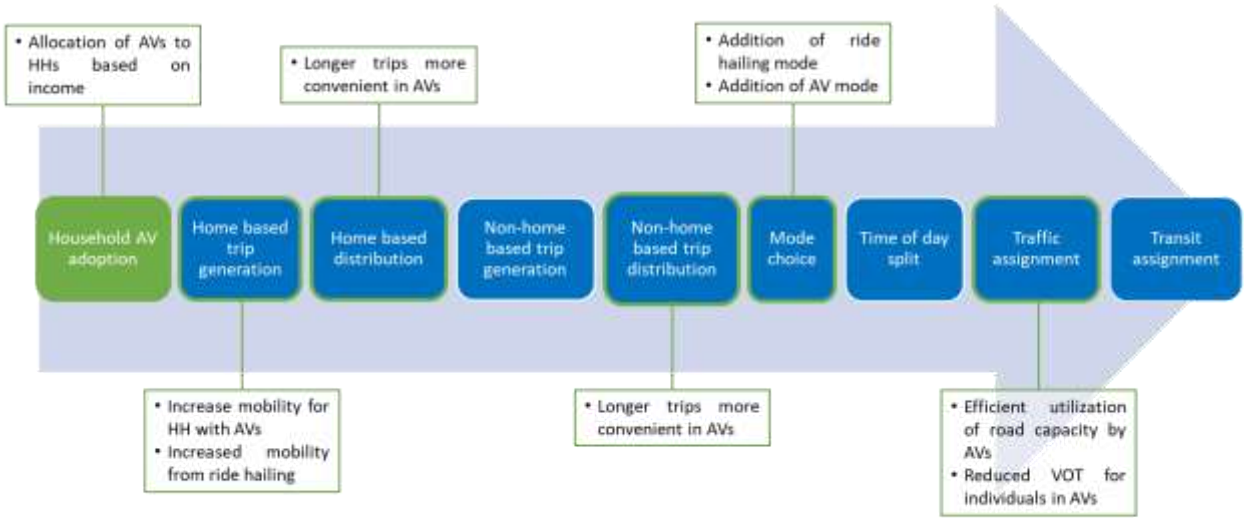

Figure 4: NCTCOG's approach for incorporating AVs into its four-step model.
Source: NCTCOG

Discussion Topics

During the peer exchange, attendees participated in several discussions to share ideas, answer questions, and offer suggestions to each other and FHWA. The following summarizes key themes from the discussions, including recommendations provided by the peers.

Managing Risk and Uncertainty in Modeling

This session focused on the peers' approach to risk management and uncertainty to identify "uncertainty" factors in the modeling chain and the transportation planning process. The key guiding question of this session was: *What risk factors are you facing in your modeling approach?* "Risks" in this case focused on assumptions or expectations for which the peers felt there was either great uncertainty, potentially large impact, or both.

Participants were asked to identify all possible risk factors as part of this exercise. Once participants identified their risk factors, they shared these with the group and discussed why they identified the factors they did. The full list of risk factors as identified by peer exchange participants can be found in Appendix D: Risk Factors.

In the second half of the exercise, participants refined their original brainstormed lists, identifying themes across the risk factors and providing input on the insights shared. Participants discussed the need to focus on actionable, measurable factors, but also questioned if the right factors are being measured. They asked, "What is the path that leads today into the future?

This exercise resulted in the following thoughts, summarized below:

- What are unknown travel behaviors that are likely to be risk factors?
    - Perceived time/value of time in vehicles
    - Parking behavior (e.g., changes in how people park)
    - Mode choice
    - Social acceptance/public perception (could vary by gender, age, etc.)
    - Changes in work schedule/non-work trips (e.g., more remote work/telework; e-commerce replacing non-work trips)
    - Long-distance travel (could increase with AVs; e.g., for "weekend getaways")
- What are the policies we will need to keep in mind?
    - Minimum age of "driver" in AV
    - Insurance policies
    - Regulations for curbside management
- What are the technology considerations?
    - Highway capacity (e.g., how closely vehicles can travel together?)
    - Speed
    - Travel time reliability
    - Drones; delivery by drone
    - Availability of 5G for transportation
    - Cost of technology – buying; sharing
- What are the land use considerations?
    - Parking/land use/freight movement
    - Connections between AV and land use/long-term choices
    - Availability of tools, such as integrated models, scenario testing, etc.
    - Response of local governments to anticipated or actual land use changes
- What are the MPO considerations?
    - Leadership support (will direction change after a change in leadership?)
    - Staffing at MPO level (staff turnover issues)

- What are other considerations?
    - Unknown private sector status and data (whether new mode of transportation will arise)
    - Congestion management in the form of routing (could disrupt the models but also could provide an opportunity for more effective system management)

Participants discussed organizing risk factors by category of assumptions (e.g., economic, land use, transportation, behavioral) to better understand how the factors relate and potentially impact each other. In addition, they discussed potential changes in costs of travel (both real and perceived). While there is tremendous uncertainty about costs, it is likely that costs will change; however, it is not certain what the change will be.

Communicating Model Results

As part of the peer exchange, participants also engaged in discussion on how they communicate modeling results and information to stakeholders, particularly to MPO boards and policymakers. Participants discussed that the way they present information must be done thoughtfully so that the information provided is understandable to an audience that may not be as familiar with travel demand modeling. Participants shared insights and lessons learned for how they have overcome challenges in presenting the complexity of model results. The following highlights several key insights shared by participants:

- *Start every declaration about what the model is telling you with an "if."* One participant discussed starting with "if" helps decisionmakers react to the results differently. They understand that the results are more similar to possible outcomes than definite realities. Every model has underlying assumptions and data. Models serve as a way to quantify the future, providing consistency across data and various assumptions. The participant discussed that, rather than focusing on scenarios, his goal is to have people think about different behavioral responses to possible future conditions. In doing so, he hopes encourage discussions about what is happening today in the world and adapt tools over time to respond to these changes. Since many MPOs have limited budgets, they may not have the resources to put toward model development regularly; the agencies therefore must be savvy about how they apply these resources. Participants discussed that decisionmakers may be more familiar with point forecasts so broadening assumptions and explaining uncertainties are part of their communications strategies.

- *Know your audience and avoid AV-related jargon.* Participants discussed limiting the use of the term, "assumption," when presenting to stakeholders as well as other related AV terms, such as "deadhead" and "zero occupancy." Stakeholders may be interested in the anticipated technologies and how AVs will operate but may be less familiar with how people may respond to AVs. The goal is not to settle the assumptions, but to learn about possible outcomes and what their implications might be. Participants discussed the importance of presenting a narrative so that people think about the behavioral response to AVs and the options for adapting behavior rather than the details of a specific scenario. One participant discussed that, when presenting to his MPO board, he does not discuss model details unless asked; in his presentations, he tries to be as simple as possible to convey the information at hand. Another discussed his agency's use of visualization as a way to strengthen storytelling.

- *Establish and maintain credibility.* One participant shared that his executive director presents information and model results to the MPO board. Having the credibility of the executive director helps when more uncertain information is presented and as MPO staff are analyzing new phenomena. The model changes gradually over time, which may outlive MPO board members' terms. Participants discussed the importance of demonstrating to their boards that staff are not being passive on the topic of AVs but rather actively trying to learn, particularly in learning from the private sector on AV advancements.

- *Seek opportunities to partner with others.* Participants raised several aspects in terms of partnering with others.
    - First, they noted a common challenge in coordinating with private sector AV, TNC, or other technology companies. The companies have been reluctant to share their data (especially regarding travel patterns), which can be challenging to an MPO trying to learn about the possible transportation impacts of new technologies on its region.
    - Second, participants discussed that modelers oftentimes may not be the ones presenting model results to the MPO board; instead, it may be planners within their agency. Internal communication among modelers and planners regularly and early on can ensure that all parties understand the information being presented, and its limitations. One participant discussed that this coordination happens from the start of an activity in his agency and that, when he is discussing the model, he frames it from a planning perspective. For example, he discussed that there are other aspects to AV modeling besides driving, including policy assumptions such as curbside management and behavioral assumptions.
    - Third, participants discussed sharing their data with local members or consultants. One participant noted that his agency does share information, but with select groups. Another discussed that his MPO allows any other agency to access the model but not the source code unless there is a convincing reason; the MPO also runs a training program to help others understand and run the model. Participants noted the challenge in that others may think they can run a model upon receipt but that it takes significant ongoing maintenance to keep the model functioning correctly. There can also be challenges about who owns part(s) of a model, particularly if a consultant was involved. One participant shared that his agency added a disclaimer to state that the model was no longer the agency's once it was provided to others. Overall, however, participants agreed on the importance in sharing information about the models. Doing so can provide "more eyes" on the model and help in demonstrating a model's credibility. One participant shared that his agency "polishes" their models through local member requests, while another agreed that the models benefit from reviews by additional users.

Modeling Information Gaps and Resource Needs

In the final discussion session, participants focused on the following primary questions about modeling information gaps and resource needs:

- How do we get data? What are some possible data sources?
- What tools and resources are needed to build capacity?

- What are the key areas for future research?

Feedback provided by participants included the following:

How do we get data? What are some possible data sources?

- *Modelers as data collectors.* Participants discussed that MPO modeling teams are heavily data oriented and often serve as "data collectors." MPOs and councils of governments are primary places for data in a region; however, obtaining private sector data can be challenging and can vary depending on the company. One participant suggested developing data templates to distribute to cities and other stakeholders to help ensure data-sharing. Having data available to MPOs can help in planning for the long-term planning horizon of a region. Another participant discussed their agency's approach in using traditional data collection (e.g., information from the U.S. Census Bureau; traffic counts from cities and counties). A third shared that their MPO is interested in conducting a TNC driver survey to learn more about deadhead VMT.
- *Use of "passive" or "synthetic" data.* Participants debated the benefits and weaknesses of using "passive" or "synthetic" data that is aggregated from multiple public and commercial data sources. One benefit was the easy-to-use interface provided by companies offering these types of data products. However, participants raised that this information resource is derived or modeled data, not observed data. While such estimated data may be useful if the underlying travel behavior is consistent, we do not know how or if the estimated data will reflect and capture emerging changes. Participants agreed that there is no perfect data source. In the absence of having limited primary data on AVs, agencies may turn to using secondary, "synthetic" data sources; however, there is value in working to acquire primary data sources or sharing information across peer MPOs to identify commonalities and differences among data inputs and assumptions.

What tools and resources are needed to build capacity?

- *Importance of engaging others.* Engage other transportation professionals involved or interested in the AV topic, including planners, engineers, and decisionmakers. One participant raised whether a peer exchange with both the modeling and planning communities could be useful. Participants also cited the work of the Association of Metropolitan Planning Organization's Vehicle Connectivity and Automation Working Group and noted opportunities for future collaboration. The Working Group recently released its *National Framework for Regional Vehicle Connectivity and Automation Planning*. A "Phase 2" for the Working Group could include involving the entire transportation planning community on the topic and holding listening dialogues or other meetings to share information.
- *Access to ABMs.* One participant discussed their MPO's interest in updating its existing model to an ABM. The MPO is also considering whether an ABM will be the most appropriate model moving forward or whether additional events will need to be modeled with a next-generation model.
- *Knowledge of Big Data.* In addition to the challenges in obtaining private sector data, participants discussed that having enough staff to mine incoming Big Data flow is another challenge. MPO staff are increasingly expected to know programming and data collection, but retaining such staff can be difficult with such expertise in high demand elsewhere. One participant discussed that they did not feel their agency was capable to compete for these staff resources against others.

What are the key areas for future research?

- *Solid research support on the relationship between model parameters and model outputs.* One participant discussed that it is understood that the presence of AVs will impact model results, but how they will do so is unknown. There is interest in having research conclusions from other cities about the real behavior of AVs.
- *Data on AV influences on attitudes and travel behaviors.* Participants further discussed the need for data specific to how AV is changing how people consider travel. One participant suggested conducting a stated preference survey but noted that this type of survey still may not be ideal given that stated and revealed preferences are not typically the same. Another participant offered that MPOs could potentially conduct household travel surveys more regularly and add in questions that could be used to characterize attitudes or awareness on AVs. These questions could be developed collaboratively to serve as a kind of template for MPOs. Participants discussed that the household travel surveys could be used as a way to simulate the presence of AVs. One participant further raised that research conducted by the U.S. Department of Energy on AVs could potentially be another resource.
- *Continued information-sharing and development of resources on AV parameters and forecasting assumptions.* Participants emphasized the tremendous uncertainty about the potential impacts AVs will have on future transportation systems. Given this great uncertainty, they discussed the notion of "strength in numbers" by encouraging information-sharing among peer MPOs. For example, participants discussed commonalities or potential opportunities for commonalities found from AV testing in their communities. These commonalities could be used as a starting point for developing future resources around common AV parameters and forecasting assumptions that MPOs across the country are considering in their modeling approaches.

Conclusion

The FHWA-sponsored peer exchange hosted by MAG in June 2019 provided an opportunity to bring together peer MPOs that are actively pursuing AV modeling in the long-range transportation planning process. The peer exchange allowed these peers to ask questions, offer insights, and discuss their agencies' approach to addressing deep uncertainty and the many unknowns presented by the potential impacts of AVs on transportation systems.

Through their discussions, participants noted current challenges and opportunities for the future. In concluding the peer exchange, they expressed interest in continuing conversations on the AV modeling topic in other forums and with other interested parties. Overall, they noted the value of convening and the opportunity to meet both virtually and in person and share ideas. Participants voiced their enthusiasm for building on the momentum provided by this effort and identifying opportunities for future coordination and information-sharing.

Appendices

Appendix A: Key Contacts

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Appendix B: Event Participants

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Diane	Jacobs*	California Department of Transportation
Keith	Killough	Arizona Department of Transportation
Vladimir	Livshits	MAG
Arash	Mirzaei	NCTCOG
Karla	Petty	FHWA Arizona Division
Hannah	Rakoff*	U.S. DOT Volpe Center
Jeremy	Raw	FHWA Office of Planning
Scott	Smith*	U.S. DOT Volpe Center
Rachel	Strauss McBrien	U.S. DOT Volpe Center
Wu	Sun	SANDAG
Romare	Truely	FHWA Arizona Division
Toni	Whitfield	FHWA Arizona Division
Cheng	Yan	FHWA Office of Planning
Eileen	Yang	MARC

*Indicates remote participant

Appendix C: Peer Exchange Agenda

Thursday, June 27, 2019

TRANSPORTATION PLANNING CAPACITY BUILDING PROGRAM (TPCB)

Sponsored by the Federal Highway Administration (FHWA)

FHWA Automated Vehicle (AV) Modeling Peer Exchange

Dates: Thursday, June 27, 2019

Location: Maricopa Association of Governments
302 N 1st Avenue, Phoenix, AZ 85003
Saguaro Room (2nd Floor)

Instructions for Remote Participation: Conference Line: 877-336-1828; Passcode: 5582088#
Web Room Link: https://connectdot.connectsolutions.com/cvavmodeling/

Goals: To benchmark current practices among Metropolitan Planning Organization (MPO) technical modelers in modeling AV in the long-range transportation planning process and identify near-term actions to address existing challenges and knowledge gaps.

Thursday, June 27, 2019

Time	Session	Speaker(s)
8:00 – 8:30 am	**Check-in / Arrivals**	
8:30 – 8:45	**Opening Remarks and Introductions**	• **Jeremy Raw, P.E.** Community Planner, FHWA Office of Planning • **Karla Petty** Administrator, FHWA Arizona Division • **Eric Anderson** Executive Director, Maricopa Association of Governments (MAG)
8:45 – 9:00	**Overview of and Goals for Peer Exchange**	• **Jeremy Raw, P.E.** FHWA Office of Planning
9:00 – 9:45	**Report on Recent Events and Resources** • UC-Davis Workshop on AV Modeling • FHWA Peer Review on Robust Decision Making under Deep Uncertainty	• **Jeremy Raw, P.E.** FHWA Office of Planning • **Scott B. Smith, Ph.D.** Operations Research Analyst, Technology Innovation and Policy Division, U.S. DOT Volpe Center

Time	Session	Speaker(s)
	• TRB Planning Applications Conference • Available Modeling Resources	
9:45 – 10:00	***Break***	
10:00 – 11:30	***Benchmarking Current Practice:*** **Peer AV Modeling Activities** *What is the context in which you are doing modeling?*	• **Bruce Griesenbeck** Data and Analysis Manager, Sacramento Area Council of Governments (SACOG) • **Vladimir Livshits, Ph.D.** Director of Transportation Technologies and Services, MAG • **Wu Sun, Ph.D.** Principal Researcher and Modeler, San Diego Association of Governments (SANDAG) • **Eileen Yang** Transportation Modeling Manager, Mid-America Regional Council (MARC) • **Arash Mirzaei, P.E.** Transportation System Modeling Manager, North Central Texas Council of Governments (NCTCOG) Facilitated by: Fred Bowers, Community Planner, FHWA Office of Planning
11:30 am – 12:00 pm	***Full-Group Exercise:*** **Managing Risk and Uncertainty in Modeling** *What risk factors are you facing in your modeling approach?*	• **All Participants** Facilitated by: Rachel Strauss McBrien, AICP, Community Planner, U.S. DOT Volpe Center
12:00 – 12:45	***Lunch***	
12:45 – 1:45	***Small Group Discussions:*** **Managing Risk and Uncertainty in Modeling** *What are the "load-bearing" assumptions for your models?*	• **All Participants** Facilitated by: Fred Bowers (FHWA), Rachel Strauss McBrien, AICP (Volpe), and Scott Smith, Ph.D. (Volpe, for remote participants)
1:45 – 2:00	***Break***	
2:00 – 2:45	***Full-Group Discussion:*** **Communicating Model Results** *How do we communicate information to stakeholders?*	• **All Participants** Facilitated by: Jeremy Raw, P.E., FHWA Office of Planning
2:45 – 3:00	***Break***	

Time	Session	Speaker(s)
3:00 – 4:00	***Looking Forward:* AV Modeling Information Gaps and Resource Needs**	• **All Participants** Facilitated by: Cheng Yan, Transportation Specialist, FHWA Office of Planning
4:00 – 4:30	**Wrap-up and Next Steps**	• **Jeremy Raw, P.E.** FHWA Office of Planning
4:30 pm	**Adjourn**	

Appendix D: Risk Factors

During the *Managing Risk and Uncertainty in Modeling* discussion session, participants identified "uncertainty" factors in the modeling chain and the transportation planning process. The guiding question of this session was: *What risk factors are you facing in your modeling approach?*

The following lists the risk factors identified by peer exchange participants. This list is presented as-is based on notes shared by participants and does not reflect any priority or order. Content shared below may not reflect the opinions or policies of FHWA.

- Private data availability (What happens if they change their mind?)
- Freight AV penetration
- Assumptions about AV penetration rates
    - Current approach is biased by the proponents of AVs. This puts pressure on the conversation we are trying to have. Worry about this bias.
- Are "driverless" vehicles truly "driverless"? Security issue/responsibility
    - Assumptions about speed and capacity—how will these changes be reflected?
- Land use changes
    - How AV will affect land use patterns; interaction between land use and AV
    - Parking—what will happen to the market for paid parking? For required parking at shopping centers? There could be an opportunity to open up new infill development.
- Effect on long-term decisionmaking (home/work locations)
- Privacy
- Safety
- Network capacity
- Transit period when both vehicles (AV and "traditional" vehicles) are on the road
- How quickly will we have AVs?
- What is the difference between AV mode and traditional mode? How do we model?
- Value of in-vehicle travel time
- Car ownership
- Driving population—how will this population be different than today?
- What if model does not fit the situation on the ground? Under/over-estimate
- Technology keeping up with the complexity of the models?
- Funding support—will there be enough funding to pay for the extra effort?
- Costs of ride-hailing TNCs as opposed to other modes
- Supply side of shared ride modes
    - TNC side dynamic with demand
    - Long way to go in modeling supply side
- Current TNC use dominated by younger population—will this continue in the future?
- Conversation of "what is a mode?" is getting out ahead of modelers (e.g., is "e-bike" the same as a "bike"?) Previously, these were considered discrete models. This affects our ability to have a conversation about what we are doing.
- Economic assumptions (household income, fuel prices, land and housing prices, value of time, goods movement and logistics, etc.)
- Socioeconomic and land use assumptions (long-term choices); follows choice structure of our models—every choice has underlying assumptions

- Technology assumptions (penetration rates [including for EVs])
- Long-term choices (work location; ownership choices)
- Changes in socioeconomic activities; travel behaviors; mode choice; route choice (e.g., if you had AV, might take a different route)
- Policies/legal issues/insurance—huge uncertainty
- What comes first? Technology or policy?
- General changes in stakeholders/generational changes/social perceptions that could change behavior
- Regions are different. We need to account for this.
- Are we looking at actionable, measurable things we can measure now?
    - We need to look at the things we can do now.
    - Discrepancy between the way we are worrying about things and the actions we will take to respond to them
    - Are we measuring the right things? What is the path that leads today into the future?
- Leadership support (will direction change after a change in leadership?)
- Staffing at MPO level (staff turnover issues)
- Mode choices
- Social acceptance/public perception (could vary by gender, age, etc.)
- Work schedule (more telework)
- Parking/land use/freight movement
- Unknown travel behaviors
    - Perceived time
    - Joined travel
    - Parking behavior – change how you park
- Policies
    - Minimum age of person in AV
    - Insurance policies (discount fare to shared AV?)
    - Curb side management (how will these regulations work?)
- Technology
    - Highway capacity – how closely vehicles can travel together?
    - Speed
    - Travel time reliability
- Connections b/w AV and land use/long-term choices
- Trips / trip maker / transportation system
    - Trips – How non-work trips seem to be declining (e-commerce replacing trips; telework)
    - Trip maker – Youth travel; value of time in vehicles (need revealed preference data)
    - Transportation system – RTPs projecting into transition period; what are we dealing with? We don't know.
- Land use implications
    - Have tools available – should be using integrated models; scenario testing
- AV acceptance by the public (largely dependent on success/failure of AV companies)
- Unknown of private company data (whether new mode of transportation will arise)
- Policy changes (drones; delivery by drone; availability of 5G for transportation)
- Population heterogeneity

    - Aging population as mobility limited; evolution of these age groups and their acceptance of technology
    - ADA population
- Long-distance travel
    - Could explode with AVs; “weekend getaways”
- Cost and technology evolution
    - Questions of what technology will look like (operational aspects)
    - Cost of technology – buying; sharing
- Local government and land use – how they respond
- Congestion management in the form of routing
    - Could disrupt the models but also an opportunity
- Major data breach destroys confidence in shared vehicle use.
- Highly publicized crime makes pooled trips attractive.
- Risks related to assumptions of structural factors of how people make decisions related to travel
- Risks related to assumptions about how closer-in communities will respond if far-away exurbs become more attractive for living and how the far-away exurbs will respond to pressure for development
- Assumptions about the business model (and hence the cost structure for users) of AV services will not consider some model that develops on the market
- Move along chain (economic assumptions, LU assumptions, transportation assumptions, behavioral assumptions, etc.) – organize by category
- We don’t know about the costs. We know costs will change, but we don’t know to what. This will have a big implication.
- Cost + time (particularly perceived time with AVs; related to value of time)
- Cost – how we represent cost in the model itself challenging (we know costs vary as much as value of time varies)

Appendix E: Acronyms

2R	2 Revolutions
3R	3 Revolutions
ABM	Activity-Based Model
AV	Automated Vehicle
AZ-SMART	Arizona's Socioeconomic Modeling and Reporting Toolbox
C/AV	Connected/Automated Vehicle
DOT	Department of Transportation
DTA	Dynamic Traffic Assignment
FHWA	Federal Highway Administration
ISIM	Interpretative Structural Modeling
MAG	Maricopa Association of Governments
MARC	Mid-America Regional Council
MPO	Metropolitan Planning Organization
MTP	Metropolitan Transportation Plan
NCHRP	National Cooperative Highway Research Program
NCTCOG	North Central Texas Council of Governments
PCE	Passenger Car Equivalent
RDM	Robust Decisionmaking
RP	Regional Plan
RTP	Regional Transportation Plan
SACOG	Sacramento Area Council of Governments
SANDAG	San Diego Association of Governments
SCS	Sustainable Communities Strategy
SHRP2	Second Strategic Highway Research Program
TDM	Travel Demand Model
TMIP-EMAT	Travel Model Improvement Program-Exploratory Analysis and Modeling
TNC	Transportation Network Company

TPCB	Transportation Planning Capacity Building
TRB	Transportation Research Board
UC Davis	University of California, Davis
ZOV	Zero-Occupancy Vehicle