Beyond Scenario Planning –
The Role of Models with Deep Uncertainty

Exploratory Modeling and Analysis in Regional Transportation Planning

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Speakers:
Mark Bradley (RSG)
Howard Slavin (Caliper)
Dan Morgan (Caliper)
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– Presenters
  • Mark Bradley (RSG)
  • Howard Slavin (Caliper)

– Content Development, Review and Editing
  • Dan Morgan (Caliper)
  • Jim Lam (Caliper)
  • Qi Yang (Caliper)
  • Janet Choi (Caliper)
  • Ben Stabler (RSG)
  • Ben Swanson (RSG)
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  • Christine Sherman (RSG)
Disclaimer

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Agenda

• Presentation Objectives
• Defining an Exploratory Modeling and Analysis (EMA) Approach
• CV/AV Project Example:
  – Variables & Assumptions
  – Methods for Modeling
  – Adaptations
  – Scenarios
• Question & Answer, Discussion
Presentation Objectives

• Define “exploratory modeling and analysis” (EMA), and why it can be valuable in the context of “deep uncertainty”

• Compare different approaches to use under “deep uncertainty”, and explain why EMA was chosen for this research.

• Provide an example of how EMA can be used in the context of connected and autonomous vehicles and vehicle-sharing.

• Use the example to provoke discussion on how exploratory approaches can be used in practice in the current long-range planning context.
Defining Exploratory Modeling and Analysis (EMA)

EMA is a systematic approach to perform sensitivity analysis using models when many of the model inputs cannot be asserted with confidence, so that a wide range of different input assumptions can be tested simultaneously, looking for patterns in the results to guide robust decision-making (RDM).
A relevant quote:

“Travel demand forecasting as widely practiced today deals inadequately with uncertainty…The current transportation modeling process is demanding in the sense that it employs a great deal of data to a large number of interconnected models having many parameters. The complexity of the modeling process, however, does not extend to the accurate representation of complex economic and social phenomena, and point estimates of many quantities are used that make it difficult to analyze or even to represent the uncertainty that characterizes transportation systems and traveler decision making”

What is typically allowed to vary in long-term travel demand forecasts?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
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<tbody>
<tr>
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<td>Total regional population, employment, demographics</td>
</tr>
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</tr>
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Sometimes socio-demographic growth scenarios allow these to vary, but....
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… to model AV/CV and “sharing economy” scenarios, these have to be varied >>>> Many uncertain assumptions
Approaches that Allow for Uncertainty

- Scenario-based planning
- Assumption-based planning
- Quantitative risk analysis
- Exploratory modeling and analysis / Robust decision-making
Scenario-Based Planning

• Typically involves creation of a small number (4 or 5) of widely divergent scenarios, created via expert judgement/Delphi methods.

• The scenarios may differ along many assumptions and sources of uncertainty, but there are not enough scenarios to systematically analyze the scenario outcomes and implications as a function of those assumptions.

>>>>

• This can be a very useful first step toward framing key assumptions, sources of uncertainty, and possible futures, but..

• Can only provide limited guidance as to how different policy options may lead to (or prevent) those possible futures.
Assumption-Based Planning


An approach designed to identify:

• **Load-bearing assumptions** – uncertain inputs that are most critical in determining the outcomes;

• **Signposts** – explicit signals that may provide early warning of the vulnerability of load-bearing assumptions;

• **Shaping actions** – actions that attempt to control the vulnerability of load-bearing assumptions; and

• **Hedging actions** – actions that attempt to better prepare the organization for the potential failure of a load-bearing assumption.

The approach is qualitative in nature, so may not accommodate or provide the level of quantitative information that transportation planners are used to using in decision-making.
Quantitative Risk Analysis


| Select one or two key outputs (e.g. ridership and revenues) |
| Select a set of key input assumptions to vary, and levels to test. Inputs tend to focus on socio-demographic inputs and a few key model parameters (e.g. toll bias or new mode constants) |
| Use an experimental design to define a set of model runs to test effects of assumptions. Do the model runs and save the outputs. |
| Use regression analysis to model the key outputs as a function of the input assumption levels. |
| Define the joint probability distribution of the input assumption levels. |
| Apply the regression model to many, many sets of input assumptions, drawing each set randomly from the joint probability distribution, to create a probability distribution of the key model outputs. |

The approach is valuable for assessing risk over a wide range of possible future assumptions, but giving the probability distribution of input assumptions is not feasible under “deep uncertainty”. Is there a similar approach that deals with greater uncertainty?
Robust Decision-Making / Exploratory Modeling & Analysis


• Define the scope of the system to be analyzed.
• Define the key system relationships and sources of uncertainty.
• Define a method for modeling the system (interactions and inputs).
• Define a method for simultaneously varying the input assumptions to cover a wide range of future scenarios along the defined dimensions of uncertainty.
• Define the method for investigating and communicating the results of applying the model(s) across the wide range of scenarios.
CV/AV Example

Define the scope of the system to be analyzed.

- The transportation supply and demand in an urban metropolitan region over a 25-30 year time horizon. (The same as for an MPO long-range plan.)
CV/AV Example: Key Variables & Assumptions

CV/AV Variables Network Side:
- Dedicated lanes for CV/AV
- Following distance / platooning
- Vehicle operating speeds
- Traffic control systems
- Parking supply and location
- Operating characteristics of paid ride-share/vehicle-share services
- Priority for empty vehicle-trips on the network.
- Frequency/severity of accidents

CV/AV Variables Demand Side:
- Private CV/AV ownership
- Use of paid ride-share/vehicle-share services
- Disutility of in-vehicle time
- Changes in parking behavior
- Changes in intra-household vehicle sharing and coordination
- Generation of empty vehicle-trips
- Latent demand for car travel in currently congested areas
- Supply and service levels for transit
- Location/density of housing and employment
CV/AV Example: Define a Method for Modeling the System

• Adapted existing models for the Jacksonville, Florida region:
  – *DaySim* activity-based travel demand simulation
  – *TransModeler* dynamic traffic simulation
  – Feedback between the simulation models

• **Assumptions**
  – Detailed simulation models will facilitate a realistic representation of new aspects of AV/CV demand and supply for exploratory analysis
  – Relevant findings from these detailed models can be adapted for use with simpler (trip-based and static) models.
1. Trucks Trips from Port
2. EE trips
3. Build Highway Network
4. Truck and EII Trips
5. Build Transit Network
6. DaySim
7. Vehicle trips table (II, EI, EE, Truck trips)
8. Highway Assignment
9. Transit Assignment
TransModeler: Microscopic DTA

Microscopic in level of detail
- Referenced to ground truth with accurate geometry
- Lane level and intersection area representation
- Temporal dynamics (as low as 0.1-sec)
- 2-d and 3-d dynamic visualization

Microscopic in modeling accuracy
- Microscopic (car following, lane changing)
- Employs realistic route choice models
- Handles complex network infrastructure (Signals, variable message signs, sensors, etc.)
- Simulates multiple modes, user classes, vehicle types
Implementation: Jacksonville, FL

Region-wide, Six-county coverage
Implementation: Jacksonville, FL

Parcel-level activity location
Implementation: Jacksonville, FL

Major and local streets and centroid connectors
Implementation: Jacksonville, FL

Intersection geometry and signal timings
## Information Flows at Model Interfaces

### DaySim/NERPM to TransModeler

- A trip list (over 6 million daily trips), parcel-to-parcel, minute-to-minute
- Trip matrices for freight, externals, etc. Processed into compatible trip lists with more detailed times and locations

### TransModeler to DaySim

- Dynamic travel time skims, TAZ-TAZ, 30 minute periods, by user class (trucks, conventional cars, autonomous cars, etc.)
CV/AV Example:
Define a method for simultaneously varying the input assumptions to cover a wide range of future scenarios along the defined dimensions of uncertainty.

Phase 1.
- Demonstrate the approach, starting with an exploratory analysis of 6-8 demand scenarios in combination with 3-4 supply scenarios

Phase 2
- Eventually use a full experimental design with more dimensions of uncertainty, and more extensive analysis of the outcomes.
Example Experimental Design for 8 Scenario Runs

<table>
<thead>
<tr>
<th></th>
<th>AV ownership level</th>
<th>AV travel time disutility</th>
<th>Paid rideshare usage</th>
<th>AV speed &amp; headway advantage</th>
<th>AV-only lane provision</th>
<th>Smart intersection control</th>
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<tr>
<td>1</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
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<td>2</td>
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<td>High</td>
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<td>High</td>
</tr>
<tr>
<td>3</td>
<td>Low</td>
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<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
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<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
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<tr>
<td>7</td>
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<td>Low</td>
<td>High</td>
<td>High</td>
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<tr>
<td>8</td>
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<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
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## Example Experimental Design for 27 Scenario Runs

<table>
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<tr>
<th></th>
<th>AV ownership level</th>
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<tr>
<td>1</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>25</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>26</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>27</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
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CV/AV Example: Key Variables & Assumptions

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- Supply and service levels for transit
- Location/density of housing and employment
CV/AV Example:
Define the method for investigating and communicating the results of applying the models across the wide range of scenarios.

Network Side:
- Speeds, delays and effective capacities for CV/AV by class:
  - Conventional vehicles
  - Occupied CV / AV
  - Empty CV / AV
- Network maps and/or animations, by time of day
- Comparative graphics for key links under different types of scenarios

Demand Side:
- Vehicle ownership levels, trip-level mode shares, average trip distances, VMT and PMT for:
  - Conventional vehicles
  - Private CV / AV
  - Shared CV / AV
- Comparative graphics for different market segments under different types of scenarios
- Regression of outputs on inputs
Phase 1 – To be completed over the next few months

Objectives:
- To demonstrate the EMA approach for a limited range of scenarios and gain experience with using the approach
- To learn more about what is needed for sound ABM-DTA integration and simulation.

Approach:
- Develop and test integration of the DTA and ABM with the Jacksonville base year inputs
- Adapt the DTA and ABM models to incorporate specific assumptions regarding AV/CV and vehicle-sharing.
- Run combinations of 6-8 demand scenarios with 3-5 supply scenarios (20-40 runs in total).
- Communicate and explain the variation in simulation results across the scenarios, depicting the results in terms of changes in travel behavior on the demand side and changes in vehicle behavior and congestion on the network side.
Example Demand Scenario Characteristics

- These are assumed demand scenarios, not forecasts.

- These initial characteristics are illustrative, from running one iteration of the AB model with base year travel times and no feedback from DTA.
Phase 1: Demand Adaptations for AB Model

Assumptions for private auto type choice (CV / AV vs conventional)

- Alternative-specific constant affecting overall penetration rate
- Adoption rate is lower for households with older adults
- Adoption rate is higher for higher income households
- Adoption rate is higher for households with longer commute distances
- Households choosing AVs are less likely to own multiple vehicles
Percent of private vehicles that are AV's by AV scenario

Avg. vehicles/household by AV scenario
Auto ownership distribution by scenario

- **Base**
- **AV low / SH low**
- **AV medium / SH low**
- **AV high / SH low**

Legend:
- 0
- 1
- 2
- 3
- 4+
Percent of private vehicles that are AVs by age category of head of household

- AV low / SH low
- AV medium / SH low
- AV high / SH low

Percent of private vehicles that are AVs by household income category

- AV low / SH low
- AV medium / SH low
- AV high / SH low

- under $50k
- $50-100k
- over $100k
Percent of private vehicles that are AVs by total household commuting travel time per day

Percent of private vehicles that are AVs by land use density within buffer around residence

AV low / SH low  AV medium / SH AV high / SH low

no commuters  under 60 min  over 60 min

AV low / SH low  AV medium / SH low  AV high / SH low

under 300  300-1000  1000-2500  over 2500
Person-trip mode share by AV scenario

- **Base**
  - Walk: 10%
  - Bike: 5%
  - SOV: 30%
  - HOV 2: 20%
  - HOV 3+: 10%
  - Transit: 15%
  - School bus: 5%
  - Paid rideshare: 5%

- **AV low / SH low**
  - Walk: 15%
  - Bike: 5%
  - SOV: 30%
  - HOV 2: 20%
  - HOV 3+: 10%
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  - Bike: 5%
  - SOV: 30%
  - HOV 2: 20%
  - HOV 3+: 10%
  - Transit: 15%
  - School bus: 5%
  - Paid rideshare: 5%

- **AV high / SH low**
  - Walk: 25%
  - Bike: 5%
  - SOV: 30%
  - HOV 2: 20%
  - HOV 3+: 10%
  - Transit: 15%
  - School bus: 5%
  - Paid rideshare: 5%
Person-trip vehicle/passenger type share by AV scenario

- **Base**
- **AV low / SH low**
- **AV medium / SH low**
- **AV high / SH low**

Legend:
- conv driver
- conv passenger
- AV main pass
- AV other pass
- other modes
Phase 1: Demand Adaptations for AB Model

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Assumptions for usage of AV-based vehicle sharing services

• Mode-specific constant affecting overall mode shares
• Usage rate is highest for trips originating in denser areas (supply effect)
• Usage rate is higher for younger households
• Higher usage is associated with lower private ownership (“sharing economy”)


Percent of private vehicles that are AVs by SH scenario

Avg. vehicles/household by scenario
Person-trip mode share by SH scenario

- Base
- AV low / SH low
- AV low / SH medium
- AV low / SH high

- walk
- bike
- sov
- hov 2
- hov 3+
- transit
- school bus
- paid rideshare
Phase 1: Demand Adaptations for AB Model

Assumptions for private auto type choice (CV / AV vs conventional)
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Assumptions for lower disutility of AV in-vehicle time
- Travel time disutility per minute is lower in AVs, by a specified percentage
Percent of person-trips in AVs by scenario

AV low / SHAV low / SHAV low / SHAV medium / SH medium / SH medium / SH high / SH medium / SH high / SH high / SH high / VOT low

0% 5% 10% 15% 20% 25% 30% 35% 40% 45% 50% 55% 60% 65% 70% 75% 80% 85% 90% 95% 100%
Average distance per person-trip (miles) by scenario
Phase 1: Supply Adaptations for DTA Model

DTA
A traffic assignment in which routes taken are motivated by costs experienced as derived from a regional microsimulation.
Phase 1: Supply Adaptations for DTA Model
Phase 1: Supply Adaptations for DTA Model

ABM ⇔ DTA Integration
Phase 1: Supply Adaptations for DTA Model

Vehicle automation: Adoption of SAE International six levels of automation

<table>
<thead>
<tr>
<th>SAE level</th>
<th>Name</th>
<th>Narrative Definition</th>
<th>Execution of Steering and Acceleration/Deceleration</th>
<th>Monitoring of Driving Environment</th>
<th>Fallback Performance of Dynamic Driving Task</th>
<th>System Capability (Driving Modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>n/a</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>Human driver and system</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene</td>
<td>System</td>
<td>System</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
</tr>
</tbody>
</table>
Phase 1: Supply Adaptations for DTA Model
Phase 1: Supply Adaptations for DTA Model

https://www.sae.org/misc/pdfs/automated_driving.pdf
Phase 1: Supply Adaptations for DTA Model

Automated Acceleration/Deceleration OR Steering

No Change

https://www.sae.org/misc/pdfs/automated_driving.pdf
Phase 1: Supply Adaptations for DTA Model

Automated Acceleration/Deceleration AND Steering

Automated Acceleration/Deceleration OR Steering

No Change

Automated Driving System Monitors Driving Environment

Human Driver Monitors Driving Environment

No Automation  Driver Assistance  Partial Automation  Conditional Automation  High Automation  Full Automation

https://www.sae.org/misc/pdfs/automated_driving.pdf
Phase 1: Supply Adaptations for DTA Model

- No Change
- Automated Acceleration/Deceleration OR Steering
- Automated Acceleration/Deceleration AND Steering
- Level 2 + Speed Limit Adherence

https://www.sae.org/misc/pdfs/automated_driving.pdf
Phase 1: Supply Adaptations for DTA Model

• Other supply side strategies:
  – **Speed Harmonization**: dynamic vehicle speed adjustments to reduce speed differentials using vehicle-to-infrastructure (V2I) highway systems
  – **Cooperative Adaptive Cruise Control (CACC)**: allows vehicles to use tighter spacing on the roadway by using wireless connectivity
  – **Queue Warning (Q-WARN)**: providing warnings sufficiently upstream of developing congestion to allow drivers to brake or modify their routes before reaching the back of queue
  – **Exclusive AV Lanes/Facilities**: reserving lanes (or entire facilities) for AV vehicles only to optimize flow
Phase 1: Supply Adaptations for DTA Model

• Aspects of Driving Behavior Identified for Adaptation
  – Acceleration/deceleration
  – Car following headways
  – Choice of travel speed
  – Gap acceptance in lane changing

• Vehicle and Driving Behavior Assumptions
  – Removal of the random/human element from aspects controlled by the vehicle
  – Aspects deterministic, predictable, homogeneous
Phase 1: Example Supply Scenarios

- Base – Current Situation
- Varying levels of automation
  - Autonomous Automation: Levels 1-5
  - Cooperative (e.g., V2V, V2I) Automation (e.g., Speed Harmonization, CACC, Q-WARN)
- Facility/lane use privileges
  - AV operation of vehicle permitted on all facilities in all lanes
  - AV operation of vehicle permitted on select facilities in all lanes
  - AV operation of vehicle permitted on select lanes
Visualizations

Level 1 Automation

Vehicle Type
- ABM AV
- ABM Non-AV
- Other

0 50 100 150
Feet

Vehicles: 41,565
1,143
144,193
417,402
318
Visualizations

Level 1 Automation, Exclusive AV Lane
Phase 2 – Next Steps

• Additional adaptation and testing of DaySim and TransModeler code, particularly related to:
  – Parking supply and behavior (including empty trips)
  – Operation of shared vehicle services on the network (including dispatching and empty trips)
  – Adaptation of within-household schedule coordination to better utilize AVs (including generation of empty trips)
  – Treatment of empty vehicle-trips on the network

• New series of runs for EMA analysis
• In-depth exploratory analysis of outputs
• Final documentation, guidance, and presentations
Q&A

Discussion
## Demand scenario settings (for reference)

<table>
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<th>AV_IncludeAutoTypeChoice</th>
<th>FBB</th>
<th>FLL</th>
<th>FLM</th>
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<th>FML</th>
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<th>FMH</th>
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<th>FHH2</th>
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