Autonomous Vehicles and Transportation Technology: Planning for an Uncertain Future

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2017 Minnesota APA Conference
# Autonomous Vehicles

## The 5 levels of driving automation

<table>
<thead>
<tr>
<th>Level</th>
<th>Automation Type</th>
<th>Human Driver</th>
<th>Automated System</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>NO AUTOMATION</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>1</td>
<td>DRIVER ASSISTANCE</td>
<td>1</td>
<td>SOME DRIVING MODES</td>
</tr>
<tr>
<td>2</td>
<td>PARTIAL AUTOMATION</td>
<td>2</td>
<td>SOME DRIVING MODES</td>
</tr>
<tr>
<td>3</td>
<td>CONDITIONAL AUTOMATION</td>
<td>3</td>
<td>SOME DRIVING MODES</td>
</tr>
<tr>
<td>4</td>
<td>HIGH AUTOMATION</td>
<td>4</td>
<td>SOME DRIVING MODES</td>
</tr>
<tr>
<td>5</td>
<td>FULL AUTOMATION</td>
<td>5</td>
<td>SOME DRIVING MODES</td>
</tr>
</tbody>
</table>

Source: SAE International
Connected Vehicles and Infrastructure

By 2040, is estimated that 90 percent of light vehicles would be V2V (Vehicle to Vehicle)-equipped
(Source: USDOT)

Connected vehicle technology could potentially address approximately 80 percent of the crash scenarios involving non-impaired drivers.
(Source: USDOT)

By 2040, 80 percent of the intersections in the United States will be V2I (Vehicle to Infrastructure) capable
(Source: USDOT)

Source: planetm.com
Forecast replacement of cars by "transportation-as-a-service" in US

Source: US Department of Transportation, RethinkX
Traffic Safety Challenges with Full Automation

- Current traffic safety sets a high bar
  - 3.3 M vehicle hours between fatal crashes (375 years of non-stop 24/7 driving)
  - 65,000 vehicle hours between injury crashes (7+ years of non-stop 24/7 driving)

- New crashes due to automation will occur

- Automated systems must be no less safe (and possibly safer to gain public acceptance)

Source: California PATH
Automated Vehicle Symposium Themes and Trends

- V2V/V2I: broadcast road hazards
- Freight platooning
- Construction Work Zone Safety
- Car industry would like unified design standards – long-term endeavor
- If drivers don’t understand all of the traffic signs and standards, how do we expect machines to?
Lyft's redesigned street concept could fix L.A. traffic

Source: CNN Money
Unless we share them, self-driving vehicles will just make traffic worse

A carbon-free, autonomous car is still a car; it still takes up space.

Updated by David Roberts | @davroberts | davroberts@vox.com | May 18, 2017, 12:18pm EDT

- Personal AV will generate up to 35 percent more VMT than conventional personal cars. Those in a shared “fleet” model would generate less.
- AVs in a taxi model, carrying single passengers all the way to their destinations, would create 90 percent more VMT than typical taxies.
- Using those taxis as a connection to transit with multiple passengers, however, would only produce 6 percent more VMT.

Source: Urban Mobility study by the International Transit Forum and Corporate Partnership Board
Trading Spaces

70 people by Bus

70 people by Bike

70 people by Car
Trading Spaces?

space required to transport 60 people

car  uber  autonomous car
“one of the biggest problems for driverless cars”. They [Cyclists] confuse the vehicles... because at other times they behave like pedestrians, at other times like cyclists, and “they don’t respect any rules usually”.
Three Revolutions in Urban Transportation

Business-as-Usual Scenario
20th Century Technology
Through 2050, we continue to use vehicles with internal combustion engines at an increased rate, and use transit and shared vehicles at the current rate, as population and income grow over time.

2 Revolutions (2R) Scenario
Electrification + Automation
We embrace more technology. Electric vehicles become common by 2030, and automated electric vehicles become dominant by 2040. However, we continue our current embrace of single-occupancy vehicles, with even more car travel than in the BAU.

3 Revolutions (3R) Scenario
Electrification + Automation + Sharing
We take the embrace of technology in the 2R scenario and then maximize the use of shared vehicle trips. By 2030, there is widespread ride sharing, increased transit performance—with on-demand availability—and strengthened infrastructure for walking and cycling, allowing maximum energy efficiency.

Number of Vehicles on the Road by 2050
- Business-as-Usual Scenario: 2.1 billion
- 2 Revolutions (2R) Scenario: 2.1 billion
- 3 Revolutions (3R) Scenario: 0.5 billion

CO₂ Emissions by 2050
- Business-as-Usual Scenario: 4,600 megatonnes
- 2 Revolutions (2R) Scenario: 1,700 megatonnes
- 3 Revolutions (3R) Scenario: 700 megatonnes

www.itdp.org

ITDP UCDAVIS
How Can Planners Prepare?

- Start the Conversation
- Transportation Plans

**TREND ANALYSIS SUMMARY**

**TECHNOLOGY**

Autonomous Vehicles, Mobile Technology, Sensors, Monitors & Big Data, Electrification & Alternative Fuels, Unmanned Aircraft Systems

The intersection of technological innovation and transportation has peaked people's interests throughout history. From the Futurama exhibit depicting an interconnected network of expressways at the 1939 New York World's Fair to flying vehicles in The Jetsons, future visions of transportation draw people in and lead us to imagine how we might get from place to place beyond the means that we have today. Change in transportation technology is happening so quickly that it sometimes seems as though advances occur overnight. Planning a transportation system that can adapt to changing technologies is vital to ensure that Minnesota doesn't fall behind in the face of technological advances.

**Autonomous Vehicles**

Autonomous vehicles are one of the most rapidly emerging transportation technologies, and have the potential to significantly change the way people think about trips, vehicle ownership, and places of residence. Vehicles are classified into one of five levels of automation based on their features and capabilities:

<table>
<thead>
<tr>
<th>Type</th>
<th>Year*</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined-function automation</td>
<td>2017</td>
<td>Automation of at least two primary control functions that work in unison.</td>
</tr>
<tr>
<td>(ex. adaptive cruise control in combination with lane centering)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited self-driving automation</td>
<td>2020</td>
<td>These vehicles enable the driver to have full control of all safety-critical</td>
</tr>
<tr>
<td>(ex. lane-keeping assistance)</td>
<td></td>
<td>functions under certain conditions. The driver is expected to be available</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for occasional control.</td>
</tr>
<tr>
<td>Full self-driving automation</td>
<td>2025</td>
<td>The vehicle is designed to perform all safety critical driving functions and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>monitor roadway conditions for an entire trip.</td>
</tr>
</tbody>
</table>

**ROLLOUT**

Early versions of vehicles that fall between the combined-function automation and limited self-driving automation categories are anticipated to be available sometime in 2017. Tesla recently released a software update that included Autopilot features falling into the limited self-driving category.
How Can Planners Prepare? (cont.)

- Adaptive Land Use and Infrastructure
- Place Making
- Improve Multi-Modal Access
- Protect the Public Realm
How Can Planners Prepare? (cont.)

- Prepare for Smart Cities (fiber, conduit, connectivity, IOT)
- Parking and Shared Mobility Policies
- Build Relationships with Ride Share / Big Data Opportunities
Automated and Connected Vehicles: Planning for Uncertainty
PLANNING IMPLICATIONS

- We plan for 20 years (or more)
- We design for 50 years (or more)
  - Elon Musk is not waiting!
  - AVs mainstream by 2030?
DECISION MAKING CHALLENGE!

- More uncertainty than usual
- We are just learning the questions…but what are the answers?
  - Technical
  - Policy
- Traditional tools and methods may not be adequate
1. Florida Automated Vehicle Initiatives (Statewide, FL)
2. TransFuture (Orlando, FL)
3. Autonomous Vehicles & Shared Mobility (Jacksonville, FL)
4. FHWA Connected Vehicle Benefit/Cost (Washington, DC)
5. Transit Alternatives Analysis (Rochester, MN)
6. On-Demand Rideshare ATCMTD Grant (Arlington, TX)
7. Integrated Corridor ATCMTD Grant App. (Riverside, CA)
8. Interstate 80 Automated Corridors (Statewide, IA)
9. Innovation Corridor I-380 (Cedar Rapids, IA)
10. Technology Corridor Assessment (El Paso, TX)
12. ITS Strategic Plan Update (Bellevue Washington)
13. Downtown Mobility Study (Denver, CO)
14. Planning & Environmental Linkages I-25 (Denver, CO)
15. Autonomous and Connected Vehicles Support (Berea, OH)
16. Interstate 24 Smart Corridor (Nashville, TN)
17. iFlorida Turnpike Sunshine Highway Design (Orlando, FL)
18. ITS America Smart City Leadership Circle (Columbus, OH)
19. Interstate 80 Master Plan (Statewide, Wyoming)
01 TransFuture
Introducing TransFuture

• Next-generation scenario planning tool
• Prepare for multiple futures
• Explicitly account for uncertainty
• Support a desirable future by incorporating flexibility
• Add-on lens to improve decision-making
Planning for Multiple Futures

- Traditional planning for most likely future
- Considering multiple futures and uncertainties
- Acknowledging uncertainty

Composite Uncertainty Cone
Development Approach

- Identify Trends
- Quantify Trends
- Deterministic to Probabilistic
- Understand Uncertainties
- Make Informed Decisions
- Implementation Plan
### Emerging Trends

<table>
<thead>
<tr>
<th>Changing Demographics</th>
<th>Improved Technology</th>
<th>Shifting User Preferences</th>
<th>Improved Travel Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Millennial travel behavior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Aging population</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Generation Z</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Automated vehicles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Electric vehicles</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>• Workplace automation</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>• Improved user information &amp; navigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Smart City</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Urbanization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Shift from individual ownership to fleet ownership</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Telecommuting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• E-commerce &amp; delivery options</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Better walking and biking options</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Improved public transit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Shared mobility</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TREND: Automated Vehicle Adoption

What % market penetration is the tipping point?

Penetration Rate

2020 2025 2030 2035 2040 2045 2050 2055 2060

- Kockelman - Aggressive
- VTPI - Conservative
- VTPI - Aggressive
- Kockelman - Conservative
- Kockelman - Moderate
- Goldman Sachs

Goldman Sachs
TREND: Shared Mobility

- Reduction in auto ownership
- Potential increase in trips
- Fleet size reduction
TREND: Workforce Automation

- Jobs at risk for automation
- Transformation of the labor force
Conceptual Framework

Front End
• Regional travel demand model files
• Define scenarios

Process
• Probabilistic results and confidence intervals - AADT, VMT, VHT, etc.
• Scenario comparison
• Facility footprint

Input

Back End
• Regression analysis
• Elasticity analysis
• Monte Carlo Simulation

Output
Accounting for Uncertainty

\[ F = f(A, B, C, D, \ldots) \]

- Impact of Aging on Demand, %
- Impact of AV on Effective Capacity, %
- Impact of Telecommuting on Demand, %
- Impact of Enhanced Navigation, %

Jointly Determined Probabilities

- Joint probability distribution

2035 LOS

A strike zone is not a single point.
Hypothetical Freeway Corridor Analysis

Baseline Scenario

- 6-lane capacity
- 8-lane capacity
- 10-lane capacity

AADT

- 8 lane by 2045;
- 10 lane by 2056
Hypothetical Freeway Corridor Analysis

Build Scenario

- 6-lane capacity
- AADT

8 lane by 2048
02 I-80 Automated Corridors
I-80 Automated Corridor Study Goals

- Develop a range of expectations for future automated vehicle (AV) adoption
- Estimate AV benefits to traffic operations and safety on rural I-80
- Determine the impact of AV on I-80 system planning and design
Introducing automated vehicles reduces crashes

- Reductions near 70% of total crashes for 85% AV
- Crash rates (normalized for volume) also drop substantially

Safety Analysis Results
I-80 Predicted Crash Rates

Crash Reduction Factor due to AV

1. Early AV Adopters (25%)
2. Rise of the AVs (50%)
3. Limited AV Adopters (20%)
4. AV Domination (85%)

Serious Injury
Injury
Property Damage
Total
Traffic Analysis

- DOT Statewide travel model runs
  - 2040 4-lane I-80
  - 2040 6-lane I-80

- Research on AV impact to demand
  - Induced trips due to AV
  - Potentially longer trips as well
Interstate 80 Automated Vehicle Simulation
Automated Vehicles in Mixed Traffic with Human Drivers

- Dark Blue – AV Car
- Light Blue – AV Car in platoon
- Green – Manual Car
- Purple – AV Truck
- Yellow – Manual Truck
FUTURE PROOFING

• Don’t over build – cost savings
• Preserve ROW for potential future need
• Invest in technology – future proof investments
  • Cable, power, machine vision (reference markers), data management
DESIGN FOR UNCERTAINTY

• Modular lanes
  • Dynamic lane markings
  • Right pavement design
  • Full depth shoulder

• Technology roadmap
Thank you

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Planning for Autonomous Vehicles at the Regional Level

Daniel Peña
Metropolitan Council
Saint Paul, MN
Agenda

• Potential Impacts of Autonomous Vehicles on Regional Plans and Policy
• Current Efforts: Regional Autonomous Vehicle Travel Model
Anticipating AV Technology

• Widespread adoption of AV technology will lead to disruption in
  • The economy
  • Travel patterns

• Potential dramatic benefits
  • Improved safety
  • Improved mobility for non-automobile users

• Rapid growth in carsharing and ridesharing services indicate the potential disruption that lays ahead
Anticipating AV Technology

• Though the disruptions that AV technology will bring are likely to come, WHEN that will happen is unknown

• The rate of at which AV technology advances and penetrates the market will determine how plans and related investment policies are impacted

• As market penetration increases, decisions related to safety and mobility will change
## Timeline of AV Market Penetration

<table>
<thead>
<tr>
<th>Stage</th>
<th>Decade</th>
<th>Vehicle Sales</th>
<th>Vehicle Fleet</th>
<th>Vehicle Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large price premium</td>
<td>2020s</td>
<td>2-5%</td>
<td>1-2%</td>
<td>1-4%</td>
</tr>
<tr>
<td>Moderate price premium</td>
<td>2030s</td>
<td>20-40%</td>
<td>10-20%</td>
<td>10-30%</td>
</tr>
<tr>
<td>Minimal price premium</td>
<td>2040s</td>
<td>40-60%</td>
<td>20-40%</td>
<td>30-50%</td>
</tr>
<tr>
<td>Standard feature on most new vehicles</td>
<td>2050s</td>
<td>80-100%</td>
<td>40-60%</td>
<td>50-80%</td>
</tr>
<tr>
<td>Saturation (everybody who wants it has it)</td>
<td>2060s</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Required for all vehicles on road</td>
<td>?</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
AV Impacts on Regional Planning

• Unknown timeline for AV market penetration presents difficulties for long range forecasting
• New AV data will provide a much richer source of data for planning needs
  • Improved alternatives analyses
  • Better understanding of:
    • New land use
    • Transportation facility use
    • Socio-economic impacts of AV
• Long range analyses will need to begin to incorporate alternative land use and economic scenarios
AV Technology and Regional Planning

Timeline

• Short Term
  • Small scale pilot projects will need to be incorporated into the Transportation Improvement Plan

• Medium to Long Term
  • AV deployments will become a standard strategy
  • Large scale investments over multiple funding cycles
  • Data provided from AV technology will improve our ability to plan and evaluate
Autonomous Vehicle Model

• Met Council’s initial attempt to understand the impact of autonomous vehicles on regional travel patterns

• Initial model highlights:
  • Differences in travel patterns when vehicles are owned or shared
  • Trip patterns of vehicles with no passengers
  • Congestion impacts due to driverless trips

• All findings are preliminary; still developing the model
Autonomous Vehicle Model

• Modelling five scenarios for 2040
  • No Autonomous Vehicles
  • All Autonomous Vehicles, Shared
  • All Autonomous Vehicles, Privately Owned
  • All Autonomous Vehicles, Mixed Owned/Shared
  • Some Autonomous Vehicles, Mixed Owned/Shared

• Assumptions
  • No adjustment to auto availability
  • No adjustment to parking or auto operating costs
  • Based on current project travel patterns for 2040
  • No change in land use
AV Model – Vehicle Fleet and Trips

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Fleet</th>
<th>Driverless Trips</th>
<th>Occupied Vehicle Trips</th>
<th>Households</th>
<th>Fleet per Household</th>
<th>Occupied Trips/Household</th>
<th>Total Veh Trips/Household</th>
</tr>
</thead>
<tbody>
<tr>
<td>No AVs</td>
<td>2,550,465</td>
<td></td>
<td>11,174,158</td>
<td>1,754,873</td>
<td>1.5</td>
<td>6.368</td>
<td>6.37</td>
</tr>
<tr>
<td>Shared AVs</td>
<td>676,060</td>
<td>6,760,340</td>
<td>11,173,094</td>
<td>1,754,873</td>
<td>0.4</td>
<td>6.367</td>
<td>10.22</td>
</tr>
<tr>
<td>Owned AVs</td>
<td>1,809,850</td>
<td>6,676,792</td>
<td>11,189,417</td>
<td>1,754,873</td>
<td>1.0</td>
<td>6.376</td>
<td>10.18</td>
</tr>
</tbody>
</table>
AV Driverless Trips
AV Model – Number of Driverless Trips

Distribution of Autonomous Vehicles by Number of Daily Trips

Average Driverless trips/veh=10.0

Trips serving less dense land uses; privately owned vehicles more likely

Trips serving denser land uses; greater potential for shared vehicles
Shared Scenario – Driverless Trips

Driverless AV Trip Length Freq Distributions by time -- SHARED

Average Trip Length = 8.9 Minutes
Person Veh-Trip Avg Trip Length = 15.6 Minutes
Ownership Scenario – Driverless Trips

Driverless AV Trip Length Freq Distributions by time -- OWNERSHIP

Average Trip Length = 15.0 Minutes
Person Veh-Trip Avg Trip Length = 18.4 Minutes
## AV Model – Performance

<table>
<thead>
<tr>
<th>Scenario</th>
<th>VMT</th>
<th>Congested VMT*</th>
</tr>
</thead>
<tbody>
<tr>
<td>No AVs</td>
<td>121,000,000</td>
<td>21,139,000</td>
</tr>
<tr>
<td>Shared AVs</td>
<td>166,000,000</td>
<td>32,878,000</td>
</tr>
<tr>
<td>Owned AVs</td>
<td>175,000,000</td>
<td>62,539,000</td>
</tr>
</tbody>
</table>
AV Model – Level of Service

VMT by LOS

Volume/Capacity Ratio

NoAVs  SHARED  OWNERSHIP
AV Model – Hours of Congestion: No AVs, 2040
AV Model – Hours of Congestion: Shared Scenario, 2040
AV Model – Hours of Congestion: Ownership Scenario, 2040
AV Model Summary

• We should be aware of the unknown impacts that AV technology will have on VMT, congestion, fleet size, and the total amount of vehicle trips in the region

• A smaller number of autonomous vehicles may be needed to provide necessary trips in the region

• There may be a dramatic increase in overall trips as vehicles begin to make driverless trips

• VMT may increase with the introduction of AV

• The private ownership AV scenario showed a sharp increase in congested VMT

• Private AV ownership may make more sense in some locations than others
AV Model Next Steps

• Continue to refine model
• Introduce more nuanced scenarios that reflect mixed ownership/shared fleets
• Greater analysis of transit impacts?
• Incorporate changes to parking/operating costs?
• Analysis of changing land uses?
Conclusion

• Questions?
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  • Daniel.Pena@metc.state.mn.us
  • (651)602-1968