3 Dimensions of Connected & Automated Vehicles

Ray Starr
Minnesota DOT
December 12, 2016
for
Regional Council of Mayors

We all have a stake in A→B
3 Dimensions of CAV

V2I Connectivity

Driving Automation & Driver Assistance

V2V Connectivity
Level 5 Full Driving Automation

- Car performs all driving tasks
- All environments

Central Power & Light Co
Level 4 High Driving Automation

- Car performs all driving tasks
- Limited environments

Photo Source: NAVYA
Level 3 Conditional Driving Automation

- Car performs all driving tasks under some environments
- Graceful transition to human driver when out of automated environment

Photo Source: Wired.com
OTTO
Level 2 Partial Driving Automation

- Car controls longitudinal AND lateral movement
- Human must always monitor
- Possibly limited environments

Photo Source: caranddriver.com
Level 1 Driver Assistance

- Car controls longitudinal OR lateral movement
- Human must always monitor
- Possibly limited environments

Schema_ICC.PNG: M.Minderhoud derivative work: Malyszkz – This file was derived from Schema ICC.PNG
Level 0 No Driving Automation

- No sustained movement control
- Human must always monitor and control
Truck Platooning

- Trucks automatically follow lead truck
- Short headways
- Reduces fuel usage, emissions and costs
Driving Automation & Driver Assistance

Transportation Agencies Should:

- Consider regulatory issues
- Consider impacts on signs, markings, other traffic control devices
- Consider impacts on 20 year plans
V2V Connectivity

Driving Automation & Driver Assistance

V2I Connectivity

Autonomous

BSM Broadcast

Application Options

Pervasive Applications

V2V Connectivity
V2V Connectivity

Transportation Agencies Should:

- Stay informed
V2I Connectivity

V2V Connectivity

Driving Automation & Driver Assistance

Autonomous

Non-DSRC Consumer & Carry-In Devices

DSRC Agency-Controlled Vehicles

DSRC BSM Listening & Emulation

DSRC Cooperative Applications

V2I Connectivity
V2I Connectivity

Transportation Agencies Should:

- Work with vehicle manufacturers
- Use agency controlled vehicles
- Create business plan
Three Dimensions of Connected & Automated Vehicles

V2V Connectivity

Driving Automation & Driver Assistance

V2I Connectivity

Autonomous

Non-DSRC Consumer & Carry-In Devices

DSRC Agency-Controlled Vehicles

DSRC BSM Listening & Emulation

DSRC Cooperative Applications

Ray Starr
Minnesota Department of Transportation
Connected Automation

Autonomous Vehicle

Operates in isolation from other vehicles using internal sensors

Connected Vehicle

Communicates with nearby vehicles and infrastructure

Connected Automated Vehicle

Leverages autonomous and connected vehicle capabilities

U.S. Department of Transportation
ITS Joint Program Office
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PLANNING FOR AUTONOMOUS VEHICLES
Safety

- Autonomous vehicles do not get distracted / tired

- Potential reduction in traffic fatalities/serious injuries by several orders of magnitude
Capacity

- Safe drivers leave 1 car length per 10 MPH between cars
- Autonomous systems react faster, thus reducing safe following distance
- Could see theoretical freeway lane capacity double
Routing

- People drive 20% less direct than optimal
- Connected vehicles & on-the-fly route updates
Mobility for All

• Convenience of driving for those who can’t/don’t want to drive
Minnesota's Senior Population

Population

- 65+
- 75+

Year
- 2011
- 2019
- 2024
- 2029
- 2034
- 2039
- 2044
- 2049
- 2054
- 2059
- 2064

Population
- 1.4M
- 1.2M
- 1.0M
- 800K
- 600K
- 400K
- 200K

Minnesota Go
A Collaborative Vision for Transportation
Mobility for People with Disabilities

- Huge potential, but not a given
- Many user-interface and vehicle design questions
Ownership

“Telling the story of this chart will occupy the remainder of my professional life.”

- Adam Jonas, Morgan Stanley auto analyst
Parking

• Potential changes in parking demands largely driven by ownership models
  – Owned autonomy will likely not reduce parking dramatically
  – Shared autonomy could lead to massive reduction in required parking

• Potential new requirement: loading/un-loading zones
• Design new parking structures with other uses in mind
Transportation Cost

• Owned vehicle costs likely to increase in short term
• Operational costs likely lower
• Potential savings related to ownership
  – Shared autonomy would save money for people who travel less
  – Safety benefits may lower insurance rates
• Car2Go experience raises equity concerns
Residential Preferences

• “Up” and “Out” patterns of development
  – Movement into cities, drawn by amenities
    • More likely with greater vehicle sharing
  – Movement away from cities, due to ease of long-distance travel
    • More likely with owned autonomy
Congestion???

• Despite crash reductions, increased lane capacity and more direct routing, congestion impact remains uncertain

  – Increased willingness to travel longer distances
  – Empty vehicles
  – Not the only trend affecting peak period travel patterns
Thinking beyond the car

Autonomous trucks & truck platooning

“Ground drones”

Transit

• May be adopted by or replace para-transit/dial-a-ride
• Could displace low-ridership routes, but…
• Autonomous vehicles will not eliminate transit need
<table>
<thead>
<tr>
<th>Change</th>
<th>Conf.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>High</td>
<td>One of the most highly touted benefits of AVs</td>
</tr>
<tr>
<td>Lane Capacity</td>
<td>High</td>
<td>Shorter following distances likely increase capacity</td>
</tr>
<tr>
<td>Parking</td>
<td>Med</td>
<td>“Mobility as a Service” model may significantly reduce parking need</td>
</tr>
<tr>
<td>Road Design</td>
<td>Med</td>
<td>“Our philosophy has always been, it has to work with the existing infrastructure” – Chris Urmson, Google</td>
</tr>
<tr>
<td>Mobility for people with disabilities</td>
<td>Med</td>
<td>Likely significant improvement in service, but not a given and may not work well for all types of disability</td>
</tr>
<tr>
<td>Congestion</td>
<td>Low</td>
<td>Despite likely reduction in crashes and increased throughput, we could see dramatic increase in VMT</td>
</tr>
<tr>
<td>Timeline</td>
<td>Low</td>
<td>Exact timeline for adoption remains unclear – “inflection point” likely mid-to-late 2020s.</td>
</tr>
<tr>
<td>Vehicle Ownership</td>
<td>Low</td>
<td>Uber/Lyft vs. Tesla Models – likely some combination of both</td>
</tr>
<tr>
<td>Residential Preference</td>
<td>Low</td>
<td>Vehicle ownership model will likely have large impact on where people will choose to live – <strong>both</strong> “Up” and “Out” scenarios plausible</td>
</tr>
</tbody>
</table>
CAUTION
TRANSITION AHEAD
Experience with Airline Industry Raises Human Factors Concerns for levels 2 & 3
First generation may not handle WINTER well
Autonomous Vehicle Adoption

- Early versions on market
- Self-driving tech required for some cars
- SMTP/MnSHIP Horizon
- Self-driving tech required for all cars
- Danger zone: Intermediate tech

*forecast by University of Minnesota Researchers

Year 10

Next Plan update
When should we design for AVs?

• Every bridge we build today will have AVs use it
  …but there will be many non-AVs too

• And we don’t know exactly when the majority of vehicles will be AV nor exactly how they will function in the real world
Current Approach

• Study and pursue targeted pilot projects
• Wait until 3-5% of on-road vehicles are Level 3+ AV before adjusting road design
• Continue flexible and performance-based design efforts
Contact Information

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LEGAL AND INSURANCE ISSUES
Bryant Walker Smith, Automated Vehicles are Probably Legal in the United States

Not explicitly prohibited equals probably permitted
Self-Driving Cars are Probably Legal . . . .

National Traffic and Motor Vehicle Safety Act (1966)
• Creates NHTSA
• Authorizes Motor Vehicle Safety Standards

Feb. 4, 2016 letter to Google
• NHTSA equates “self-driving System” to Driver
Federal Automated Vehicle Policy (9/20/2016)

• Vehicle Performance Guidance for Automated Vehicles
  – 15 point Safety Assessment

• Model State Policy
  – Clear distinction between Federal and State responsibilities for regulation

• Current Regulatory Tools
  – Outline Current regulations that can be used to safe development.

• Modern Regulatory Tools
  – Identify potential new regulatory tools that may aid the deployment
<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></td>
<td>Automated driving system (&quot;system&quot;) monitors the driving environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></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>

Copyright © 2014 SAE International. The summary table may be freely copied and distributed provided SAE International and J3016 are acknowledged as the source and must be reproduced AS-IS.
Self-Driving Cars are Probably Legal . . . .

• States with laws allowing testing:
  – Nevada, California, Florida and Michigan (also District of Columbia)

• Complications in CA
  – Regs prohibit Level 5 vehicles

• Complications in MI
  – Law as passed prohibited
  – Required new legislation
In 2016
Self-Driving Cars are Probably Legal . . . .

- States where testing is occurring without legislation
  - Texas
  - Pennsylvania
  - Arizona
  - New Jersey
  - Washington
  - . . .
Self-Driving Cars are Probably Legal . . . .

- Trucks are operating without Legislation too
  - Colorado, I-25, October 2016
  - Ohio, Route 33, November 2016

SO WHAT IF SOMETHING DOES GO WRONG?

For example, at levels 1 – 3, (or 4?)
“Danger Zone” . . .
Current “Products Liability”

• If Caused Only by Defect in Manufacture, Design, Warning, Instructions—The OEM and Others in the Chain.

• Move OEMs from Current 2% responsibility to 80%-100% responsibility?
  – Defect in Manufacturer—Does not Meet OEM’s Design Specs.
  – Warnings and Instructions—Absence of Warning, Over Promotion, Ineffective Manuals.
  – Duty to Update
  – Foreseeable Use/Misuse—Tesla Backseat Drivers!

• BUT . . . Google, Mercedes, Volvo already on the record as accepting all liability
“Mobility for All”
- Americans with Disabilities Act
- Olmstead Plan
  - People with disabilities will have access to reliable, cost-effective, and accessible transportation choices that support the essential elements of life such as employment, housing, education, and social connections. They will have increased access to transit options and transportation modes.
  - 50% increase in Greater MN Transit trips by 2025 (Goal 2)
  - Expand transit coverage so that 90% of the public transportation service areas in Minnesota meet minimum service guidelines for access by 2020 (Goal 3)
- Legal Requirement to Allow Automated Vehicles???
A couple additional sources . . . .


• Any thoughts or questions?

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• Adeel Lari
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• Kory Andersen
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**Arrival of the “mass market” EV**

<table>
<thead>
<tr>
<th><strong>Chevy Bolt EV</strong></th>
<th><strong>Tesla Model 3</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• 238 miles of range per charge</td>
<td>• 215 miles of range per charge</td>
</tr>
<tr>
<td>• Starting at $37,495 ($29,995 after federal tax credit)</td>
<td>• Starting at $35,000 ($27,500 after federal tax credit)</td>
</tr>
<tr>
<td>• Currently under production at Orion Assembly Plant in Michigan</td>
<td>• Starting production in mid-2017</td>
</tr>
<tr>
<td></td>
<td>• 325,000 pre-orders in one week, over 400,000 total pre-orders</td>
</tr>
</tbody>
</table>
Rapid growth projected in EV market

- EVs to be 35% of global new car sales by 2040.
- During 2020s, EVs will be a more economic option than gasoline cars, *without a tax credit*.
- Lithium-ion battery costs dropped 64% since 2010, falling further in the future.

» Bloomberg New Energy Finance
EVs are already the cheapest and cleanest

- Out of 125 vehicle models on the road today, plug-in hybrid and battery electric vehicles are most often cheaper than their fossil fuel counterparts over the lifetime of the automobile. They also offer the lowest GHG emissions.

MIT
EVs are already the cheapest and cleanest
Volkswagen settlement – opportunity for progress in MN

- $2 billion for U.S.
- Run by VW
- Eligible activities:
  - Charging stations
  - Education and outreach

- $43 million for MN
- Run by MPCA
- Eligible activities:
  - Charging stations
  - EV vehicles (transit buses, school buses, trucks, shuttle buses, etc)
EVs and Cities – fleet vehicles

MN Dept of Admin Commitment:
- Acquire 25 PEV/ZEVs in 2017
- Install 15 level 2 charging stations in FY 2017
- Require all new vehicles to have EPA ratings of 7 or higher
- Achieve a fleet composition of 20% PEV or ZEV by 2027

POSSIBLE ROLE FOR CITIES:
- Collaborate w/ MN Dept of Admin on joint discount “bulk buy”.
- Adopt similar fleet commitments
- Be part of a State of MN “Zero Emission Fleet Challenge”
Volkswagen Settlement can help support adoption of electric vehicles in various categories:

- Replace **Class 8 truck** with EV truck
- Replace **Class 4-7 Medium truck** with EV truck
- Replace **Class 4-8 School Bus, Shuttle Bus, or Transit Bus** with EV bus

Other categories:
- Freight switchers
- Ferries/tugs
- Ocean going vessel shorepower
- Airport ground support equipment
- Forklifts

Minnesota has $43 million to support these activities, available over 10 years.
EVs and Cities – Charging Infrastructure

• Volkswagen settlement can support installation of Light Duty Vehicle charging equipment (up to 15% of $43,000,000 allocated to MN)
  • They want to see evidence that chargers will be used (combine charging strategy w/ EV adoption strategy)

• Does your city have an EV Charging Plan?
  • Workplace charging
  • Multi-family buildings
  • Public charging
  • City-owned facilities
  • DC Fast Charger Corridors
EVs and Cities - Building codes

- Create “EV Ready” Multi-family, Workplace, Business.
- Inexpensive to add conduit up front to parking ramps and parking lots, very expensive to retrofit.
EVs and Cities – Outreach and Education

Possible activities:
• Ride-and-drive events
• EV displays at city festivals
EVs and Autonomous Vehicles

• If autonomous vehicles are EV:
  • They will have lower lifecycle emissions and zero tailpipe emissions, enhancing the impact
  • They will help justify investments in EV charging infrastructure through greater utilization.
  • They will increase deployment and manufacturing of EV batteries, resulting in continued cost decreases.
  • EVs are higher upfront-cost, lower lifecycle cost – the more you drive, the cheaper they are. Clear advantage for shared AV fleets.
Shared Autonomous Vehicles and Land Use

Thomas Fisher
Minnesota Design Center
University of Minnesota
Parking
Phase 1: 2018-2025
Garage adapts to autonomous vehicles.

Today, the typical car is used only 5% of the time. (95% of the time it is parked in a garage, at a house, or on the street.) However, by the time today’s garages are built, self-parking cars and shared fleets will likely be a reality.

Driverless vehicle storage is packed in hyper-efficient rows on the top level. Garages designed for autonomous or self-parking vehicles can substantially increase their efficiency and use 60% less space.

Floor-to-floor heights are designed to accommodate future uses such as residential or office.

Conventional parking on lower levels for increased accessibility.

By 2025, fully autonomous cars are expected to be available to the general public for an additional $10,000.

Source: Boston Consulting Group
Phase 2: 2025-2035
Building adapts to fully autonomous vehicles and new uses.

As car ownership evolves to a subscription service with intelligent fleets, there will be less need for parking. Garages are transformed into other uses, such as offices, residential, and hotels.

In 2035, the need for parking is estimated to decline by more than 5.7 billion square meters in the United States. (This equates to half the size of Connecticut) Source: The McKinsey & Co.

Upper levels evolve into residential, office, recreation and entertainment spaces.

Buildings adapt to accept packages from drones, eliminating loading docks and need for delivery vehicles.

Vehicles automatically charge when not being driven.

Users call cars via personal mobile devices and pick up vehicles in retrieval zones.
Streets
Land Use