Road Vehicle Automation: Challenges and Opportunities

Steven E. Shladover, Sc.D.
California PATH Program
University of California, Berkeley
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Outline

• Diverse types of vehicle automation, with very different capabilities
• Potential transportation impacts of each type of automation
• Timing for automation market introduction and growth
• Example unresolved questions
• Near-term opportunities
Diversity of Vehicle Automation

- Automated driving systems classified according to:
  - Levels of automation (division of roles between humans and system)
  - Operational Design Domain (ODD)
  - Architecture (autonomous/unconnected vs. connected)
Operational Design Domain (ODD)

• The specific conditions under which a given driving automation system is designed to function, including, ...
  – Roadway type
  – Traffic conditions and speed range
  – Geographic location (boundaries)
  – Weather and lighting conditions
  – Availability of necessary supporting infrastructure features
  – Condition of pavement markings and signage
  – (and more…)
Levels of Automation
(SAE J3016 - http://standards.sae.org/j3016_201609/)

*Driving automation systems* are categorized into levels based on:

1. Whether the driving automation system performs *either* longitudinal or lateral vehicle motion control.
2. Whether the driving automation system performs *both* the longitudinal and lateral vehicle motion control simultaneously.
3. Whether the driving automation system *also* performs object and event detection and response.
4. Whether the driving automation system *also* performs *fallback* (recovery from failures).
5. Whether the driving automation system is limited by an ODD.
## Example Systems at Each Automation Level

<table>
<thead>
<tr>
<th>Level</th>
<th>Example Systems</th>
<th>Driver Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adaptive Cruise Control OR Lane Keeping Assistance</td>
<td>Must drive other function and monitor driving environment</td>
</tr>
<tr>
<td>2</td>
<td>Adaptive Cruise Control AND Lane Keeping Assistance Traffic Jam Assist (Mercedes, Tesla, Infiniti, Volvo...) Parking with external supervision</td>
<td>Must monitor driving environment (system nags driver to try to ensure it)</td>
</tr>
<tr>
<td>3</td>
<td>Traffic Jam Pilot</td>
<td>May read a book, text, or web surf, but be prepared to intervene when needed</td>
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<tr>
<td>4</td>
<td>Highway driving pilot Closed campus “driverless” shuttle “Driverless” valet parking in garage</td>
<td>May sleep, and system can revert to minimum risk condition if needed</td>
</tr>
<tr>
<td>5</td>
<td>Ubiquitous automated taxi Ubiquitous car-share repositioning</td>
<td>No drivers needed</td>
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</tbody>
</table>
No Automation and Driver Assistance (Levels 0, 1)

- Primary safety advancements likely at these levels, adding machine vigilance to driver vigilance
  - Safety warnings based on ranging sensors
  - Automation of one function facilitating driver focus on other functions
- Driving comfort and convenience from assistance systems (ACC)
- Traffic, energy, environmental benefits depend on cooperation
- Widely available on cars and trucks now
Partial Automation (Level 2) Impacts

- Probably only on limited-access highways
- Somewhat increased driving comfort and convenience (but driver still needs to be actively engaged)
- Possible safety increase, depending on effectiveness of driver engagement
  - Safety concerns if driver tunes out
- (only if cooperative) Increases in energy efficiency and traffic throughput
- When? Now (Mercedes, Tesla, Infiniti, Volvo...)
Intentional Mis-Uses of Level 2 Systems

Mercedes S-Class

Infiniti Q50

Let's see how well the Active Lane Control works on the new Infiniti Q50S
Conditional Automation (Level 3) Impacts

- Driving comfort and convenience increase
  - Driver can do other things while driving, so disutility of travel time is reduced
  - Limited by requirement to be able to re-take control of vehicle in a few seconds when alerted

- Safety uncertain, depending on ability to re-take control in emergency conditions

- (only if cooperative) Increases in efficiency and traffic throughput

- When? Audi planning first product introduction this year.
High Automation (Level 4) Impacts – General-purpose light duty vehicles

• Only usable in some places (limited access highways, maybe only in managed lanes)
• Large gain in driving comfort and convenience on available parts of trip (driver can sleep)
  – Significantly reduced value of time
• Safety improvement, based on automatic transition to minimal risk condition
• (only if cooperative) Significant increases in energy efficiency and traffic throughput from close-coupled platooning
• When? Starting 2020 – 2025?
High Automation (Level 4) Impacts – Special applications

• Buses on separate transitways
  – Narrow right of way – easier to fit in corridors
  – Rail-like quality of service at lower cost

• Heavy trucks on dedicated truck lanes
  – (cooperative) Platooning for energy and emission savings, higher capacity

• Automated (driverless) valet parking
  – More compact parking garages

• Driverless shuttles within campuses or pedestrian zones
  – Facilitating new urban designs

• When? Could be just a few years away
Vehicle-Infrastructure Protection for L4 Shuttle Vehicle – La Rochelle, France
Full Automation (Level 5) Impacts

• Electronic taxi service for mobility-challenged travelers (young, old, impaired)
• Shared vehicle fleet repositioning (driverless)
• Driverless urban goods pickup and delivery
• Full “electronic chauffeur” service

• Ultimate comfort and convenience
  – Travel time won’t discourage longer trips
• (if cooperative) Large energy efficiency and road capacity gains
• When? Many decades… (Ubiquitous operation without driver is a huge technical challenge)
Heavy Truck Automation - Platooning

• Likely early adopters of CAV technology based on strong return on investment
  – Energy cost savings as initial motivation for long-haul trucking (L1, L2 automation)
  – Changes in driving responsibilities (L3, L4)
• Significantly reducing traffic impacts of trucks
• Dedicated truck lanes could facilitate higher levels of automation by simplifying driving environment and enhancing safety (L4)
• Potential losses of truck driving jobs - decades away
  – Non-driving responsibilities of drivers
  – Safety assurance challenges for automation
# Personal Estimates of Market Introductions

**based on technological feasibility**

<table>
<thead>
<tr>
<th>Everywhere</th>
<th>Level 1 (ACC)</th>
<th>Level 2 (ACC+ LKA)</th>
<th>Level 3 Conditional Automation</th>
<th>Level 4 High Automation</th>
<th>Level 5 Full Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some urban streets</td>
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<td></td>
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<tr>
<td>Campus or pedestrian zone</td>
<td></td>
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<tr>
<td>Limited-access highway</td>
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<td></td>
<td></td>
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<tr>
<td>Fully Segregated Guideway</td>
<td></td>
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</tbody>
</table>

**Color Key:**
- **Now**
- ~2020s
- ~2025s
- ~2030s
- ~2075

+ add decades to turn over vehicle fleet!
Fundamental Safety Challenge

• Current traffic safety sets a very high bar:
  – 3.4 M vehicle hours between fatal crashes (390 years of non-stop 24/7 driving)
  – 61,400 vehicle hours between injury crashes (7 years of non-stop 24/7 driving)

• Automated systems must be no less safe than this (and probably safer to gain public acceptance)
  – How to design an automated vehicle to be this safe?
  – How to demonstrate that this level of safety has been achieved?
Traffic Safety Challenges for High and Full Automation

• Extreme external conditions arising without advance warning (failure of another vehicle, dropped load, lightning, …)

• NEW CRASHES caused by automation:
  – Strange circumstances the system designer could not anticipate
  – Software bugs not exercised in testing
  – Undiagnosed faults in the vehicle
  – Catastrophic failures of vital vehicle systems (loss of electrical power, …)

• Driver not available to provide fallback
Why this is a super-hard problem

- Software intensive system (no technology available to verify or validate its safety under its full range of operating conditions)
- Electro-mechanical elements don’t benefit from Moore’s Law improvements  
  - Cannot afford extensive hardware redundancy for protection from failures
- Harsh and unpredictable hazard environment
- Non-professional vehicle owners and operators cannot ensure proper maintenance and training
## Much Harder than Commercial Aircraft Autopilot Automation

<table>
<thead>
<tr>
<th>Measure of Difficulty – Orders of Magnitude</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of targets each vehicle needs to track (~10)</td>
<td>1</td>
</tr>
<tr>
<td>Number of vehicles the region needs to monitor (~10^6)</td>
<td>4</td>
</tr>
<tr>
<td>Accuracy of range measurements needed to each target (~10 cm)</td>
<td>3</td>
</tr>
<tr>
<td>Accuracy of speed difference measurements needed to each target (~1 m/s)</td>
<td>1</td>
</tr>
<tr>
<td>Time available to respond to an emergency while cruising (~0.1 s)</td>
<td>2</td>
</tr>
<tr>
<td>Acceptable cost to equip each vehicle (~$3000)</td>
<td>3</td>
</tr>
<tr>
<td>Annual production volume of automation systems (~10^6)</td>
<td>-4</td>
</tr>
<tr>
<td>Sum total of orders of magnitude</td>
<td>10</td>
</tr>
</tbody>
</table>
Main Unresolved Questions (1/2)

• How safe is “safe enough”? 
• How can an AV be reliably determined to meet any specific target safety level?
• What roles should national and regional/state governments play in determining whether a specific AV is “safe enough” for public use?
• Should AVs be required to inhibit abuse and misuse by users?
• How long will it take to achieve the fundamental technological breakthroughs needed for higher levels of automation?
Main Unresolved Questions (2/2)

- How much support and cooperation do AVs need from roadway infrastructure and other vehicles?
- What should the public sector role be in providing infrastructure support?
- Are new public-private business models needed for higher levels of automation?
- How will shared-ride AVs change public transport services and VMT, energy and environmental impacts? What are the relative contributions of:
  - Automation?
  - Shared occupancy of vehicles?
  - Electric propulsion?
Opportunities for Early Wins (1/2)

- Deploy wireless communication infrastructure to support I2V/V2I cooperation at intersections, freeway interchanges
  - Collision warnings to enhance safety (L0)
  - Speed harmonization, eco-driving speed profiles and cooperative ACC to enhance traffic flow and efficiency (L1)
- Encourage use of managed lanes as testbeds and early deployment sites for connected automation systems (starting with L1 cooperative adaptive cruise control)
  - Significant traffic flow improvements as market penetration grows in those lanes
Opportunities for Early Wins (2/2)

• Heavy truck CACC and platooning to cluster trucks in high-volume corridors (L1, then L2, eventually L4)
  – Reduce traffic congestion impacts
  – Save significant energy
• Low-speed automated shuttle vehicles for niche applications (L4)
  – Closed campuses (university or industrial)
  – Retirement and resort communities
  – Commercial activity centers
  – Pedestrian malls or zones
  – Feeder services to line-haul transit