Road Vehicle Automation: Challenges and Opportunities

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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.
<table>
<thead>
<tr>
<th>Level</th>
<th>Example Systems</th>
<th>Driver Roles</th>
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<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</td>
<td>Must monitor driving environment (system nags driver to try to ensure it)</td>
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<td></td>
<td>Traffic Jam Assist (Mercedes, Tesla, Infiniti, Volvo…)</td>
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<td></td>
<td>Parking with external supervision</td>
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<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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<td>4</td>
<td>Highway driving pilot</td>
<td>May sleep, and system can revert to minimum risk condition if needed</td>
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<td></td>
<td>Closed campus “driverless” shuttle</td>
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<td></td>
<td>“Driverless” valet parking in garage</td>
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<tr>
<td>5</td>
<td>Ubiquitous automated taxi</td>
<td>No drivers needed</td>
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<tr>
<td></td>
<td>Ubiquitous car-share repositioning</td>
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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>Location</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>
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<tbody>
<tr>
<td>Everywhere</td>
<td><strong>Now</strong></td>
<td>~2020s</td>
<td>~2025s</td>
<td>~2030s</td>
<td>~2075</td>
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<tr>
<td>Some urban streets</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Campus or pedestrian zone</td>
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<tr>
<td>Limited-access highway</td>
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<tr>
<td>Fully Segregated Guideway</td>
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+ 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>
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<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 (~10⁶)</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 (~10⁶)</td>
<td>- 4</td>
</tr>
<tr>
<td>Sum total of orders of magnitude</td>
<td>10</td>
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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