Road Vehicle Automation: Diverse Opportunities and Challenges

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Automation Is a Tool for Solving Transportation Problems

- Alleviating congestion
  - Increase capacity of roadway infrastructure
  - Improve traffic flow smoothness
- Reducing energy use and emissions
  - Improve traffic flow smoothness
  - Aerodynamic “drafting”
- Improving safety
  - Reduce and mitigate crashes

...BUT the vehicles need to be ‘connected’ to gain these benefits
Autonomous and Cooperative ITS

Autonomous ITS (Unconnected) Systems

Cooperative ITS (Connected Vehicle) Systems

Automated Driving Systems
Diversity of Automation Concepts

• Goals to be served by the automation system
  – Comfort/convenience, congestion relief, travel time saving, energy and environment, safety…

• Roles of driver and automation system
  – Levels of automation

• Complexity of operational design domain
  – Degree of segregation from other road users
  – Traffic complexity (speed, density, mix of users)
  – Weather and lighting conditions
  – Availability of I2V, V2V data
  – Standardization of signage and pavement markings
# SAE J3016 Definitions – Levels of Automation

<table>
<thead>
<tr>
<th>SAE Level</th>
<th>Name</th>
<th>Narrative Definition</th>
<th>Execution of Steering/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></td>
<td><strong>Automated driving system (&quot;system&quot;) monitors the driving environment</strong></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>
## 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, Volvo, Infiniti)</td>
<td>Must continuously monitor driving environment (system nags driver to try to ensure it)</td>
</tr>
<tr>
<td>3</td>
<td>Traffic Jam Pilot Automated parking with supervision</td>
<td>May read a book, text, or web surf, but be prepared to intervene when needed</td>
</tr>
<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>Automated taxi (even for children) Car-share repositioning system Drives anywhere people can drive</td>
<td>No driver needed</td>
</tr>
</tbody>
</table>
Improving Safety

- Current U.S. traffic safety sets a very 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)

- How much safer does an automated system need to be? (2X? 5X? 10X?)
- How do you determine that the automated system has reached its safety goal?
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 and V2V/V2I communicated information
  – 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, Infiniti, Volvo)
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? Unclear – safety concerns could impede introduction
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) – 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
  - First mile/last mile access to line-haul transit
- When? Could be just a few years away
Full Automation (Level 5)

- 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

- Many decades away because ubiquitous operation without driver poses huge technical challenges
### Personal Estimates of Market Introductions

**based on technological feasibility**

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

**Color Key:**
- **Now**: Green
- **~2020s**: Yellow
- **~2025s**: Orange
- **~2030s**: Brown
- **~2075**: Red

*Personal Estimates of Market Introductions based on technological feasibility*
Why will Level 5 take so long?

- Impossibility of specifying and designing for all hazards the vehicle will encounter
  - Other road users, environmental conditions, internal fault conditions…
- No viable methods exist to develop and verify complex safety-critical software making life-or-death decisions
- Sensor signal processing to achieve near-zero false negatives and false positives
  - Distinguishing genuine hazards from benign objects
Fundamental Challenges in Defining Automation Regulations

- Balancing need to protect public safety with desire to encourage technological innovation
- Automation blurs the traditional boundary between federal responsibility for regulating new vehicle equipment and state responsibility for regulating how vehicles are operated in U.S.
- Lack of technical standards to provide baseline references for performance, safety or testing protocols or procedures
- Lack of national standards and diversity of state approaches
- Cultural differences between automotive and information technology industries
- Self-certification vs. third-party certification