Why Automated Vehicles Need to be Connected Vehicles

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Outline

- Automation vs. autonomy
- Levels of automation
- Why cooperation is needed
- Higher performance enabled by cooperation
- Safety challenges
Google’s Goal

Automated Highway Systems (AHS)

Commercially Available Automotive Collision Warning and ACC

DOT’s Safety Pilot Program

Autonomous Adaptive Cruise Control (CACC)

Cooperative Adaptive Cruise Control (CACC)

Intelligent and Adaptation

Full Automation

Control Assistance

Warning
# Summary of SAE International’s Draft Levels of Automation for On-Road Vehicles (July 2013)

SAE’s draft levels of automation are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level. “System” refers to the driver assistance system, combination of driver assistance systems, or automated driving system, as appropriate. NHTSA’s levels of automation are provided to indicate approximate correspondence.

<table>
<thead>
<tr>
<th>NHTSA level</th>
<th>SAE level</th>
<th>SAE name</th>
<th>SAE narrative definition</th>
<th>Execution of steering and acceleration/deceleration</th>
<th>Monitoring of driving environment</th>
<th>Backup performance of dynamic driving task</th>
<th>System capability (driving modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Non-Automated</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>1</td>
<td>Assisted</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>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>Automated driving system (“system”) monitors the driving environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<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>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>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)</td>
<td>Must monitor driving environment (system nags driver to try to ensure it)</td>
</tr>
<tr>
<td>3</td>
<td>Traffic Jam Pilot Automated parking</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 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</td>
<td>No driver needed</td>
</tr>
</tbody>
</table>
Cooperation Can Augment Sensing

- Autonomous vehicles are “deaf-mute”
- Cooperative vehicles can “talk” and “listen” as well as “seeing”
- Communicate performance and condition data directly rather than sensing it indirectly
  - Reduce uncertainties
  - Reduce filtering lags
  - More sources of information available, including beyond line of sight
- Expand performance envelope – capacity and ride quality
Cooperative System Advantages

• All vehicles sharing status information
  – Current and planned actions
  – Identification of hazards
  – Earlier and safer responses possible
• Vehicles “negotiating” maneuvers for safety and efficiency
• Augmenting remote sensor data with more reliable and cheaper “self” state information
• DSRC communication may be mandated by NHTSA
  → likely to cost <$100 per new car
• Safety can be based on definitive “handshakes”
  → Higher performance enabled
Examples of Performance That is Only Achievable Through Cooperation

• Vehicle-Vehicle Cooperation
  – Cooperative adaptive cruise control (CACC)
  – Automated merging of vehicles, starting beyond line of sight
  – Multiple-vehicle automated platoons at short separations
  – Truck platoons at short enough spacings to reduce drag

• Vehicle-Infrastructure Cooperation
  – Precision docking of transit buses
  – Precision snowplow control
Example 1 – Production Autonomous ACC (at minimum gap 1.0 s)
Example 2 – Cooperative ACC (at minimum gap 0.6 s)
Other Functions Only Possible with Cooperation
Sensor Challenges for **Autonomous Automation**

- High-performance, costly sensors are needed (accuracy, field of regard, discriminant capability)
- No single sensor technology can satisfy all needs, so fusion of multiple sensors with complementary faults and vulnerabilities is necessary
  - Cost
  - Complexity
- Filtering is necessary, but introduces lags
- Remote sensors are slower and more uncertain than onboard sensors (speed, acceleration, driver actions)
- Sensors cannot detect subtle cues from other vehicles and drivers like experienced drivers
Safety Challenges for Full Automation

- Must be “significantly” safer than today’s driving baseline (2X? 5X? 10X?)
  - Fatal crash MTBF > 3 million vehicle hours
  - Injury crash MTBF > 65,000 vehicle hours

- How many hours of testing are needed to show safety better than this?

- Cannot **prove** safety of software for safety-critical applications

- Complexity – cannot **test** all possible combinations of input conditions and their timing

- How many hours of **continuous, unassisted** automated driving have been achieved in real traffic under diverse conditions?
Safety and the Driver

- If maximum safety is indeed the goal...
  - Why not ADD the system’s vigilance to the driver’s vigilance instead of bypassing the driver’s vigilance?
  - Comprehensive hazard warnings plus some control assistance (e.g., ACC)
- But, if the driver is out of the control loop (texting, sleeping, incapable, or not present), the system has to handle EVERYTHING...
  - Bad scenarios none of us can imagine
  - Ethically untenable scenarios
Managing Customer Expectations

- What level of automation is being promised to the driver?
  - Complete? (door-to-door chauffeuring of your 7-year-old child)
  - For freeway driving only? All freeways? All traffic and weather conditions or only some conditions?
  - Can the driver sleep?
  - If not, how soon does s/he need to be prepared to intervene? What happens if s/he is too slow to respond?
  - If required to remain vigilant and engaged, what benefit does s/he gain from the system?
Definitions
(per Oxford English Dictionary)

• autonomy:
  1. (of a state, institution, etc.) the right of self-government, of making its own laws and administering its own affairs
  2. (biological) (a) the condition of being controlled only by its own laws, and not subject to any higher one; (b) organic independence
  3. a self-governing community.

autonomous:
  1. of or pertaining to an autonomy
  2. possessed of autonomy, self-governing, independent
  3. (biological) (a) conforming to its own laws only, and not subject to higher ones; (b) independent, i.e., not a mere form or state of some other organism.

• automate: to apply automation to; to convert to largely automatic operation

automation: automatic control of the manufacture of a product through a number of successive stages; the application of automatic control to any branch of industry or science; by extension, the use of electronic or mechanical devices to replace human labour.