Road Vehicle Automation: Distinguishing Reality from Hype

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Outline

• Historical development of automation
• Levels of road vehicle automation
• Why cooperation is needed
• Impacts of each level of automation on travel (and when?)
• Technical challenges
• What to do now?
History of Highway Automation in the U.S.

- 1939 – General Motors “Futurama” exhibit
- 1949 – RCA technical explorations begin
- 1950s – GM/RCA collaborative research
- 1950s – GM “Firebird II” concept car
- 1964 – GM “Futurama II” exhibit
- 1964-80 – Research by Fenton at OSU
- 1986 – California PATH program started
- 1994-98 – National AHS Consortium
- 2003 – PATH automated bus and truck demos
- 2010 – Google announcement
General Motors 1939 Futurama

General Motors' Futurama
1939 New York World's Fair
GM Firebird II Publicity Video
GM Technology in 1960
Robert Fenton’s OSU Research

Automatically Controlled
1965 Plymouth at
Transportation Research Center of Ohio
The Ohio State University (OSU)
1977
Automated Highway Systems (AHS)

Google’s Goal

Commercially Available Automotive Collision Warnings and ACC

DOT’s Safety Pilot Program

Autonomous Adaptive Cruise Control (CACC)

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 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</td>
<td>No driver needed</td>
</tr>
</tbody>
</table>
Cooperation Augments Sensing

- Autonomous vehicles are “deaf-mute”
- Cooperative vehicles can “talk” and “listen” as well as “seeing”, using 5.9 GHz DSRC comm.
  - NHTSA regulatory mandate in process
- Communicate vehicle performance and condition directly rather than sensing indirectly
  - Faster, richer and more accurate information
  - Longer range
- Cooperative decision making for system benefits
- Enables closer separations between vehicles
- Expands performance envelope – safety, capacity, efficiency and ride quality
Challenges to Achieving Cooperation

• “Chicken and egg” problem – who equips first?
  – May need regulatory “push” to seed the market

• Benefits scale strongly with market penetration
  – Need to concentrate equipped vehicles in proximity to each other

• Deployment opportunity using managed lanes
  – Economic incentives
  – Productivity increases
Examples of Performance That is **Only** Achievable Through Cooperation

- **Vehicle-Vehicle Cooperation**
  - Cooperative adaptive cruise control (CACC) to eliminate shock waves
  - Automated merging of vehicles, starting beyond line of sight, to smooth traffic
  - Multiple-vehicle automated platoons at short separations, to increase capacity
  - Truck platoons at short enough spacings to reduce drag and save energy
- **Vehicle-Infrastructure Cooperation**
  - Speed harmonization to maximize flow
  - Speed reduction approaching queue for safety
  - 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
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? Starting this year (Mercedes S-class)
Conditional Automation (Level 3) Impacts

• Driving comfort and convenience increase
  – Driver can do other things while driving, so value 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

- May only be available in some places (limited access highways, 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
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 value plunge

- (if cooperative) Large energy efficiency and road capacity gains

- When? Many decades… (Ubiquitous operation without driver is a huge technical challenge)
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...
  - 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)

- 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?
What to do now?

- Focus on connected vehicle capabilities to provide technology for cooperation
- For earliest public benefits from automation, focus on transit and trucking applications in protected rights of way
  - Professional drivers and maintenance
  - Direct economic benefits
- Capitalize on managed lanes to concentrate equipped vehicles together
- Develop enabling technologies for Level 5 automation (software verification and safety, real-time fault identification and management, hazard detection sensing,...)
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.