Road Vehicle Automation Challenges

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What are we talking about?

- What are the goals? What problem(s) are we trying to solve?
- Need precise terminology and operational concepts in order to understand each other
  - Not “driverless”, “self driving” or “unmanned”
- Automation vs. autonomy
- Definitions of driver vs. “system” roles
- Automation under what operating conditions/environmental complexity?
- Technical challenges
Potential Goals

- Mobility
- Safety
- Efficiency
- Environment
- Comfort/Convenience
- Affordability
Constraints

- Automated Vehicles
- Roadway Infrastructure
- Human Abilities
- Technology
- Economics
- Safety Requirements
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.
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- **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.
Autonomous and Cooperative ITS

Autonomous ITS (Unconnected Systems)  Cooperative ITS (Connected Vehicle Systems)

Automated Driving Systems
# SAE J3016 Definitions

<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>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</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>
</tr>
<tr>
<td>4</td>
<td>Highway driving pilot</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>
How to manage driver interaction?

- Can’t redesign the driver → must design the system to be usable by the driver

- Force driver to stay engaged? (nuisance)

- Disregard driver? (system must take full responsibility)

- Re-engage driver when system is disabled? (how much time needed to guarantee arousing a sleeping or texting driver?)
Safety Requirements

• Not an “unmanned” vehicle, but a safety-of-life critical system
• “Significantly” safer than today’s driving to gain public acceptance and provide benefits
  – Fatal crashes MTBF > 3.3 million vehicle hours
  – Injury crashes MTBF > 65,000 vehicle hours
• What software-intensive consumer electronic product can approach these MTBF levels?
• How to PROVE that an automated driving system is better than this?
  – To trust this vehicle to carry your family
  – To get affordable insurance
  – To manage risk of the system vendor
Driving Environment Diversity (1/2)

- Existing infrastructure, unchanged
  - Off-road
  - All roads
  - All paved roads
  - Well-marked paved roads
  - Urban and suburban arterials
  - Rural highways
  - Residential streets
  - Limited-access highways (freeways)
  - Parks or low-speed pedestrian zones
  - Enclosed parking facilities
Driving Environment Diversity (2/2)

• Existing infrastructure, augmented for automation
  – Dedicated lanes within limited-access highway
  – Special markings or electronics added

• Separate new infrastructure
  – Dedicated, protected lanes on limited-access highways
  – Fully automated parking facilities
  – Physically separated guideways (PRT)
Driving Environment Complexity

- Cluttered, highly dynamic environment
  - Vehicles, pedestrians, bikes, kids, pets
  - Scofflaw and aggressive drivers
  - Adverse weather and visibility
  - Poorly maintained markings and signs

- How to replicate defensive driving skills, including use of subtle visual cues and eye contact?

- Murphy’s Law is unavoidable
Orders of Magnitude Harder than Commercial Aircraft Automation

• Positioning accuracy ~ 10 cm
• Many simultaneous threats to track and avoid
  – Relative locations of targets ~10 cm
  – Relative speeds of targets ~1 m/s
• Threat response needed in <100 ms
• Fault recovery needed in <100 ms
• No operator (driver) training
• No preventive maintenance, >10 year lifetime
• Unit capital cost target ~ $3 K
Need for Communication/Cooperation to Gain Transportation Benefits

• Infrastructure must provide traffic signal status, variable speed limits, dynamic restrictions on lane use (work zones)

• Extremely beneficial to have other vehicles providing:
  – Maneuver intentions
  – Message/condition acknowledgments
  – Advance alerts about hazards
  – Cooperation to improve efficiency, enable close clustering to reduce drag

• By contrast, autonomous vehicles are deaf-mute drivers
Technological Challenges

• Sensor performance and cost
• Logic and data processing
• Software complexity and safety
Sensor Challenges for Autonomous Automation in Mixed Traffic

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

• Sensor signal processing (e.g., distinguishing hazardous from benign obstacles)
  – Any object large enough to cause harm
  – BUT, ignore innocuous “soft” targets
  – “Zero” missed detections (false negatives)
  – “Near-zero” false alarms (false positives)

• Predicting future actions of other vehicles

• General driving threat assessment (defensive driving)

• Decision making in ethically ambiguous threat situations (truck vs. motorcycle)

• Moore’s Law does not provide salvation
Software Challenges for Fully Automated Driving

• Complexity – cannot test all combinations of conditions
• Cannot prove safety of software for safety-critical applications
• Need comprehensive fault detection, identification and reconfiguration – self-healing

• How many hours of testing are needed to prove safety better than human driving?
• How many hours of continuous, unassisted automated driving has anybody achieved in real traffic?
Where to go from here?

• Simplify, simplify, simplify… to focus on tractable problems to solve
  – Protected environments
  – Commercial vehicles, professional drivers
  – Use all available data (including V2V, I2V)
  – Limited levels of automation (retaining driver as safety backup)

• Automation of buses on busways
• Automation of trucks in truck lanes and terminals
• Parking in enclosed garages