Fundamental Issues in Road Transport Automation

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Outline

• Diversity of automation concepts
• State of the art and of the market
• Technological maturity
• Non-technical issues
• Business models and public/private roles
• Topics needing more attention
Diversity of Automation Concepts

• Diversity impedes mutual understanding until we get specific about:
  – Goals to be served by the automation system
  – Roles of driver and automation system
  – Complexity of operating environment

• Need to get around misunderstandings caused by misleading, vague and inaccurate terminology in common use: “driverless”, “self-driving”, “autonomous”…
Goals that Could be Served by an Automation System

- driving comfort and convenience
- freeing up time heretofore consumed by driving
- reducing vehicle user costs
- reducing user travel time
- improving vehicle user safety or broader traffic safety
- enhancing and broadening mobility options
- reducing traffic congestion in general
- reducing energy use and pollutant emissions
- making more efficient use of existing road infrastructure
- reducing cost of future infrastructure and equipment
## 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>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>

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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></td>
<td>Traffic Jam Assist</td>
<td></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></td>
<td>Driverless valet parking in garage</td>
<td></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></td>
<td>Closed campus shuttle (driverless)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Automated taxi (even for children)</td>
<td>No driver needed</td>
</tr>
<tr>
<td></td>
<td>Car-share repositioning system</td>
<td></td>
</tr>
</tbody>
</table>
Automated Driving: Complexity of Operating Environment

- Degree of segregation from other road users
  - Exclusive guideways (automated people movers)
  - Dedicated highway lanes
  - Protected campus/special-purpose pathways
  - Enclosed parking garages
  - Pedestrian zones
  - Urban streets
- Traffic complexity (speed, density, mix of users)
- Weather and lighting conditions
- Availability of I2V, V2V data
- Standardization of signage and pavement markings
Today’s Crash Avoidance Systems Form the Foundation for AV

*increasingly becoming standard equipment*

- Electronic Stability Control
- Lane Centering
- Automatic Braking
  - front
  - rear
- Blind spot Monitoring
- Pedestrian Detection
- Fatigue Alert
- Night Vision
- Speed Sign Recognition
Today’s Crash Avoidance Systems Form the Foundation for AV

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- Lane Centering
- Automatic Braking
  - rear
  - front
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- Pedestrian Detection
- Fatigue Alert
- Night Vision
- Speed Sign Recognition

Automatic Emergency Braking:
14% reduction in crashes.
Automated Driving: Key Technology Elements

- Sensors
  - radar, stereo/mono cameras, lidar
- Image processing systems detect traffic signal status relevant to the host vehicle’s lane
- Dynamic maps play an important role, refreshed through car data sharing.
- Data via V2X communications enhances operations.
  - enables some applications
Automated Driving: Enabling Technology

Source: Texas Instruments ADAS Solutions Guide
Automated Driving: **Supporting** Technology

HIGH DEFINITION MAPS

V2X COMMUNICATIONS

Source: Texas Instruments ADAS Solutions Guide
State of the Art: Passenger Cars

- **Highway Operation**
  - prototypes driving in-lane, changing lanes, merging

- **Street Operation**
  - prototypes driving wide range of city streets
  - handling elements such as signalized intersections, roundabouts

- **Level 4 Automated Chauffeuring**
  - seen as a natural evolution by some OEMs
  - pursued by Google, Uber, others
  - street level automated driving
  - low speed
  - limited geographic area
State of the Market: Passenger Cars

- Now available: limited Level 2 highway use systems
  - Simultaneous adaptive cruise control and lane centering (full speed range)
    - handles limited highway curvature
    - Acura, Infiniti, Mercedes, Hyundai
  - Traffic Jam Assist
    - low speed automated lateral/longitudinal control
    - driver instructed to keep hands on wheel, otherwise system disables
    - BMW, Mercedes, Volkswagen, Volvo Cars
State of the Market: Passenger Cars

- Level 2 highway use systems available by end of decade
  - full speed range, full range of normal highway curvatures
  - some approaches will actively monitor the driver’s attention/gaze and warn if the driver does not have eyes on the road.
  - Some systems will simply drive the vehicle in-lane; others will also do lane changes as needed.

- OEM announcements include
  - “mid-decade”: Toyota
  - 2016: Audi, GM
  - 2018: Nissan (with lane changing)
  - 2020: BMW

- Aftermarket systems
  - small start-ups active
  - bringing systems to market successfully questionable
State of the Market: Passenger Cars

- Level 3 highway use systems
  - 2017: Volvo “Drive Me”
    - 100 vehicles for use by public
    - limited to specific roads
- Level 4 Automated Valet Parking
  - 2016: Nissan
Level 4 Automated Chauffeuring

- Small scale systems operating now in Europe
  - CityMobil2
    - Lausanne
    - La Rochelle
    - Vantaa
    - Milan
  - Innovate UK
    - Bristol
    - Greenwich
    - Milton-Keynes
    - Further deployments planned
- Singapore: testing underway
- Google pilot testing likely by end decade
  - California regulations allowing public use of AV’s a key factor
- Uber likely to become active
  - Recent investment to create Pittsburgh R&D center
AV Use Cases for Heavy Trucks

On-Road

- **Fuel Economy**
  - Driver Assistive Truck Platooning
    - Level 1 (hands on, feet off)
    - Level 2 (hands off, feet off)
  - Level 2 (hands off, feet off)

- **Productivity**
  - One-Driver Platooning (no driver in followers)
  - Traffic Jam Assist
  - Automated Movement in Queue
  - Automated Trailer Backing
  - Highway Pilot
  - Parcel Delivery Automation

Constrained Environments

- Inside < > Outside
- Drayage
- Mine Hauling
- Dispersed Local Sites
  - manufacturing
  - distribution
State of the Art: Trucks

• Level 1 close-headway platooning systems under development
  – multiple demo’s have occurred
  – USDOT currently funding two Level 1 research projects
    • Caltrans/UC-Berkeley
    • Auburn University
  – European government activity, R&D
• Level 3 prototypes shown by OEMs
  – aimed at long haul freight transport on well structured highways
Freightliner “Inspiration:”
1st Truck with Nevada AV License Plate
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Near Term: Truck Platooning

• Two truck platoons
• Combining vehicle-vehicle communications with radar
  – ensures that braking by front truck occurs simultaneous with follower truck
• Enables safe ops at close following distances (10-15 meters)
  – electronic tow bar
• Significant fuel savings due to aerodynamics
  – aerodynamic drag is ~65% of fuel use at 65 mph
• Follower truck driver still responsible for steering (Level 1 automation)
Driver Assistive Truck Platooning

- Fuel savings at 60 mph, 11m gap:
  - following truck: 10.0%
  - lead truck: 4.5%

Driver Assistive Truck Platooning

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Is This Legal In Your State?
State Regulations for Truck Platooning

- Low level of automation eases the way for platooning.
- State-level following distance laws are key
  - 28 states: no minimum following distance
  - 5 states: ready for pilot testing (UT, MI, NV, AL, TX)
  - 2 states: legislation in process (FL, CA)
  - 7 states: positioning for trials but early in process
- National associations involved to create model legislation
State of the Market: Trucking

• Automatic Emergency Braking now required on new heavy trucks in Europe.

• Truck Platooning
  – Level 1 systems (longitudinal control only)
  – radar, V2V enable close following
  – substantial fuel economy benefits compelling to industry

• Commercial offerings expected within 2-3 years
  – pilot testing in U.S. likely to begin this year
State of the Market: Summary

- Two parallel paths:
  - Everything Somewhere (Google, CityMobil, others)
    - Level 4 car-as-a-service
    - constrained geographic area
    - fleet likely to need frequent servicing and testing to ensure safe operation is maintained
  - Something Everywhere (vehicle OEMs)
    - classic incremental approach
    - systems are brought to market capable of operating on “any” road (at least of a certain type)
    - no limitation re geographic area
- Truck AV a blend of both, depending on Use Case
Infrastructure Support

• Importance for automation product introduction under debate
  – essential to gain transportation benefits

• Various types of support
  – I2V (and V2V) real-time data
  – Physical protection from hazards
  – Digital infrastructure (static and dynamic data)
  – “sensor friendly” signage and markings, better lighting
  – Higher maintenance standards

• Scenarios for providing support
  – Private providers
  – Industry and users push public agencies to prioritize this support
  – Public agencies provide it based on perceived public benefits
Organizational Framework

- Vehicle manufacturers and their suppliers
- Other technology industry companies
- Regulators and public authorities
- Infrastructure/road operators
- Public transport operators
- Goods movement industry
- Users/private drivers
- Vulnerable road users (peds, bikes)
- Shared vehicle and fleet operators
- Insurers
- (Big data) service providers
- Research/academic
- Legal experts
Technological Maturity (1/2)

- Challenges for Level 3+ automation (cannot expect the driver to be the backup)
- Technologies needing development, but no fundamental breakthroughs:
  - Wireless communications (DSRC, 4G+,…)
  - Localization (GNSS, SLAM)
- More challenging requirements:
  - Human factors/driver interface: safe control transitions, deterring misuse and abuse, encouraging vigilance, facilitating correct mental models of system behavior
  - Cyber security (and privacy)
Technological Maturity (2/2)

- Breakthroughs potentially needed (in order of increasing difficulty):
  - Fault detection, identification and accommodation (within cost constraints)
  - Ethical considerations in computer control
  - Environment perception and threat assessment (minimizing false positives and false negatives under diverse conditions with affordable sensors, predicting future motions of target objects)
  - Software safety (designing, developing, verifying and validating complex software systems – What mix of formal methods, simulation and testing? How to “prove” a safety goal has been met?)
Non-Technological Issues

- Public policy
- Legal issues
- Vehicle certification and licensing
- Public acceptance
- Insurance
- Benefits and impacts
Public Policy Issues

- Regulations at national vs. lower levels?
- Changes in driver licensing and insurance?
- Changes in vehicle registration rules?
- Restrictions to subsets of the road network?
- Changes in motor vehicle codes?
- Priority for infrastructure modifications?
- More uniform infrastructure standards?
- Business models for infrastructure-vehicle cooperation?
- Public financial incentives for AV use?
- Interactions with law enforcement?
- Land use and parking changes?
- Changes in disutility of travel time?
Legal Issues

- Determining responsibility for failures, especially with cooperative automation systems
- Shift of some liability from drivers to others
- Importance of instructions to driver about system capabilities and limitations
- Relaxing Vienna Convention rules (for other countries)
- No show-stoppers
Vehicle Certification & Licensing (1/2)

• How to determine a specific system is “safe enough”?
  – Defining safety requirements (no less safe than today, and maybe better):
    • 3 M hour fatal crash MTBF
    • 65 K hour injury crash MTBF
  – How to verify that requirement has been met?
• Serious challenges:
  – No technical standards to cite
  – Naturalistic testing is unaffordable to collect enough data on rare safety-critical events
  – Frequent updates requiring new certification?
Vehicle Certification & Licensing (2/2)

Possible approaches:

- Manufacturer self-certification
- Manufacturer self-certification + make data public
- Third-party review of manufacturer functional safety processes
- Third-party review of detailed design
- Comprehensive acceptance test by public agency or third party
Public Acceptance Issues

• Some highly enthusiastic, some intensely hostile
• Hard to predict based on previous automotive innovations because of change in traveling or "driving" experience
• J.D. Power survey (2014) – 24% of 15,000 respondents interested at $3 K price premium
  – 41% of Gen. Y (1977-95)
  – 25% of Gen. X (1965-76)
  – 13% of Boomers (1947-64)
Insurance Issues

• If crashes are reduced, auto insurance business could shrink
• Some risk transferred to manufacturers
• Risk associated more with vehicle characteristics than driver performance
• Easier to assign fault based on event data recorders
• Effects will vary, depending on different state regulations
Assessing Benefits and Impacts

- Diverse, complex and highly uncertain impacts
- Many assumptions needed to make predictions – need sensitivity studies
- Market uncertainties
  - AV development – timing of feasibility of different capabilities
  - Customer willingness to pay for each AV capability
- Societal/institutional uncertainties
  - Availability of public infrastructure support
  - Effects of commercially successful AV systems on traffic flow, energy and emissions
  - Safety, accounting for system faults and ped/bike interactions
  - Public preferences for housing/urban form
  - Employment patterns and telecommuting
  - Elasticity of travel demand with respect to AV travel time
Business Models and Public-Private Roles

• “Standard” approach of private vehicles on public infrastructure (roads), with limited interaction

• Automation benefits from closer coupling of vehicles and infrastructure, opening integrated business models:
  – Common ownership of vehicles and infrastructure, providing transportation service (like railroads)

• Financing infrastructure elements:
  – Joint public-private financing
  – Road user charging
  – New public-private partnerships
  – Investments from information technology industry seeking access to “driver” eyeballs
Research Needs – Technological (1/2)

- Robust wireless communication technologies
- Highly dependable vehicle localization
- Human factors and driver interfaces to support mode awareness and safe mode transitions
- Methods to efficiently develop and update high-definition map data
- Incorporating ethical considerations into control system design
Research Needs – Technological (2/2)

• Fault detection, identification and accommodation methods to enhance safety when fault conditions arise
• Cybersecurity methods (applicable to all modern vehicles)
• Environment perception technologies to provide extremely low rates of false positive and false negative hazard identifications
• Software safety design, development, verification and validation methods that can be implemented affordably.
Research Needs – Non-Technological (1/3)

• What to regulate at the national level vs. at state/regional level?
• Should driver licensing and testing requirements change?
• Should non-drivers be allowed to travel unaccompanied in AVs?
• Should an AV be permitted to operate on all public roads, or only on specific roads?
• How to determine that a specific AV can be used on public roads?
• What vehicle codes should be modified to account for enhanced AV capabilities?
Research Needs – Non-Technological (2/3)

- How should public agencies prioritize investments in modifying roadway infrastructure for AVs?
- Should government agencies apply more uniform standards to roadway and roadside infrastructure?
- Should new organizational and financing models be used to facilitate infrastructure-vehicle cooperation for AV operations?
- Public financial incentives for purchase and use of AVs?
- How should law enforcement interact with AVs?
- Legal issues such as vehicle codes?
- Should laws be modified to ease liability concerns?
Research Needs – Non-Technological (3/3)

• How should minimum safety requirements be determined?
• How should compliance with safety requirements be determined?
• Who should certify the safety of AVs?
• How much will the public be willing to pay for various levels of driving automation?
• How rapidly will the market grow for the various levels of driving automation?
• How will the insurance industry have to adapt based on changes in crash rates and causes?
Big Unresolved Questions (1/2)

- 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?
- To what extent do higher levels of automation require fundamental breakthroughs in some technological fields?
- What roles should national and regional/state governments play in determining whether a specific AV is “safe enough” for public use?
- How safe is “safe enough”? 
Big Unresolved Questions (2/2)

• How can an AV be reliably determined to meet any specific target safety level?
• Should AVs be required to inhibit abuse and misuse by drivers?
• Are new public-private business models needed for higher levels of automation?
• How will AVs change public transport services, and will societal goals for mobility be enhanced or degraded?
• What will be the net impacts of AVs on vehicle miles traveled, energy and environment?
For More Information

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