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>Human driver monitors the driving environment.</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>Conditional Automation</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>High Automation</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>
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
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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)

• **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%

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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?