Fundamental Issues in Road Transport Automation

Steven E. Shladover and Richard Bishop

ITS America Webinar

July 15, 2015

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

SAE Level	Name	Narrative Definition	Execution of Steering/ Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability (*Driving Modes*)
Human driver monitors the driving environment						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	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*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	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*	**System**	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	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*	System	**System**	Human driver	Some driving modes
4	High Automation	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*	System	System	**System**	Some driving modes
5	Full Automation	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*	System	System	System	**All driving modes**

Example Systems at Each Automation Level

Level	Example Systems	Driver Roles
1	Adaptive Cruise Control OR Lane Keeping Assistance	Must drive other function and monitor driving environment
2	Adaptive Cruise Control AND Lane Keeping Assistance Traffic Jam Assist	Must monitor driving environment (system nags driver to try to ensure it)
3	“Traffic Jam Pilot” Driverless valet parking in garage	May read a book, text, or web surf, but be prepared to intervene when needed
4	“Highway driving pilot” Closed campus shuttle (driverless)	May sleep, and system can revert to minimum risk condition if needed
5	Automated taxi (even for children) Car-share repositioning system	No driver needed

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

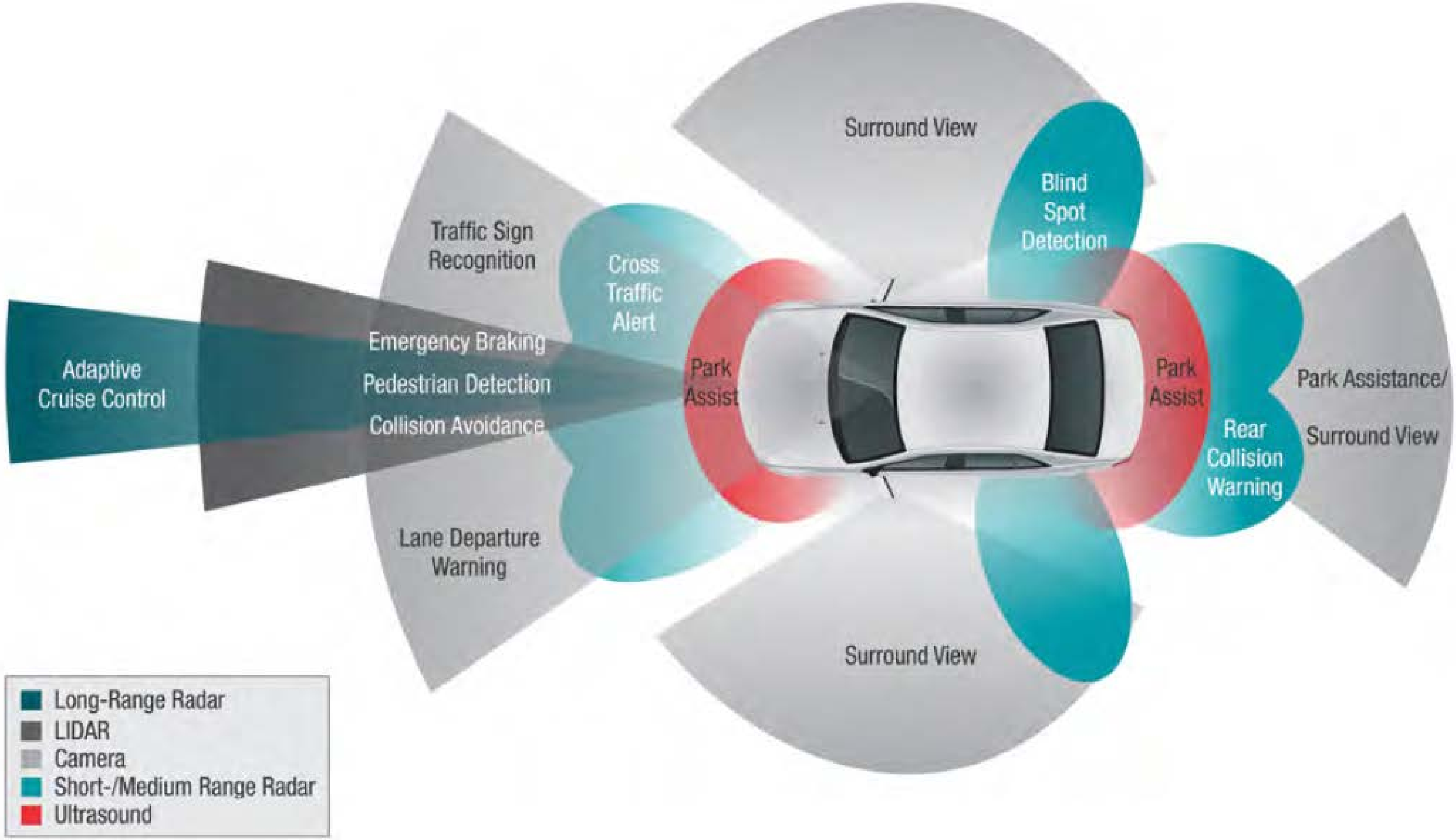
- Electronic Stability Control
- Lane Centering
- Automatic Braking
  - rear
  - front
- Blind spot Monitoring
- Pedestrian Detection
- Fatigue Alert
- Night Vision
- Speed Sign Recognition

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

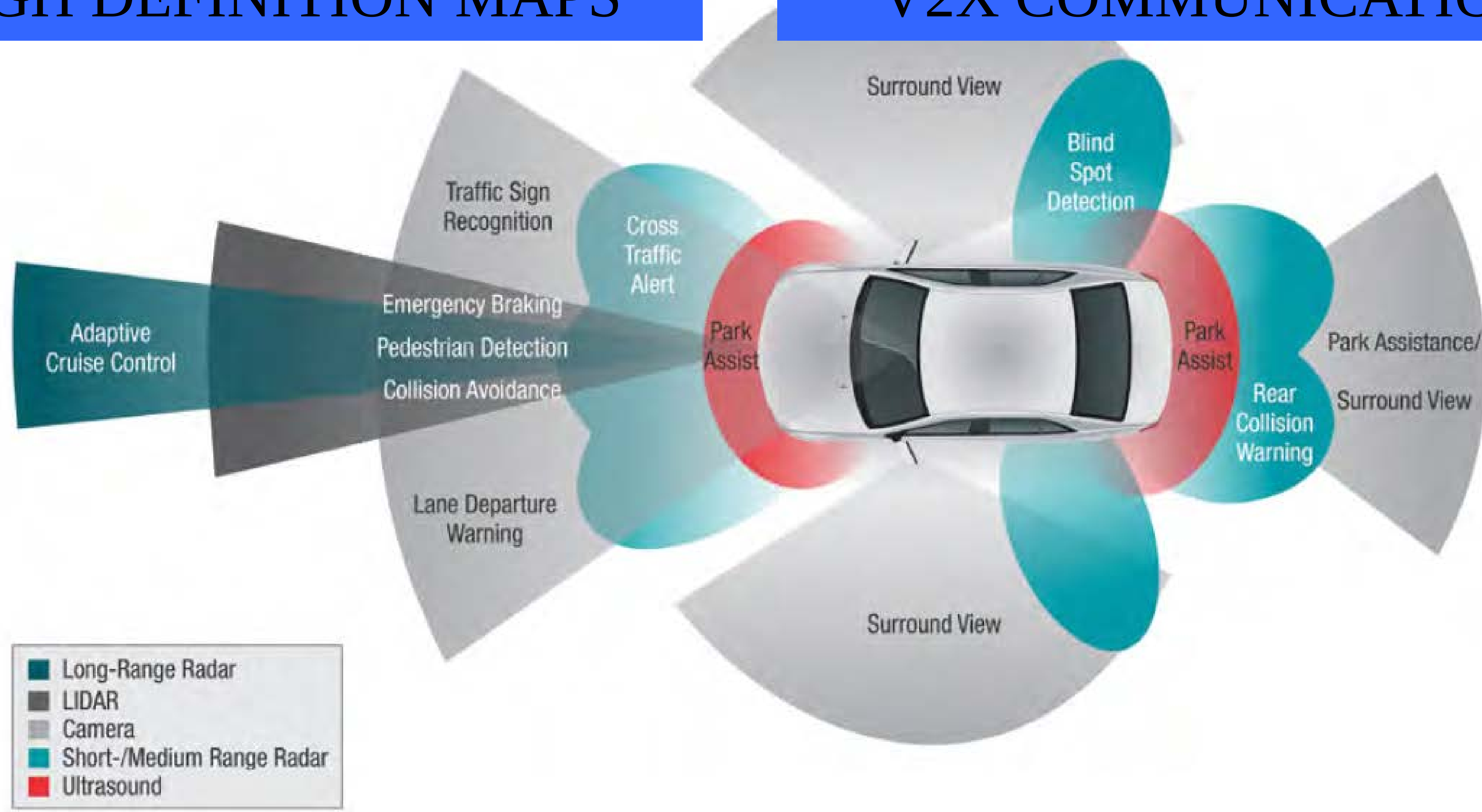


Source: Texas Instruments ADAS Solutions Guide

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)**
- **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

Freightliner “Inspiration:”
1st Truck with Nevada AV License Plate

Freightliner "Inspiration:" 1st Truck with Nevada AV License Plate

Freightliner "Inspiration:"
1st Truck with Nevada AV License Plate

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%

North American Council for Freight Efficiency (2013).
CR England Peloton Technology platooning test Nov 2013.

Driver Assistive Truck Platooning

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

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 <u>hour</u> fatal crash MTBF
    - 65 K <u>hour</u> 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?**