# 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

| 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<br>Lane Keeping Assistance | Must drive other function and monitor driving environment |
| 2 | Adaptive Cruise Control AND Lane Keeping Assistance<br>Traffic Jam Assist | Must monitor driving environment (system nags driver to try to ensure it) |
| 3 | "Traffic Jam Pilot"<br>Driverless valet parking in garage | May read a book, text, or web surf, but be prepared to intervene when needed |
| 4 | "Highway driving pilot"<br>Closed campus shuttle (driverless) | May sleep, and system can revert to minimum risk condition if needed |
| 5 | Automated taxi (even for children)<br>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**

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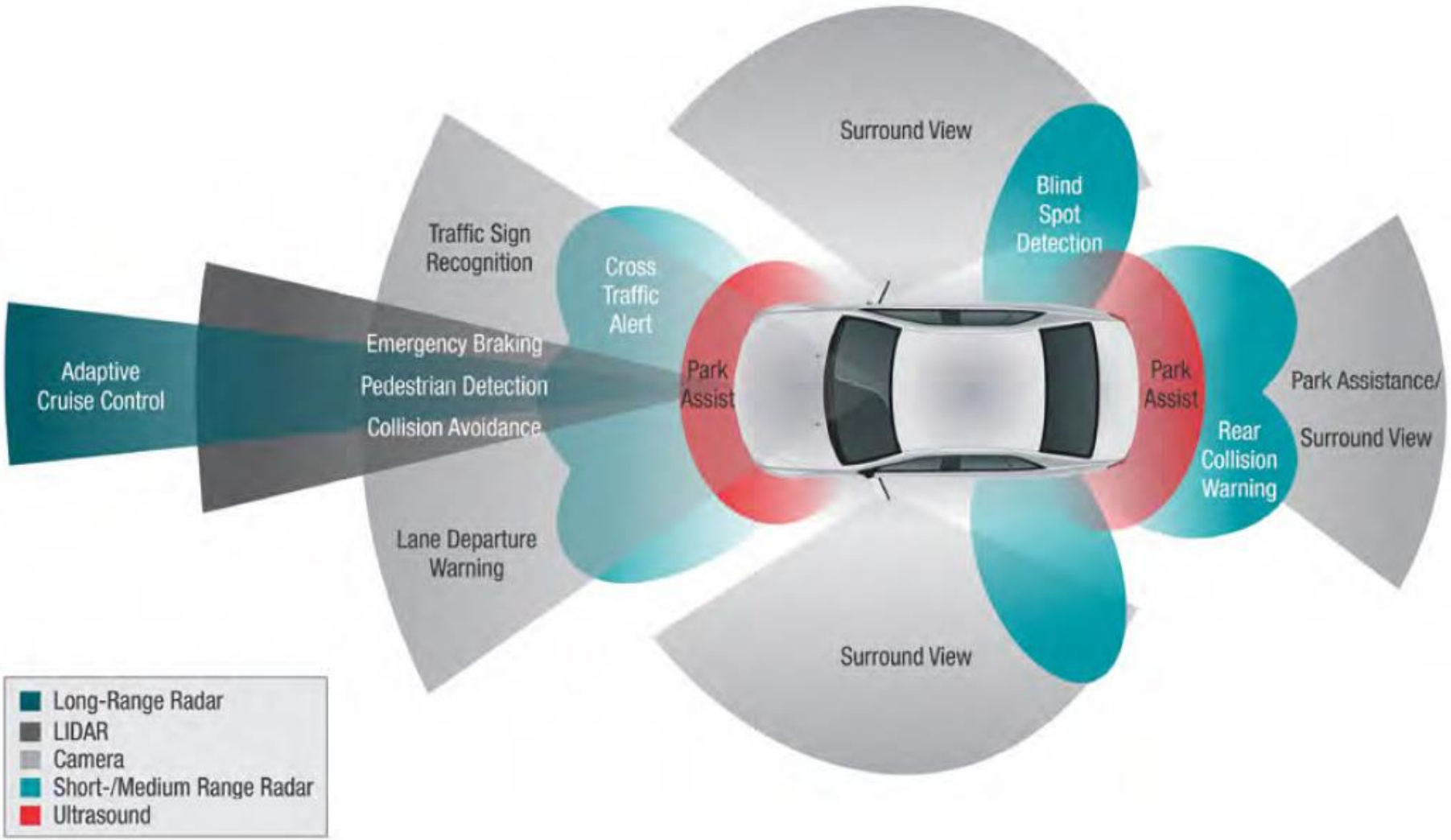
Automatic Emergency Braking:
14% reduction in crashes.

# 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

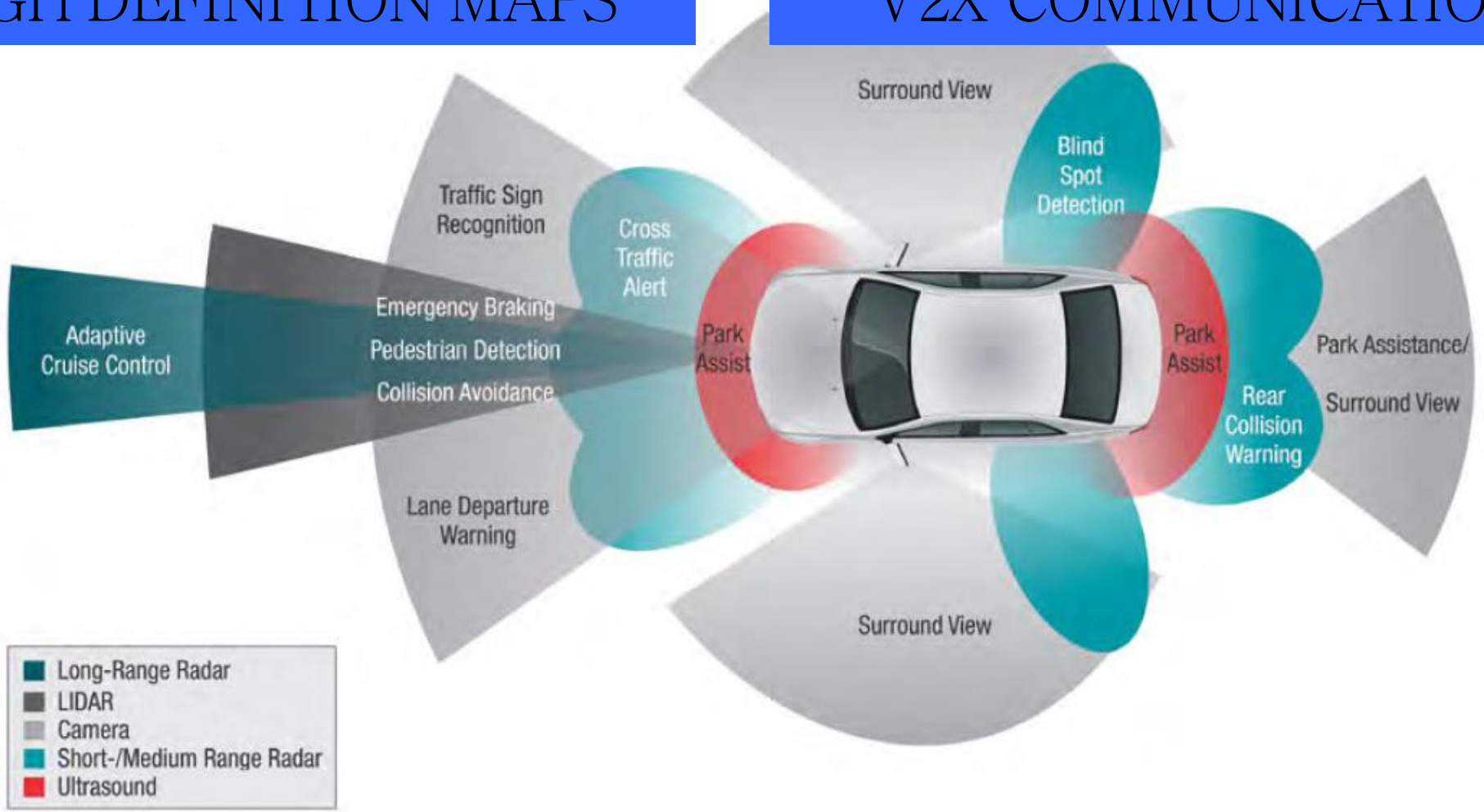



Source: Texas Instruments ADAS Solutions Guide

# 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%


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

# 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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