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# **Road Vehicle Automation: Reality, Hype and Policy Implications**

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# Outline

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- **Historical development of automation**
- **Levels of road vehicle automation**
- **Why cooperation is needed**
- **Impacts of each level of automation on travel (and when?)**
- **Technical challenges**
- **State regulatory challenges**
- **Other policy issues**
- **What should California do?**

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**Policy and regulations are NOT  
slowing progress on automation –**

**The main limitations are  
technological!**

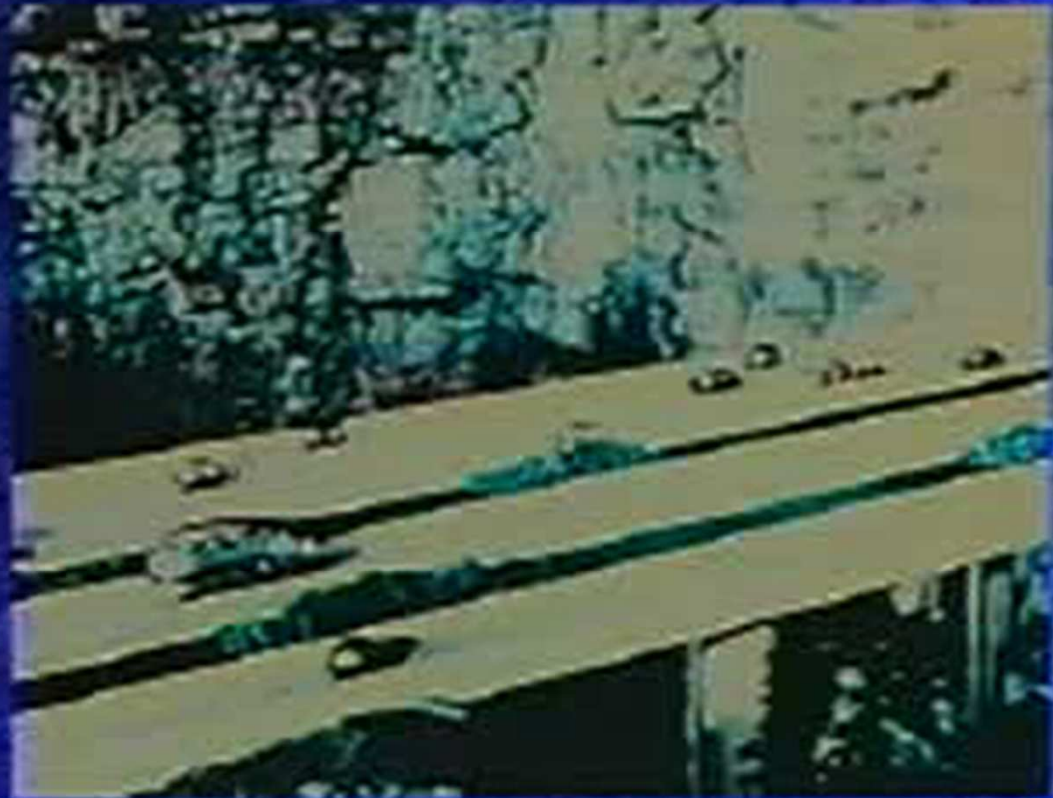
# History of Highway Automation in the U.S.

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- 1939 – General Motors “Futurama” exhibit
  - 1949 – RCA technical explorations begin
  - 1950s – GM/RCA collaborative research
  - 1950s – GM “Firebird II” concept car
  - 1964 – GM “Futurama II” exhibit
  - 1964-80 – Research by Fenton at OSU
  - 1986 – California PATH program started
  - 1994-98 – National AHS Consortium
  - 2003 – PATH automated bus and truck demos
  - *(2004 - 2007 – DARPA Challenges)*
  - 2010 – *Google announcement*
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# General Motors 1939 Futurama

General Motors' Futurama  
1939 New York World's Fair





# GM Firebird II Publicity Video



# GM Technology in 1960

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# Robert Fenton's OSU Research

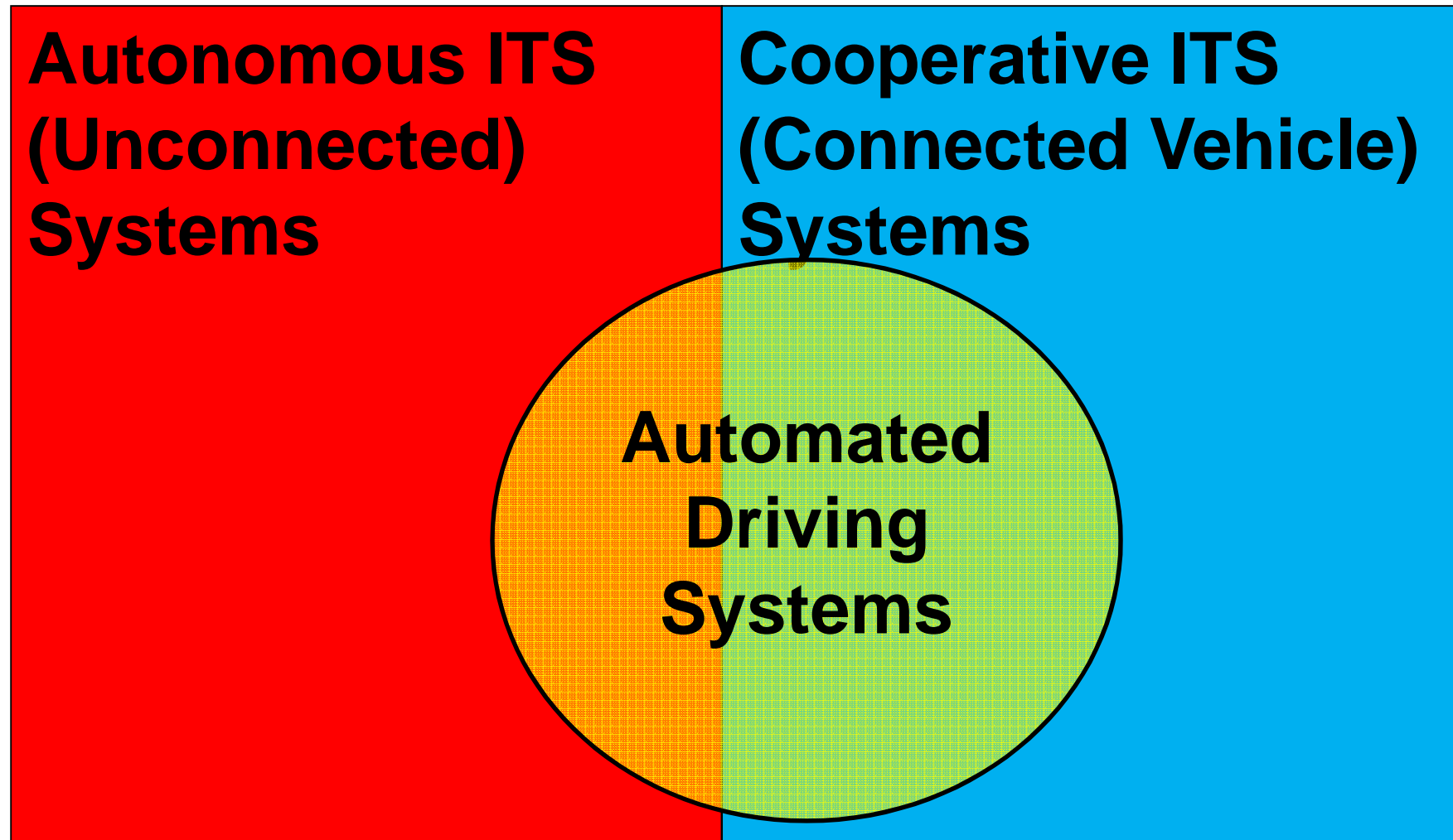
Automatically Controlled  
1965 Plymouth at  
Transportation Research Center of Ohio  
The Ohio State University (OSU)  
1977





# Autonomous and Cooperative ITS

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# 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)
<i>Human driver monitors the driving environment</i>						
0	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the <i>driving mode</i> -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 <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the <i>driving mode</i> -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 <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human driver	Human driver	Some driving modes
<i>Automated driving system ("system") monitors the driving environment</i>						
3	Conditional Automation	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human driver	Some driving modes
4	High Automation	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	System	Some driving modes
5	Full Automation	the full-time performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	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 <u>other</u> function and monitor driving environment
2	Adaptive Cruise Control AND Lane Keeping Assistance Traffic Jam Assist (Mercedes)	Must monitor driving environment (system nags driver to try to ensure it)
3	Traffic Jam Pilot Automated parking	May read a book, text, or web surf, but be prepared to intervene when needed
4	Highway driving pilot Closed campus driverless shuttle Driverless valet parking in garage	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

# Cooperation Augments Sensing

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- Autonomous vehicles are “deaf-mute”
- Cooperative vehicles can “talk” and “listen” as well as “seeing”, using 5.9 GHz DSRC comm.
  - **NHTSA regulatory mandate in process**
- Communicate vehicle performance and condition directly rather than sensing indirectly
  - **Faster, richer and more accurate information**
  - **Longer range**
- Cooperative decision making for system benefits
- Enables closer separations between vehicles
- Expands performance envelope – safety, capacity, efficiency and ride quality



# Challenges to Achieving Cooperation

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- **“Chicken and egg” problem – who equips first?**
  - **Regulatory “push” to seed the vehicle market**
- **Benefits scale strongly with market penetration**
  - **Need to concentrate equipped vehicles in proximity to each other**
- **Deployment opportunity using managed lanes**
  - **Economic incentives**
  - **Productivity increases**

# Examples of Performance That is Only Achievable Through Cooperation

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- **Vehicle-Vehicle Cooperation**
    - Cooperative adaptive cruise control (CACC) to eliminate traffic shock waves
    - Automated merging of vehicles, starting beyond line of sight, to smooth traffic
    - Multiple-vehicle automated platoons at short separations, to increase capacity
    - Truck platoons at short enough spacings to reduce drag and save energy
  - **Vehicle-Infrastructure Cooperation**
    - Speed harmonization to maximize flow
    - Speed reduction approaching queue for safety
    - Precision docking of transit buses
    - Precision snowplow control
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# Example 1 – Production Autonomous ACC (at minimum gap 1.0 s)

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## Example 2 – Cooperative ACC (at minimum gap 0.6 s)

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# Other Functions Only Possible with Cooperation



# Partial Automation (Level 2) Impacts

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- Probably only on limited-access highways
- Somewhat increased driving comfort and convenience (but driver still needs to be actively engaged)
- Possible safety increase, depending on effectiveness of driver engagement
  - **Safety concerns if driver tunes out**
- (*only* if cooperative) Increases in energy efficiency and traffic throughput
- When? Available now (Mercedes S-class)

# Conditional Automation (Level 3) Impacts

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- **Driving comfort and convenience increase**
  - **Driver can do other things while driving, so value of travel time is reduced**
  - **Limited by requirement to be able to re-take control of vehicle in a few seconds when alerted**
- **Safety uncertain, depending on ability to re-take control in emergency conditions**
- **(*only* if cooperative) Increases in efficiency and traffic throughput**
- **When? Unclear – safety concerns could impede introduction**

# High Automation (Level 4) Impacts – General-purpose light duty vehicles

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- May only be available in some places (limited access highways, managed lanes)
- Large gain in driving comfort and convenience on available parts of trip (driver can sleep)
  - **Significantly reduced value of time**
- Safety improvement, based on automatic transition to minimal risk condition
- (*only* if cooperative) Significant increases in energy efficiency and traffic throughput from close-coupled platooning
- When? Starting 2020 – 2025?



# High Automation (Level 4) Impacts – Special applications

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- Buses on separate transitways
  - Narrow right of way – easier to fit in corridors
  - Rail-like quality of service at lower cost
- Heavy trucks on dedicated truck lanes
  - (cooperative) Platooning for energy and emission savings, higher capacity
- Automated (driverless) valet parking
  - More compact parking garages
- Driverless shuttles within campuses or pedestrian zones
  - Facilitating new urban designs
- When? Could be just a few years away

# Full Automation (Level 5) Impacts

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- Electronic taxi service for mobility-challenged travelers (young, old, impaired)
- Shared vehicle fleet repositioning (driverless)
- Driverless urban goods pickup and delivery
- Full “electronic chauffeur” service
- Ultimate comfort and convenience
  - Travel time value plunge
- *(if cooperative)* Large energy efficiency and road capacity gains
- When? Many decades... (Ubiquitous operation without driver is a huge technical challenge)

# Personal Estimates of Market Introductions

Everywhere					
Some urban streets					
Campus or pedestrian zone					
Limited-access highway					
Fully Segregated Guideway					
	Level 1 (ACC)	Level 2 (ACC+ LKA)	Level 3 Conditional Automation	Level 4 High Automation	Level 5 Full Automation
<b>Color Key:</b>	<b>Now</b>	<b>~2020s</b>	<b>~2025s</b>	<b>~2030s</b>	<b>&gt;&gt;2040</b>

# Safety Challenges for Full Automation

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- Must be “significantly” safer than today’s driving baseline (2X? 5X? 10X?)
  - Fatal crash MTBF > 3.3 million vehicle hours
  - Injury crash MTBF > 65,000 vehicle hours
- How many hours of testing are needed to show safety better than this?
- Cannot prove safety of software for safety-critical applications
- Complexity – cannot test all possible combinations of input conditions and their timing
- How many hours of continuous, unassisted automated driving have been achieved in real traffic under diverse conditions?



# Safety and the Driver

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- If maximum safety is indeed the goal...
  - **ADD the system's vigilance to the driver's vigilance instead of bypassing the driver's vigilance**
  - **Comprehensive hazard warnings plus some control assistance (e.g., ACC)**
- If the driver is out of the control loop (texting, sleeping, incapable, or not present), the system has to handle **EVERYTHING...**
  - **Bad scenarios none of us can imagine**
  - **Ethically untenable scenarios**

# State DMV Regulatory Issues

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- Due diligence in protecting general public while unproven systems are being tested among them
- Trying to ensure that general public really understands limitations of their vehicles
- Detecting unsafe systems as early as possible (earlier than NHTSA?)
- Adapting or re-interpreting existing codes:
  - Responding to law enforcement officer commands
  - Exchanging insurance information after crashes
  - Restrictions on driver behaviors (DUI, open alcohol containers, cell phones, texting, distraction, recklessness...)
  - Protection of unattended children...

# Fundamental Challenges in Defining Automation Regulations

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- **Balancing need to protect public safety with desire to encourage technological innovation**
- **Automation blurs the traditional boundary between federal responsibility for regulating new vehicle equipment and state responsibility for regulating how vehicles are operated**
- **Lack of technical standards to provide baseline references for performance, safety or testing protocols or procedures**
- **Lack of national standards and diversity of state approaches**
- **Cultural differences between automotive and information technology industries**
- **Self-certification vs. third-party certification**

# Basic Steps in California Process

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- **Sept. 2012 – Legislature created VC38750 and mandated DMV develop regulations by 1/1/15**
  - **DMV formed statewide steering committee of affected agencies to provide advice (Caltrans, CHP, OTS, Insurance, NHTSA regional office)**
  - **DMV contracted with PATH in 7/13 for technical advice**
  - **DMV developed testing regulations, which were adopted 5/19/14. (Testers require state permits as of 9/16/14.)**
  - **DMV drafted regulations on public operation, with PATH advice – to be released for public comment at unknown future time**
  - **Multiple administrative steps required for public operation regulations before adoption**
  - **Regulations will be updated periodically**
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# Legislative and Administrative Rules

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- **Legislative requirements (in CA Vehicle Code) are legally binding and can only be changed by legislation**
  - **Definitions**
  - **Some specific safety provisions**
  - **Bonding**
  - **Timelines**
- **DMV needs to write administrative rules (in CA Code of Regulations) to implement legislative requirements**
  - **Some specific mandates from Legislature**
  - **Clarifications of ambiguous issues in legislation**
  - **Specific guidance on how to implement legislative intent**



# Systems Covered by Regulations

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- "Autonomous technology" means technology that has the capability to drive a vehicle without the active physical control or monitoring by a human operator.
  - "Autonomous vehicle" means any vehicle equipped with autonomous technology that has been integrated into that vehicle.
  - An autonomous vehicle does not include a vehicle that is equipped with one or more collision avoidance systems, including, but not limited to, electronic blind spot assistance, automated emergency braking systems, park assist, adaptive cruise control, lane keep assist, lane departure warning, traffic jam and queuing assist, or other similar systems that enhance safety or provide driver assistance, but are not capable, collectively or singularly, of driving the vehicle without the active control or monitoring of a human operator.
- This means that SAE Level 3 or higher systems are covered, except:
- "If the operator does not or is unable to take control of the autonomous vehicle, the autonomous vehicle shall be capable of coming to a complete stop." (which effectively prohibits many Level 3 systems)

# Testing on Public Roads (Published)

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- **Legislative:**
  - \$5 M bond/proof of self-insurance
  - Test driver must be designated by manufacturer
  - “The driver shall be seated in the driver's seat, monitoring the safe operation of the AV, and capable of taking over immediate manual control...”
- **Administrative:**
  - Application to test covers specific vehicles and test drivers
  - Many test driver qualifications (driving record, training)
  - No motorcycle, commercial or heavy vehicle testing
  - Prior “controlled testing” under comparable conditions
  - Report total amount of test driving and all disengagements associated with failures or driving hazards
  - (no provision for naturalistic testing with naïve drivers)

# Deployment for Public Operation

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- **Legislative highlights in CA Vehicle Code:**
  - “The AV shall allow the operator to take control in multiple manners, including, without limitation, through the use of the brake, the accelerator pedal, or the steering wheel...”
  - Separate EDR for “autonomous technology sensor data” for at least 30 seconds
  - “The department [DMV] shall notify the Legislature of the receipt of an application from a manufacturer seeking approval to operate an AV capable of operating without the presence of a driver inside the vehicle...”
  - \$5 M bond/proof of self-insurance

# Deployment for Public Operation

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- **Potential administrative regulation topics:**
    - Identification as AV on registration
    - Specify valid types of driving environments (“areas of operation”)
    - Evidence of minimum behavioral competency for operation in these areas
    - Safety monitoring plan
    - Consumer education plan
    - Information privacy disclosure
    - Vehicle labeling
    - Operator responsibility for violations
    - No special driver training or licensing
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# Additional Issues for Driverless Operation

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- **Special license plate**
- **Emergency stop mechanisms for occupants**
- **Communication to owner/operator for emergency conditions**
- **Owner/operator information available for post-incident data exchanges**
- **Legislature must be notified of application, with 120-day hold period to decide on need for any additional legislation**

# What next for state regulations?

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- Further updates of California regulations based on public input, experience in the field, new technology developments
- Uncertain prospects for additional state legislation (Google backed off lobbying)
- Industry standards development proceeding, but very slowly
- Everybody waiting for NHTSA to act (but don't hold your breath)
  - Their 5/30/13 policy statement advised states to hold off on authorizing public use of Level 3 or above



# Broader Policy Issues for National Consideration (State, local level)

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- Define business models for funding supporting infrastructure deployment
- Define public policy actions to facilitate automation implementation
- Facilitate national harmonization of state goals and regulations
- Clarify Fed/state/local responsibility boundary
- Collect lessons learned from Safety Pilot and CV Pilots
- Lessons learned from other transportation tech. rollouts (e.g. 511, Next Gen air traffic control)

# General Recommendations

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- Focus on connected vehicle capabilities to provide technology for cooperation first
- For earliest public benefits from automation, focus on transit and trucking applications in protected rights of way
  - Professional drivers and maintenance
  - Direct economic benefits
- To accommodate technology limitations:
  - Partial automation in simplest operating conditions (protected freeway lane cruising)
  - Higher automation only under strict restrictions on speed, weather and infrastructure protection
- Develop enabling technologies for Level 5 automation

# CV/AV Actions for State Government

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- **Outreach to regions and cities about needed or desirable modifications to their infrastructure**
- **Provide cost-sharing for California teams competing for national projects**
- **Support field testing in California, facilitating access to roadside infrastructure**

# AV Actions for State Government

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- Study changes needed to roadway infrastructure (communications, pavement markings, signage, cooperative infrastructure)
- Promote development of AV testing sites for industry and researchers
  - **Competitiveness for national projects**
- Identify sites for early AV field testing with (limited) infrastructure support or protection and facilitate partnerships for national FOTs
- Estimate economic development potential for California being the leader in AV tech.

# What to do now?

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- Focus on connected vehicle capabilities to provide technology for cooperation
- For earliest public benefits from automation, focus on transit and trucking applications in protected rights of way
  - Professional drivers and maintenance
  - Direct economic benefits
- Capitalize on managed lanes to concentrate equipped vehicles together
- Develop enabling technologies for Level 5 automation (software verification and safety, real-time fault identification and management, hazard detection sensing,...)