Caltrans Interests in Connected/Automated Vehicles

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Today’s Transportation Challenges
Connected Vehicle Concepts and DSRC
Connected Vehicle Applications
Safety Pilot Model Deployment
Affiliated Connected Vehicle Test Beds
California Connected Vehicle Test Bed
Automated Vehicle Levels and Definitions
Caltrans/PATH History with Automated Vehicles
Related Current Automated Vehicle Activities
Operational Considerations
Today’s Transportation Challenges

Safety
- 32,367 highway deaths in 2011
- 5.3 million crashes in 2011
- Leading cause of death for ages 4 - 27

Mobility
- 4.8 billion hours of travel delay
- $101 billion cost of urban congestion

Environment
- 1.9 billion gallons of wasted fuel

National Vision for Connected Vehicles

**Infrastructure Messages**
- Signal Phase and Timing
- Fog Ahead
- Train Coming
- Drive 35 mph
- 50 Parking Spaces Available

**Vehicle Data**
- Latitude, longitude, time, heading angle, speed, lateral acceleration, longitudinal acceleration, yaw rate, throttle position, brake status, steering angle, headlight status, wiper status, external temperature, turn signal status, vehicle length, vehicle width, vehicle mass, bumper height
Technology for Safety - 5.9 GHz DSRC

What is it?
• Wi-Fi radio technology adapted for the vehicle environment
• Low cost; easy to build in large quantity
• FCC originally allocated spectrum in 1999; revised in 2004 and 2006

How does it work?
• Messages transmitted 10 times/second (~300m range, restricted to line of sight)
• **Basic Safety Message (BSM)**: vehicle position, speed, heading, acceleration, size, brake system status, etc.
• Privacy is protected (vehicle location is **NOT** recorded or tracked)

Benefits of DSRC technology compared to radar/laser technology:
• Reduced cost
• Improved reliability; fewer false alarms
• Increased performance; addresses more crash types

Drawbacks to using DSRC technology:
• Both vehicles need to be equipped in order to gain the benefit
• Requires back-office security infrastructure
Connected Vehicle Applications

SAFETY APPS (V2V)
- Forward Collision Warning (FCW)
- Emergency Electronic Brake Light (EEBL)
- Intersection Movement Assist (IMA)
- Blind Spot Warning (BSW)/Lane Change Warning (LCW)
- Left Turn Across Path / Opposite Direction (LTAP)

SAFETY APPS (V2I)
- Red Light Violation Warning
- Curve Speed Warning
- Stop Sign Gap Assist
- Stop Sign Violation
- Railroad Crossing Violation Warning
- Spot Weather Impact Warning
- Oversize Vehicle Warning
- Reduced Speed/Work Zone Warning
- Pedestrian Warning for Transit Vehicles
- Smart Roadside

MOBILITY APPS
- Integrated Dynamic Transit Operations (IDTO)
- Intelligent Network Flow Optimization (INFLO)
- Multi-Modal Intelligent Traffic Signal System (M-ISIG)
- Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.)
- Enable Advanced Traveler Information System (EnableATIS)
- Freight Advanced Traveler Information System (FRATIS)

ENVIRONMENT APPS
- Dynamic Low Emissions Zone
- Dynamic Eco-Lanes
- Eco-Traveler Information
- Eco-Signal Operations
- Eco-ICM
- Support AFV Operations

ENVIRONMENT APPS
- Enhanced Maintenance Decision Support System
- Information for Maintenance and Fleet Management Systems
- Variable Speed Limits for Weather-Responsive Traffic Management
- Motorist Advisories and Warnings
- Information for Freight Carriers
- Information and Routing Support for Emergency Responders

Road Weather
Moving towards Infrastructure Deployment

- Pilots/Early Deployments
- Defined Safety (V2I), Mobility (V2V & V2I), AERIS and Weather Apps
- FHWA Deployment Guidelines
- NHTSA Decision Heavy Vehicles
- NHTSA Decision Light Vehicles

Timeline:
- 2011: Defined V2V Apps
- 2012: Application Development
- 2013: NHTSA Decision Light Vehicles
- 2014: NHTSA Decision Heavy Vehicles
- 2015: FHWA Deployment Guidelines
- 2016: Pilots/Early Deployments
Connected Vehicle Safety

• NHTSA Agency Decisions
  o 2013 NHTSA agency decision on V2V safety communications systems
  o Similar milestone in 2014 for a decision regarding V2V safety technology on heavy vehicles
  o Information to support the decisions will come from many sources, including the Safety Pilot Model Deployment

• Policy Work (ongoing)
  o System Security
  o Privacy
  o Governance
  o Business Models
  o Legal Issues
Safety Pilot Model Deployment, Ann Arbor

- 2800 vehicles (cars, buses, and trucks) equipped with V2V devices
- Will provide data for determining the technologies’ effectiveness in reducing crashes
- Includes vehicles with integrated safety applications, and others that use aftermarket devices (not built into the vehicle)
- Applications being tested include:
  - Blind Spot Warning/Lane Change Warning
  - Forward Collision Warning
  - Electronic Emergency Brake Lights
  - Intersection Movement Assist
  - No Not Pass Warning
  - Driver Control Loss Warning
Affiliated Connected Vehicle Test Beds

- Real-world, operational test beds that offer the supporting vehicles, infrastructure, and equipment to serve the needs of public and private sector testing and certifications activities
- Draft Memorandum of Agreement (MOA) – the purpose is to create an affiliation of 5.9 GHz DSRC roadside equipment makers, operators of V2I installations, and developers of applications that use V2I communications
  - Agreements will help to facilitate the sharing of tools and resources across all locations to bring about the future deployment of 5.9 GHz DSRC and other V2I communications technology
  - Based on feedback from the draft version, a second version is now being circulated for consideration by stakeholders
- The finalized MOA is expected to be ready by March 2014
Affiliated Test Bed Sites

- **Michigan:**
  - 2008 Proof of Concept Test Bed in Oakland County (Detroit region)
  - Safety Pilot Model Deployment (Ann Arbor)
- **New York** (2008 ITS World Congress)
- **Florida** (Orlando; 2011 ITS World Congress)
- **Virginia** (under construction in Northern Virginia)
- **Arizona** (Maricopa County [Phoenix])
- **California** (installed 2005; currently being upgraded)
California Connected Vehicle Test Bed

- Proposed
- TBD
- Existing

Stanford
Cambridge
Page Mill
Portage/Hansen
Matadero
Ventura
Los Robles
Maybell
Charleston
California Connected Vehicle Test Bed

1. Stanford
2. Cambridge
3. California
4. Page Mill
5. Portage/Hansen
6. Matadero
7. Curtner
8. Ventura
9. Los Robles
10. Maybell
11. Charleston
Example Installation

6. Matadero Avenue
RSE goes above mast arm on the vertical Antenna on the mast arm; Needs Bracket
Actual Installation (Page Mill Road and El Camino Real)
Example Layout Schematic

Intersection list:
Stanford
Cambridge
California
Page Mill
Portage / Hansen
Matadero
Ventura
Los Robles

Schematic 1
Somak Datta Gupta 01/18/2013

Note: Not to scale
Applications

- **Applications developed, under development, and planned**
  - Traveler Information (collect vehicle probe data; process it into traffic information and send it back to the driver)
  - Electronic Payment and Toll Collection
  - Ramp Metering
  - Cooperative Intersection Collision Avoidance Systems (CICAS)
  - Curve Over-Speed Warning
  - Auto Industry Applications, such as Customer Relations and Vehicle Diagnostics
  
  - Multi-Modal Intelligent Traffic Signal Systems (Pooled Fund Study project)
    - Intelligent Traffic Signal System (ISIG)
    - Transit Signal Priority (TSP)
    - Mobile Accessible Pedestrian Signal System (PED-SIG)
    - Emergency Vehicle Preemption (PREEMPT)
    - Freight Signal Priority (FSP)
  
  - Nissan/PATH Cooperative “Green Wave”
  - BMW/PATH Cooperative “Green Wave”
  - At-Grade Light Rail Crossing Safety Research
  - ITSIS (Intelligent Transit Stop Information System)
Connected Vehicles set the stage for Vehicle Automation!

**Infrastructure Messages**
- Signal Phase and Timing
- Fog Ahead
- Train Coming
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**Vehicle Data**
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## Summary of SAE International’s Draft Levels of Automation for On-Road Vehicles (July 2013)

SAE’s draft levels of automation are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level. “System” refers to the driver assistance system, combination of driver assistance systems, or automated driving system, as appropriate. NHTSA’s levels of automation are provided to indicate approximate correspondence.

### Human driver monitors the driving environment

<table>
<thead>
<tr>
<th>NHTSA level</th>
<th>SAE level</th>
<th>SAE name</th>
<th>SAE narrative definition</th>
<th>Execution of steering and acceleration/deceleration</th>
<th>Monitoring of driving environment</th>
<th>Backup performance of dynamic driving task</th>
<th>System capability (driving modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Non-Automated</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>1</td>
<td>Assisted</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>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>
</tbody>
</table>

### Automated driving system (“system”) monitors the driving environment

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</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<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>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>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 control other function, and still continuously monitor driving environment</td>
</tr>
<tr>
<td>2</td>
<td>Adaptive Cruise Control AND Lane Keeping Assistance; “Traffic Jam Assist” (Mercedes)</td>
<td>Must still continuously monitor the driving environment (system nags driver to ensure they are paying attention)</td>
</tr>
<tr>
<td>3</td>
<td>“Traffic Jam Pilot” (Volvo); Automated Parking</td>
<td>May read a book, text, or web surf, but must still be prepared to intervene when needed</td>
</tr>
<tr>
<td>4</td>
<td>Highway driving pilot; Closed campus driverless shuttle; Valet parking in garage</td>
<td>May sleep, and system can still 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>
History: NAHSC; 1997 Demo

- Core Member, along with PATH, of the National Automated Highway System Consortium (NAHSC)
- Highlight was the 1997 Demo on I-15 in San Diego
- Passenger car automation demonstrated
- NAHSC ended its work in 1998
History: 2003 Bus Demo

- Caltrans and PATH continued automated vehicle research after the end of the NAHSC
- Changed focus to heavy vehicles: buses and trucks
- Hosted a national workshop on Bus Automation in 2003, also on I-15 in San Diego
- Light Rail alternative?
History: Truck Platooning

- Caltrans and PATH tested automated truck platoons on a closed track in 2003
  - Significant fuel savings measured (12-18%)
- Real-world testing by PATH in Nevada in 2009 confirmed the fuel savings benefits
Vehicle Assist and Automation

- Steering automation only on narrow right-of-way: circulator system in Eugene, OR; San Mateo Bridge Toll Plaza
- Oregon system operated in revenue service
Truck Platooning on I-710

- Caltrans and PATH have partnered with LA Metro and Gateway Cities to win FHWA EAR grant funding
- Efficient movement of trucks travelling in and out of the Ports of LA and Long Beach
- Builds on prior truck development work from 2003 and 2009 projects
- Pilot Test
Cooperative ACC

- PATH continues working with Nissan to develop CACC for passenger cars
- Potential to safely reduce headways, which should increase throughput on existing roadways
- Travel speed could also be commanded by the roadway operator as a strategy for speed harmonization (VSL)
- Might be effective on Managed Lanes
Operational Considerations

- Intelligence balance between vehicles and infrastructure
- Emphasize heavy vehicle applications; early adopters?
  - Professional drivers; well-maintained vehicles; open standards for equipment; fleets sensitive to business costs
- Mixed or Segregated Operation?
  - Mixed will offer safety improvements, but may not increase throughput (could decrease?)
  - Segregated should provide both safety and mobility benefits, in greater amounts, with complications
- Active Traffic Management (VSL?)
Questions and Discussion

For more information, please visit:

www.dot.ca.gov/research

Caltrans Improves Mobility Across California
**BSM also Effective for Mobility, Weather, and Environment Apps**

- Connected V2V safety applications are built around the SAE J2735 Basic Safety Message, which has two parts:
  - BSM Part 1
    - Contains the core data elements (vehicle size, position, speed, heading, acceleration, brake system status)
    - Transmitted approximately 10 times per second
  - BSM Part 2
    - Added to part 1, depending upon events (e.g., ABS activated)
    - Contains a variable set of data elements drawn from many optional data elements (availability varies by vehicle model)
    - Transmitted less frequently; triggered by an event
  - No on-vehicle BSM storage of BSM data
  - The BSM is transmitted using DSRC (range ~300 meters)

- The BSM is tailored for low latency, localized broadcasts required by V2V safety applications, but is also effective for other apps
Test Bed Objectives

Near Term Objectives
- Upgrade and rejuvenate the existing Test Bed
- Ensure compliance with national standards (RSE, Backhaul, and Back Office)
- Take current applications to operational status

Long Term Objectives
- Serve as an incubator and proving ground for Connected Vehicle technology and applications
- Build partnerships with a focus on current and future Connected Vehicle research
- Leverage the proximity to the Silicon Valley to take the Test Bed and associated research to the next generation

Users
- Automotive OEMs (BMW, VW/Audi, Mercedes, Toyota)
- DSRC Vendors (Arada, Savari, Denso?)
- Transit agencies (Santa Clara VTA, SamTrans)
- Potential Silicon Valley Partners