# PATH Experience in Road Vehicle Automation

**November 2015**

# Vehicle Control and Automated Driving Research at PATH

- **Strong emphasis for 25+ years → over 600 labor years of PATH effort**
- **Approached from perspectives of vehicle dynamics and control and human factors**
  - **Deep understanding of mechanical dynamics of vehicles**
  - **Designing for both high positioning accuracy and smooth ride quality**
  - **Driver and passenger acceptance based on ride quality and user interfaces**
- **Experimental verification on full-scale vehicles (20+ passenger cars, 7 heavy trucks, 6 transit buses, 1 snowblower)**

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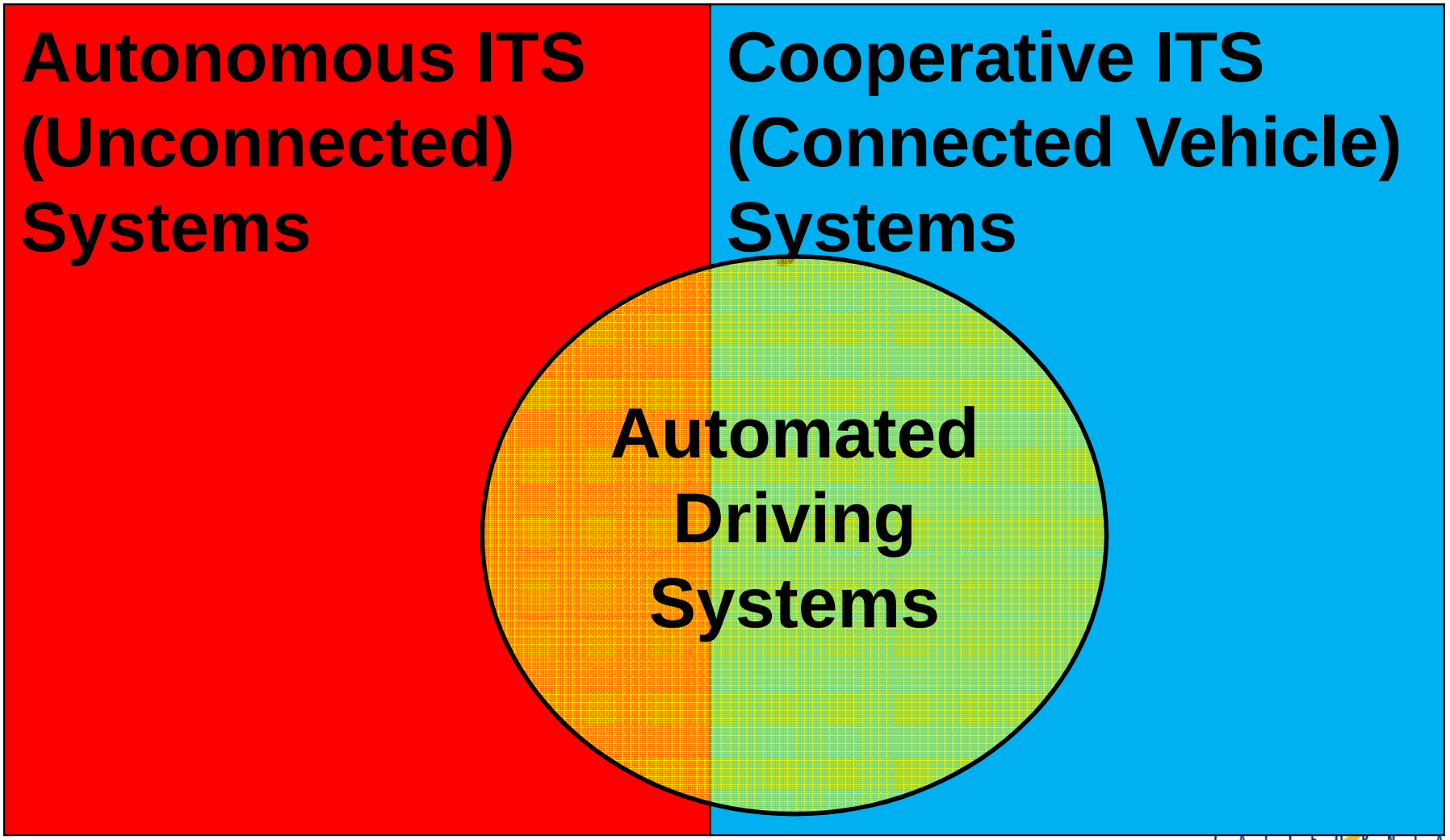
# Autonomous and Cooperative ITS

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# Automation is a Tool for Solving Transportation Problems

- Alleviating congestion
  - Increase capacity of roadway infrastructure
  - Improve traffic flow dynamics
- Reducing energy use and emissions
  - Aerodynamic “drafting”
  - Improve traffic flow dynamics
- Improving safety
  - Reduce and mitigate crashes
- Using V2V and I2V connectivity to gain these benefits

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# PATH Automation Milestones

- 1988 – Basic AHS concepts defined
- 1991 – Hierarchical information architecture
- 1992 – First automated vehicle experiments (4-car longitudinal control platoon, one car automated steering control) and first FHWA funding support
- 1993 – AHS Precursor System Analyses
- 1994-8 – National AHS Consortium (including Demo ’97)
- 1998 – Demo ’98, Netherlands
- 2000 – Demo 2000, Japan
- 2003 – Bus and truck automation demonstrated
- 2007-11 – Mobility Applications for VII project
- 2013 – New CA DMV and FHWA EARP projects
- 2014 – Bus guidance in public service

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# Key Accomplishments in Automation

- Definition of hierarchical architecture to simplify design and development of automation systems
- Creation of modeling and simulation tools to evaluate system designs and performance
- Development of high-performance automated test vehicles, both light and heavy duty
- Proving feasibility of high-accuracy vehicle control, while maintaining passenger comfort
- Demonstrating that automated driving is pleasant rather than threatening
- Public implementation of bus guidance

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# Lateral Control (Automatic Steering)

- **Many projects over 20+ years**
- **Extremely high performance systems, exceeding capabilities of human drivers**
  - **Precision docking bus (within 1 cm)**
  - **High-g curve following (0.8 g lateral)**
  - **High-speed reverse driving (>50 km/h)**
  - **High-speed lane tracking (to 170 km/h)**
- **Lane referencing from magnetic markers (our invention), DGPS/INS with digital maps, and video image processing**

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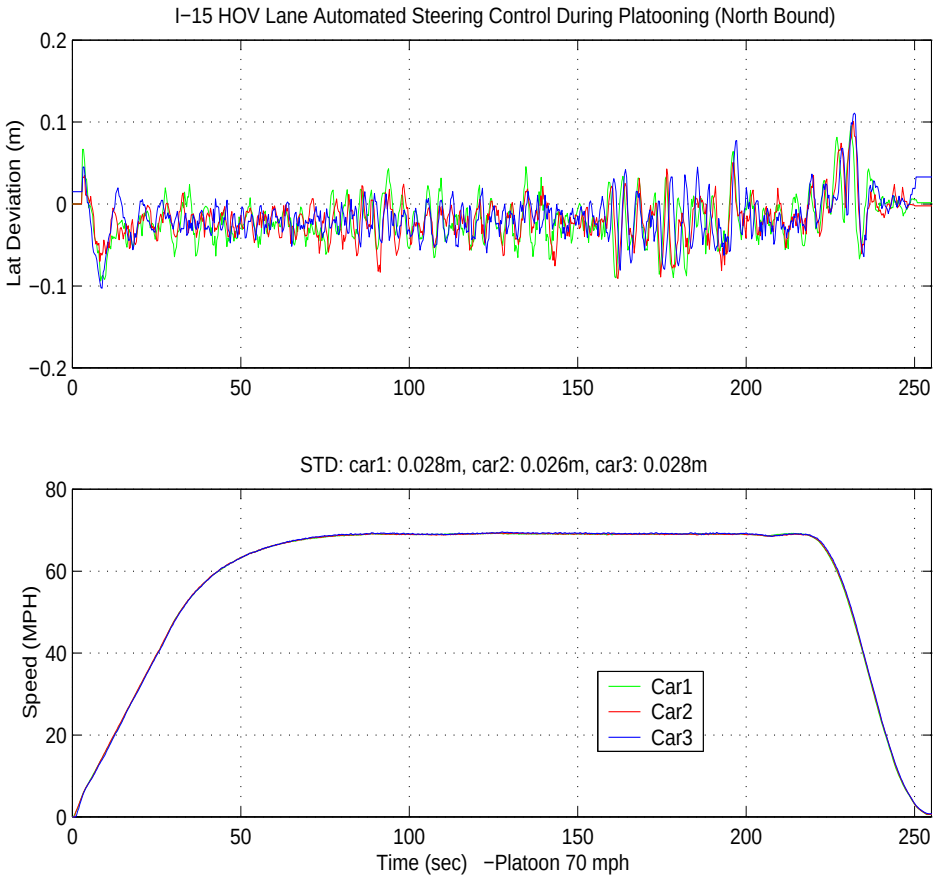
# Consistent, Accurate Steering on Highway




- **3 cm lateral variations at every location at highway speeds**

# Automatic Longitudinal (Platoon) Control

- **Engines and brakes of conventionally powered vehicles can be controlled accurately enough for precision vehicle following in platoons (20 cm accuracy)**
- **Precise vehicle following can be done with smooth ride quality**
- **Vehicles can be driven in close-formation platoons (3 – 5 m gaps) without exposing occupants to exhaust gases or impeding cooling air to radiators**
- **Vehicles can merge into the middle of a passing platoon, using wireless coordination**

# Automated Platoon Longitudinal Control and Merging

2000

1997

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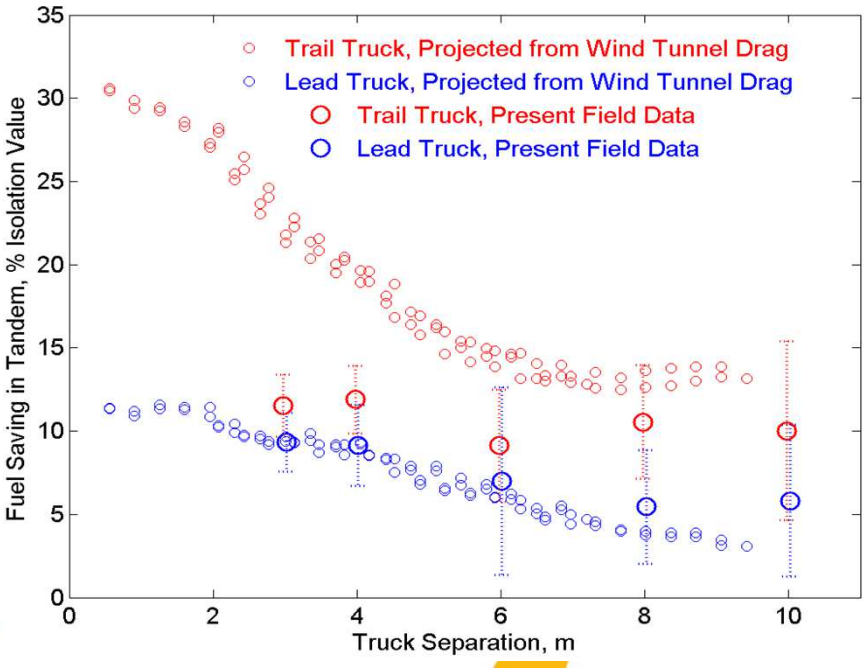
# Automated Truck Platooning, 2003-11

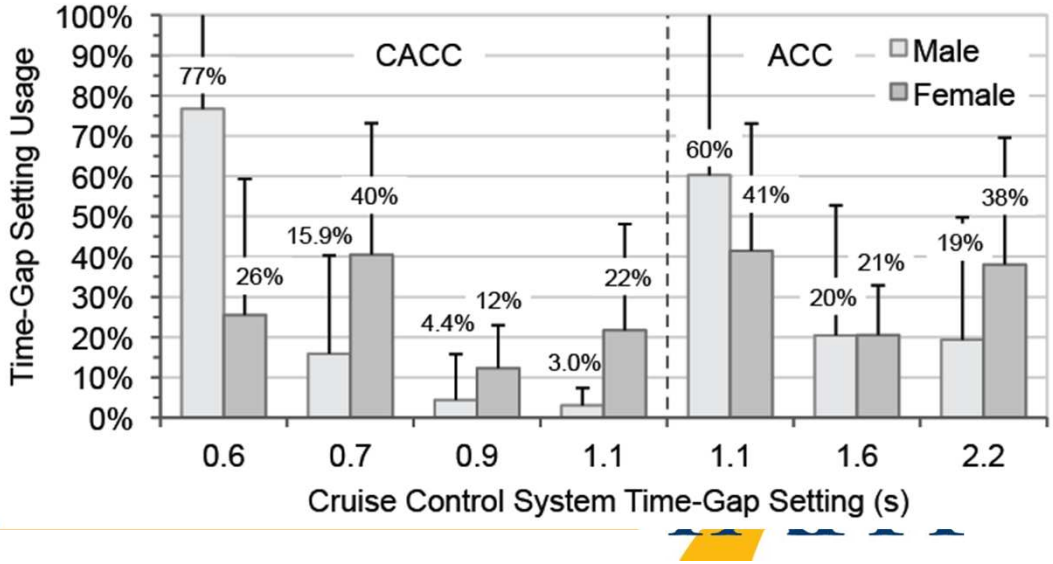
- **Developed and tested 2- and 3-truck platoons under automatic spacing control at gaps from 3 m to 10 m**
- **All hardware and software implementation by PATH, without industry help**
- **Fuel savings of 10 -15%**
- **Current EAR project with Caltrans, Volvo – 3-truck CACC**

# Cooperative Adaptive Cruise Control (since 2002)

- 3 generations of design, sponsored by Caltrans, FHWA and Nissan
- First-generation system showed driver acceptance of short gap following (0.6 s)
- Second generation showed string stability
- Traffic simulations showed lane capacity doubling potential
- Third generation for STOL Laboratory - 2015
- Current EAR project on CACC string strategies





# Other Recent Automation Projects

- **International scan of state of development of automation for FHWA EARP helped stimulate U.S. program – 2012 reports**
- **NCHRP 20-24(98) - AASHTO research roadmap on automation topics for state and local governments - 2014**
- **Technical support for California DMV in development of state regulations for public use of automated driving systems - ongoing**
- **Modeling of benefits of adding V2X to automation systems (Toyota ITC) - new**

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