Vehicle and Highway/Roadway Automation with VII

Xiao-Yun Lu, Ph. D.

***Researcher*, PATH, ITS, U. C. Berkeley**

***Scientist,* Lawrence Berkeley National Laboratory**

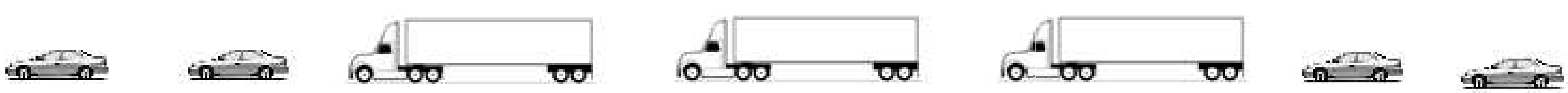
10/14/2020

Outlines

- **Vehicle Automation**
- **Highway/Roadway Automation**
- **Microscopic Simulation of Mixed Traffic with CAVs**

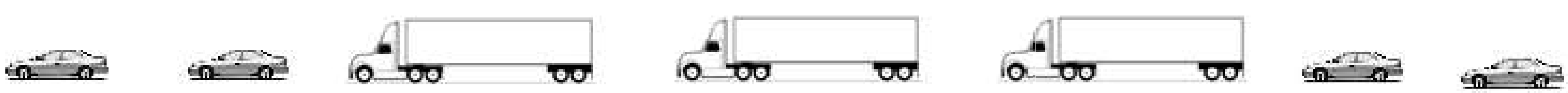
Vehicle Automation

- Vehicle Internal System Automation
- Driver Assistance System (DAS)
- Progressive Automation
- Full Automation for Operation
- Challenges for Vehicle Automation
- Rolls of VII in Vehicle Automation
- Fuel Saving for Truck CACC/Platooning
- Factors Affecting Vehicle Energy Consumption



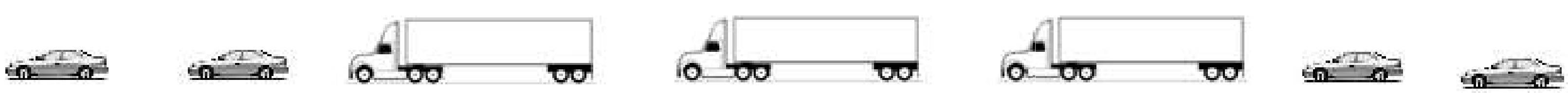
Vehicle Internal System Automation

- Onboard sensors
  - Wheel speed, acceleration/deceleration, gyro, GPS, road grade (tilting), brake pressure, …
- Onboard data bus:
  - Passenger cars: CAN Bus
  - Trucks: J1857 ➔ J1939 Bus
- Remote sensors:
  - Video camera, Doppler radar, lidar, …
- Control actuators

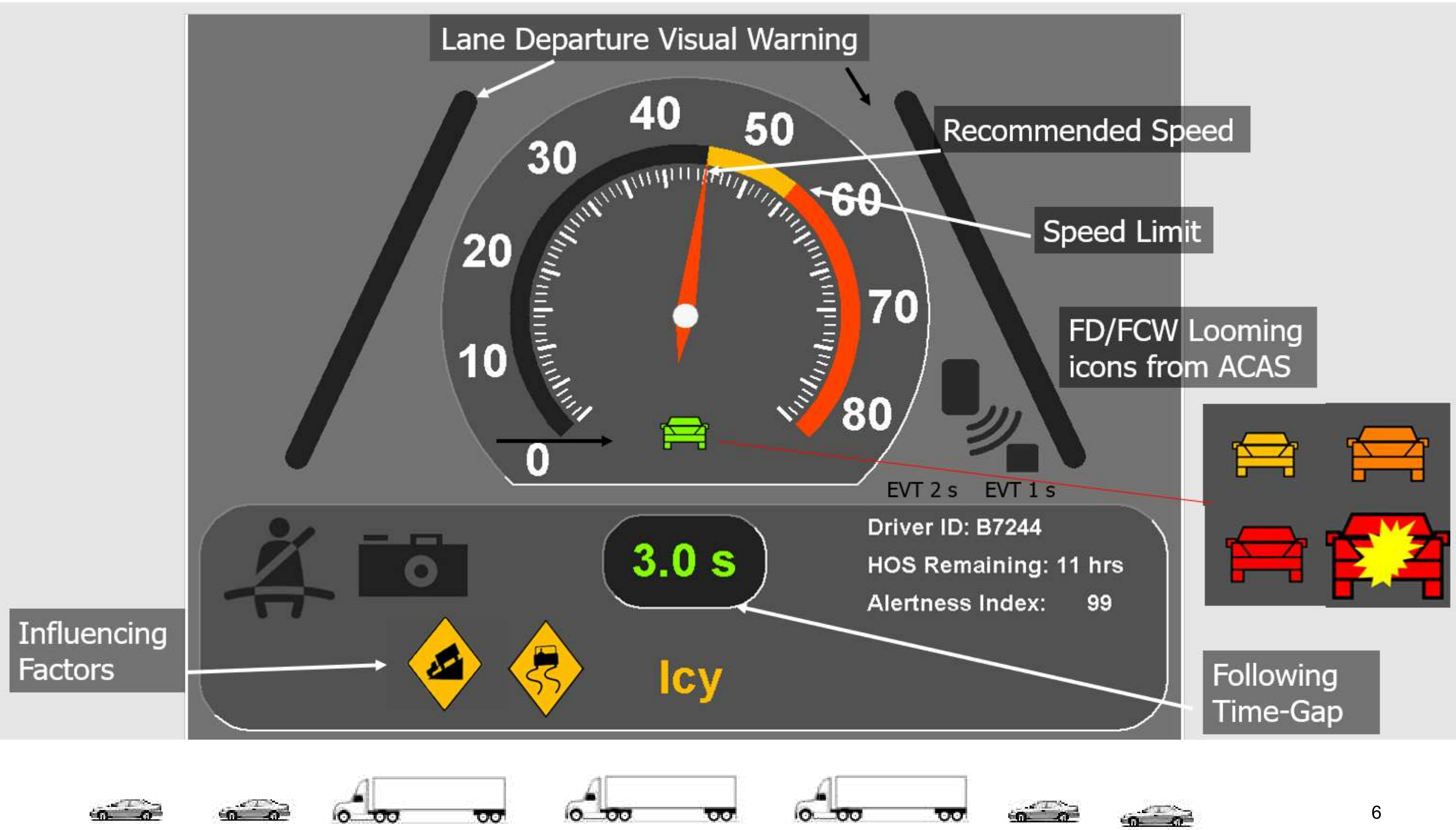


Vehicle Internal System Automation

- Engine:
  - Higher Level: Speed control and torque control
  - Lower Level:
    - Engine control – fueling timing
    - Sparking timing
    - Transmission control
    - Integrated control of engine and transmission
    - Jake brake control (truck)
- Transmission: Gearbox → E-Gearbox → fully automatic transmission
- Braking: power braking → E-braking → braking by wire
- Steering; power steering → automatic steering control module → steering by wire

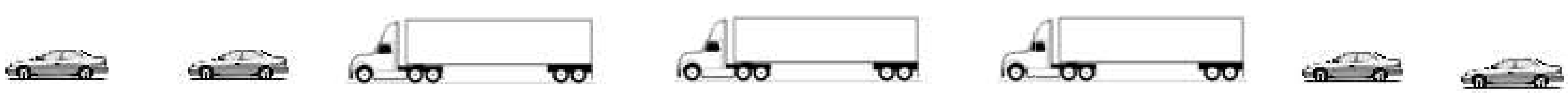


Passive Driver Assistance System – with Warning



Active Driver Assistance System – with Control

- Vehicle stability control (active rollover prevention)
- ABS
- Lane keeping & lane changing
- CC (Cruise Control), ACC (Adaptive Cruise Control)
- Automatic parking assistance (Parallel Parking – Lexius)
- Emergency braking
- Collision avoidance
- Collision avoidance with situation awareness (detection + comm)
- Coordinated Onramp Merging Assistance with comm.
- Coordinated Lane Changing Assistance with comm.
- Coordinated Emergency braking Assistance with comm.

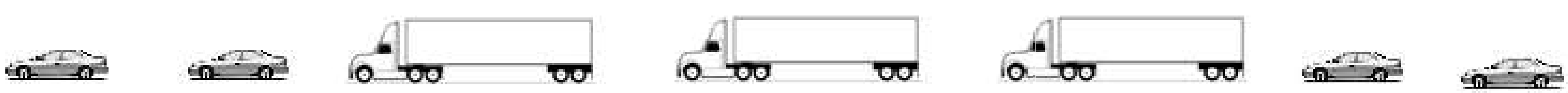


Progressive Automation

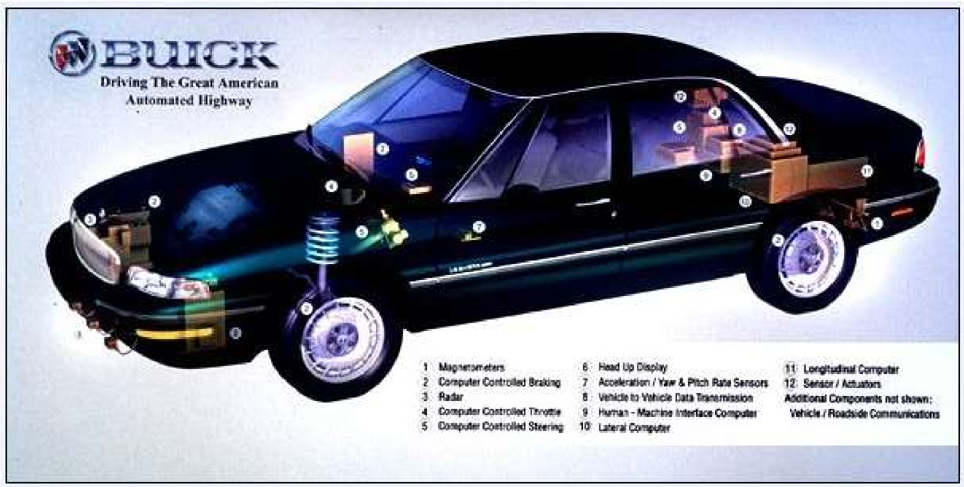
- **Partial Automation = Driver Assistance System**
  - **CC – Cruise Control: speed control; driver distance control**
  - **ACC - Adaptive Cruise Control: speed and distance control**
  - **Both of them need driver steering**

Progressive Automation

- Platooning
  - Constant distance gap, maintain string stability in following
- CACC – cooperative Adaptive Cruise Control
  - Constant Time Gap: higher speed with longer following distance
  - Mimic driver behavior, maintain string stability in folowing
  - Coordinated emergency braking
- Fully Automated Vehicle
  - Longitudinal Control
  - Lateral Control
- Autonomous vs. Connected Automated Vehicle (CAV)
  - Autonomous: Only using sensor detection for control
  - CAV: sensor + communication



Progressive Automation – PATH Automated Vehicles



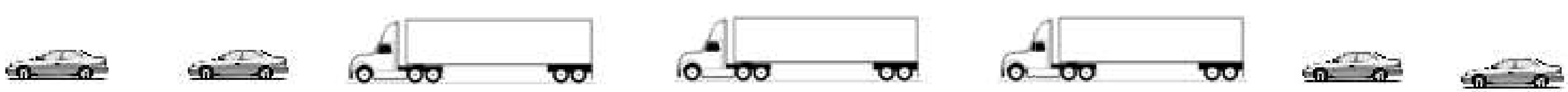
Progressive Automation – PATH CAV Milestones

1997: 8 fully automated Buick Platooning demo 6m following 60mph on I-15

2000: 3-car coordinated automated vehicle merging

2003: 2-Truck Platooning at 3m distance

2009: 3-Truck Platooning with 4m on SR722 Nevada at 55mph



Progressive Automation – PATH CAV Milestones

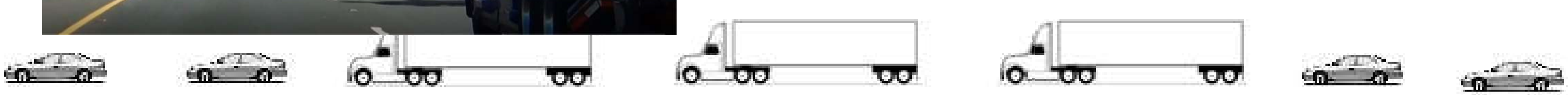
- **2015 - 2017: 3-Volvo Class-8 fully loaded truck CACC**
  - **on Transport Canada Test 4m**
  - **On highways with public traffic: I-80, I-580, Highway 4 & 24, I-680, I-5, I-205, I-110, I-66**

LA Demo I-110

Transport Canada Test Track, Montreal

On Highway 4 EB

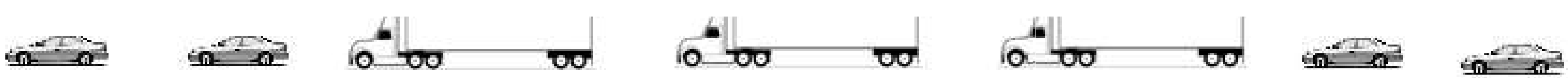
On I-80 EB



Progressive Automation – PATH CAV Milestones

2013: 4 - passenger Infiniti CACC driving with public traffic

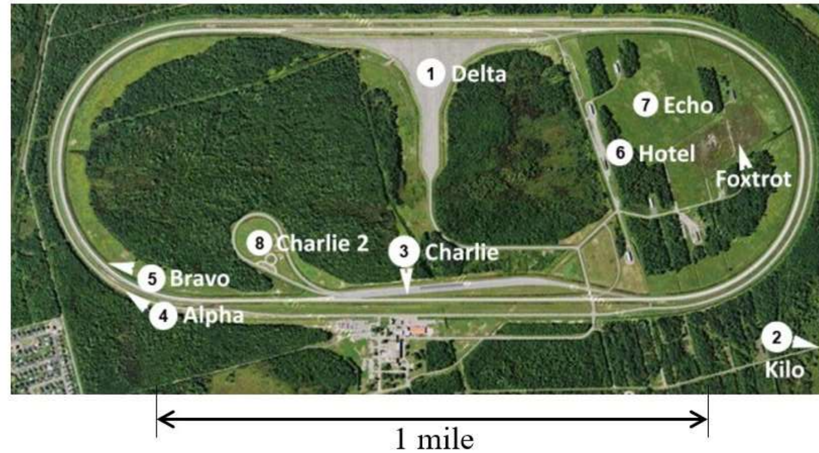
2015: Implemented CACC on 5 Cadillac of FHWA Saxton Lab



Progressive Automation – PATH CAV Milestones

- **2017: Test Track & Scenarios:**

4m CACC following



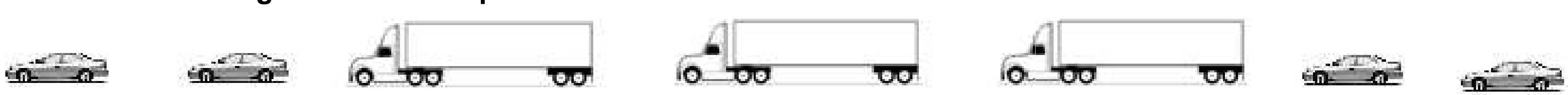
Transport Canada's Motor Vehicle Test Centre, Blainville, Québec

Speed variation with 18m D-Gap

Long combination vehicle testing

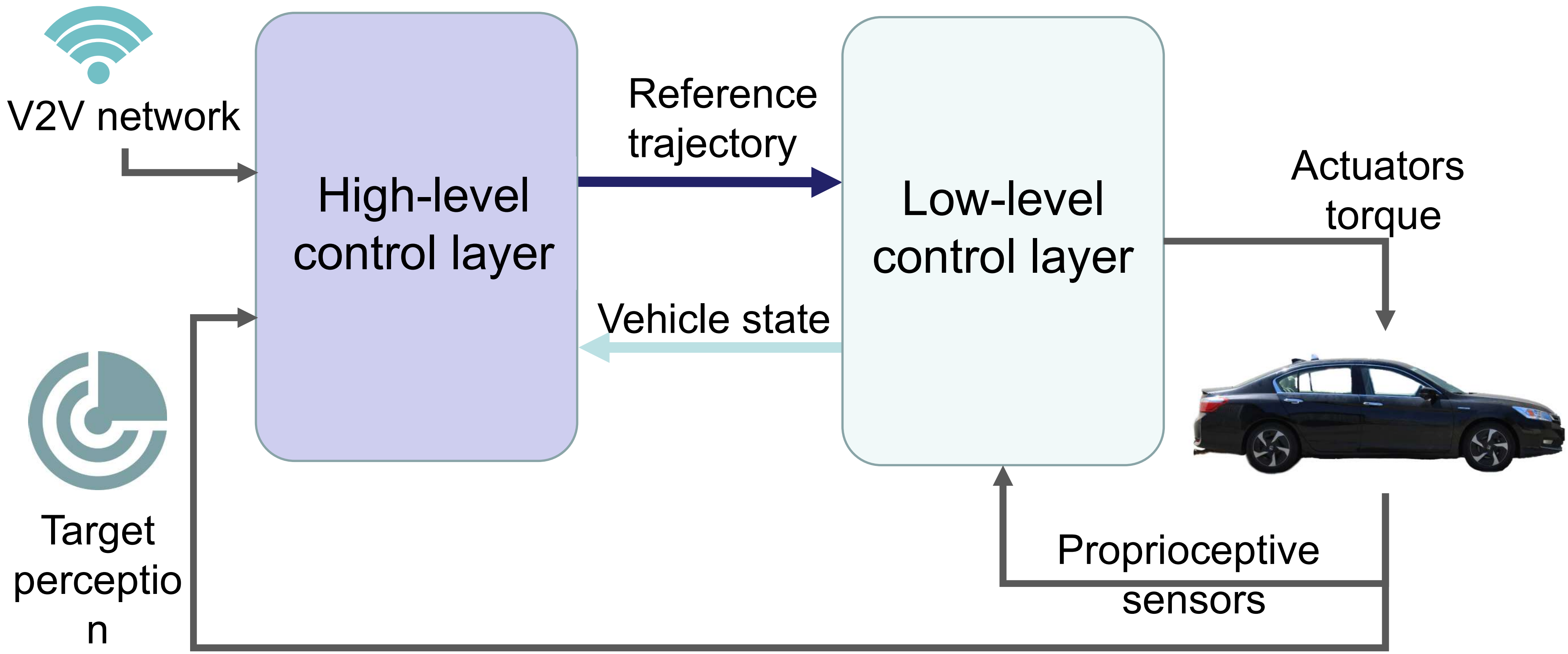
Cut-in CACC string with 35m D-Gap

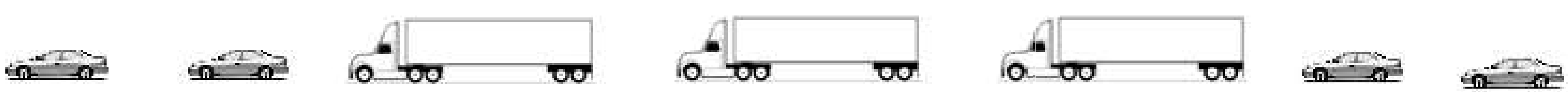
Manually driven SUV leading 3-truck CACC with 56m separation & 12m between trucks



Generic CACC Design for Vehicle with Different Powertrains

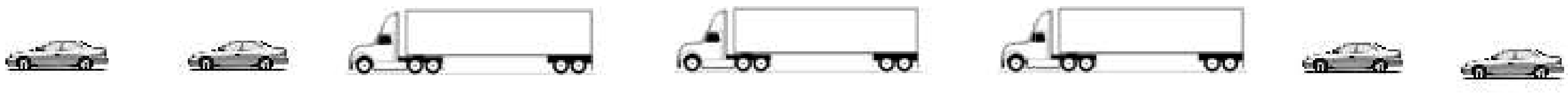
U.S. DEPARTMENT OF ENERGY SMARTMOBILITY Systems and Modeling for Accelerated Research in Transportation





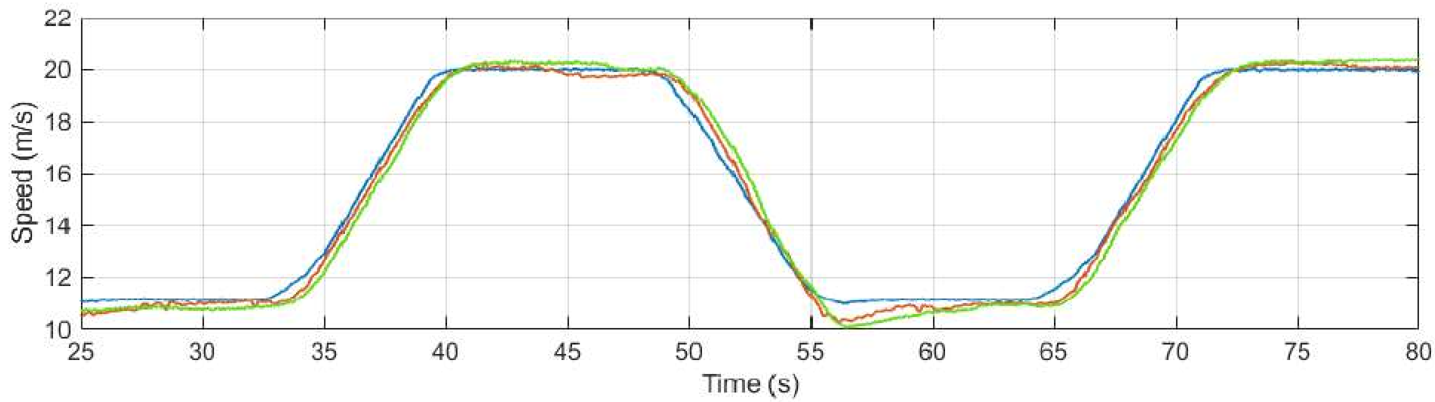
Generic CACC Design for Vehicle with Different Powertrains - Tests

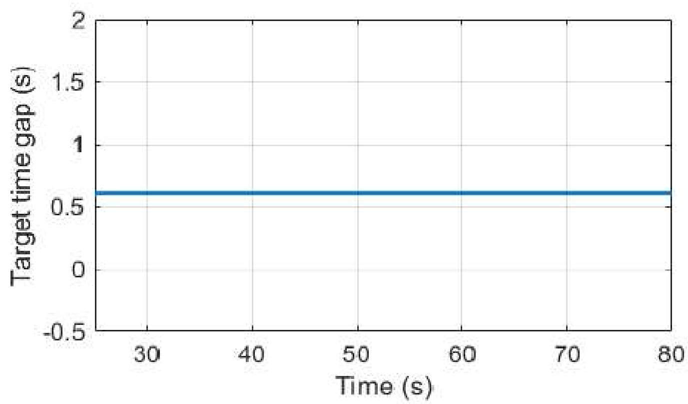
- CACC system tested in Crows Landing tracks
- Scenarios tested:
  - Speed steps with different rates
  - Smooth speed steps
  - Multisine profile for string stability study
  - Cutting in vehicle
  - Emergency braking

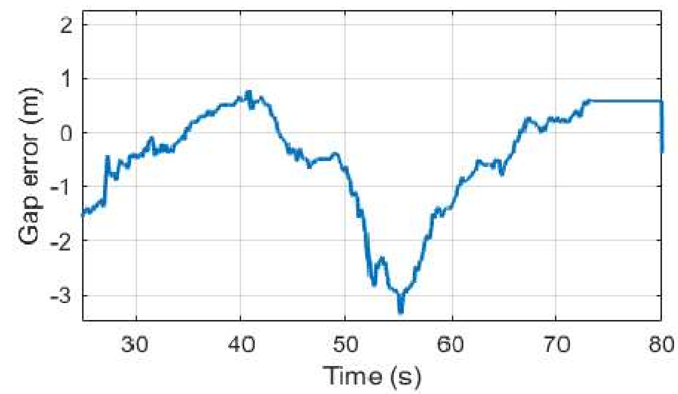


Generic CACC Design for Vehicle with Different Powertrains - Tests

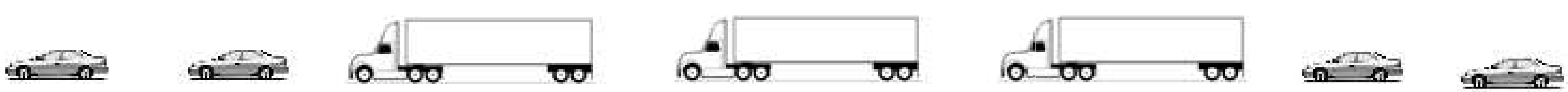
Speed steps of a=±1.5 m/s²





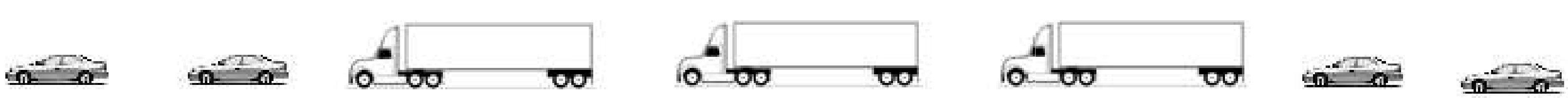


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



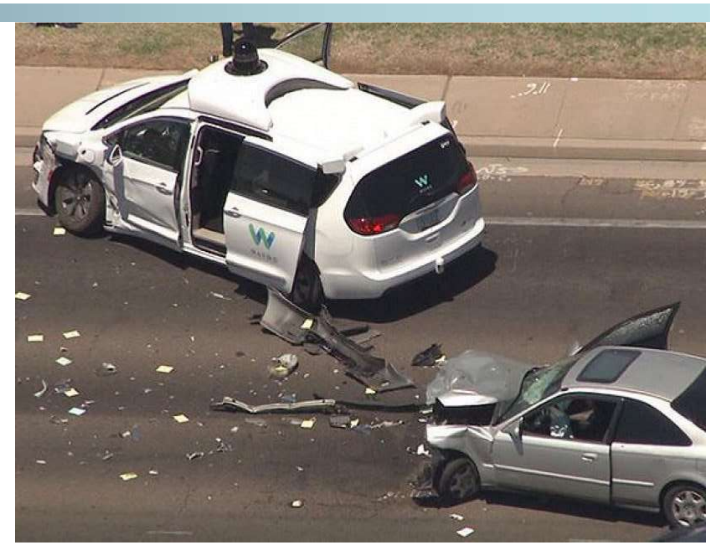
Challenges for Vehicle Automation

- Reliability of road and target detection/perception
  - Space
  - Time
- Interaction with others in mixed traffic
  - Complicated environment: road + traffic + other objects
  - Driver behavior differences
  - Vehicle control performance differences
- Roadway design: roadside detection & wireless communication
- Fault detection and management
- Institutional issues
  - Policies and regulation
  - Driver trust and acceptance



Challenges for Vehicle Automation

Tesla AutoPiolet



Waymore

Uber

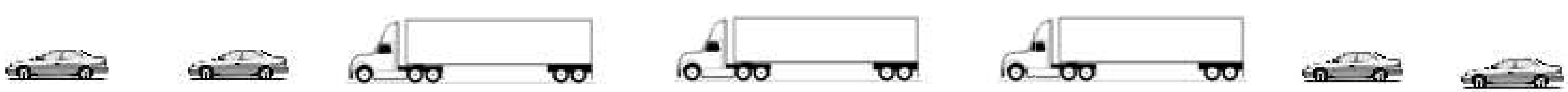
Challenges for Vehicle Automation – Where are We?

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) AUTOMATION LEVELS

Full Automation

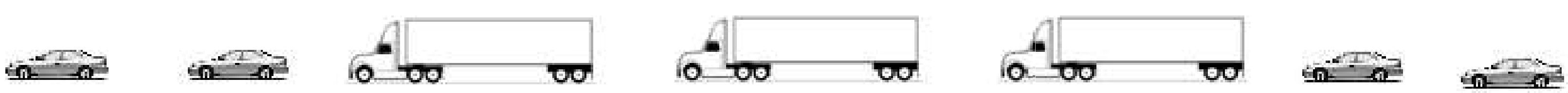
0	1	2	3	4	5
No Automation	**Driver Assistance**	**Partial Automation**	**Conditional Automation**	**High Automation**	**Full Automation**
Zero autonomy; the driver performs all driving tasks.	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

We are still here



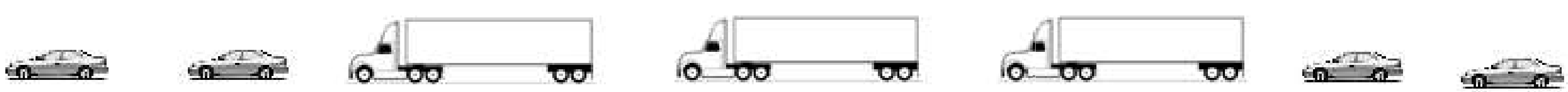
Roles of VII in Vehicle Automation

- **VII:**
  - **V2V: DSRC - Dedicated Short Range Communication**
  - **I2V: Vehicle to/from Infrastructure**
  - **I2I: Infrastructure to Infrastructure (data system, ATM)**
- **DSRC – local situation awareness**
  - **for vehicle guidance:**
    - **Longitudinally following**
    - **Lateral: lane keeping and lane changing**
  - **10+ Hz and 300 ~ 500m range**
  - **Dynamic assignment of Vehicle ID**
  - **Following IEEE Standard and *SAE***
- **DSRC vs 5G, which is better for V2V?**
  - **Small packet ~ 200 bytes, reliable, local, cyber security, …**



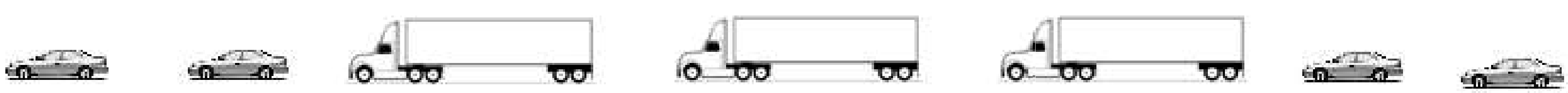
Roles of VII in Vehicle Automation

- Cooperative Driving
  - Changing driver behavior
  - Coordinated merging
  - Coordinated braking for collision avoidance and impact mitigation
  - Coordinated following (CACC & platooning) with shorter distance
    - Reducing fuel consumption due to aerodynamic drag reduction
    - Increasing traffic capacity
    - Collision avoidance (both lateral and longitudinal)

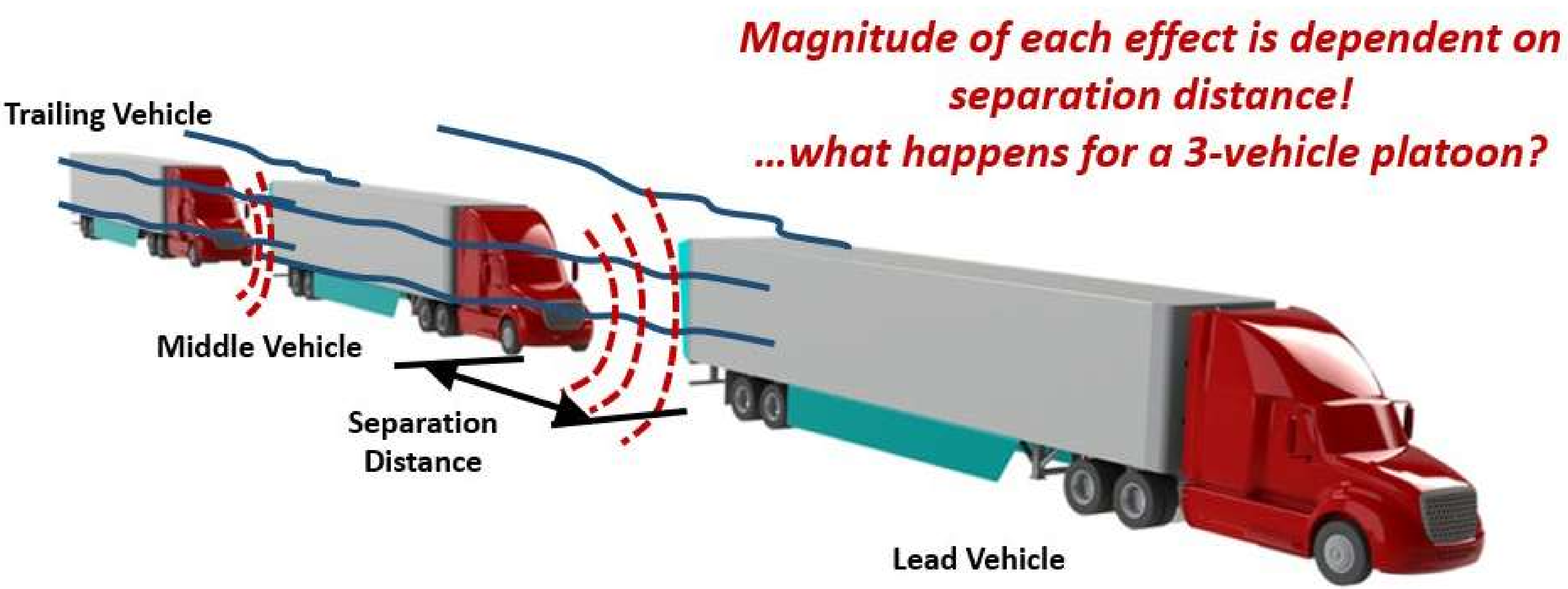


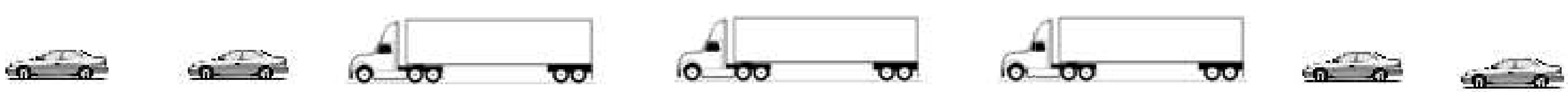
Roles of VII in Vehicle Automation

- **Active Safety**
  - Location
  - Speed
  - Lane ID if GPS is available
  - Throttle peddle deflection
  - Brake peddle deflection
  - Steering angle and rate
  - Fault mode
  - …



Fuel Saving for Truck CACC/Platooning



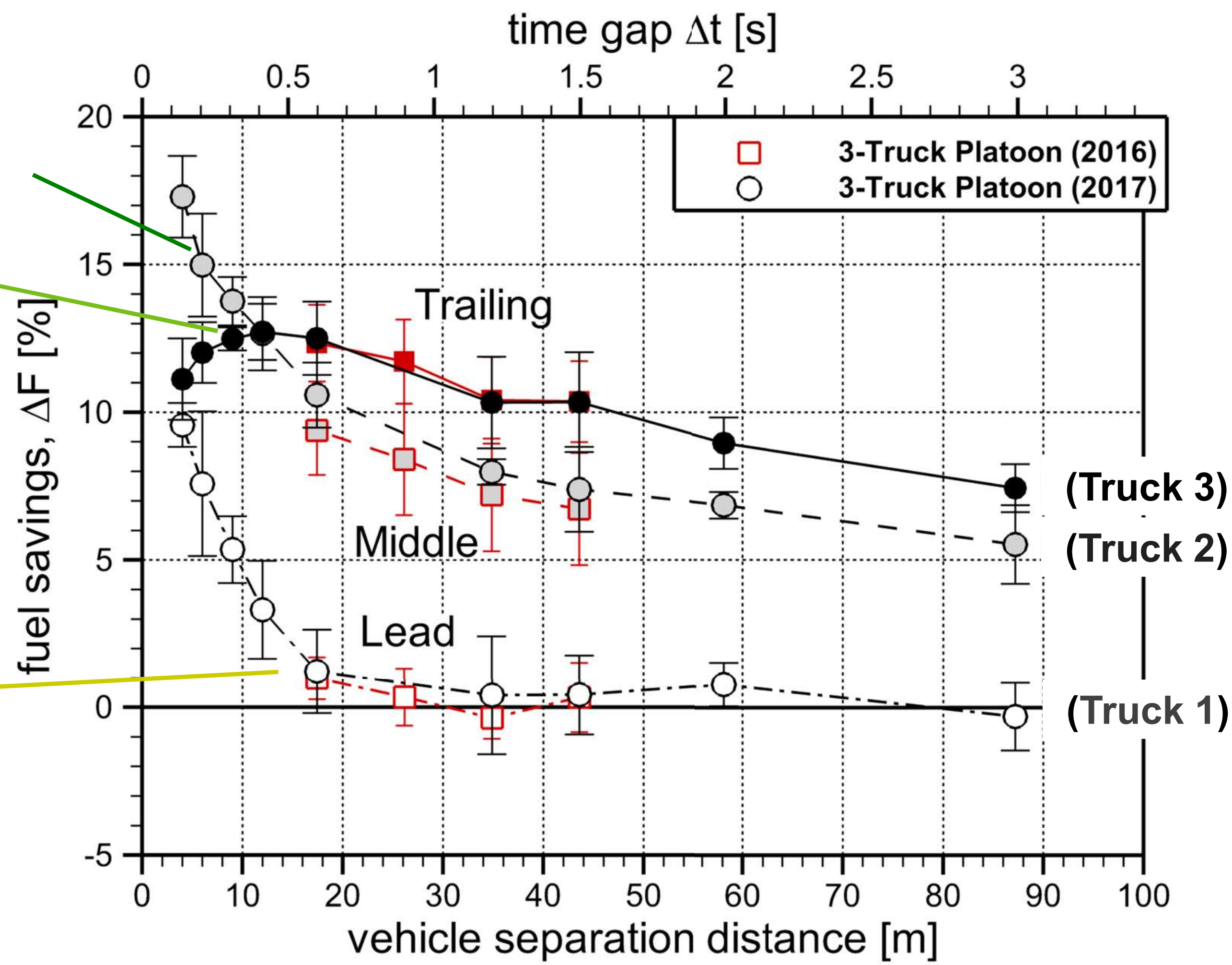


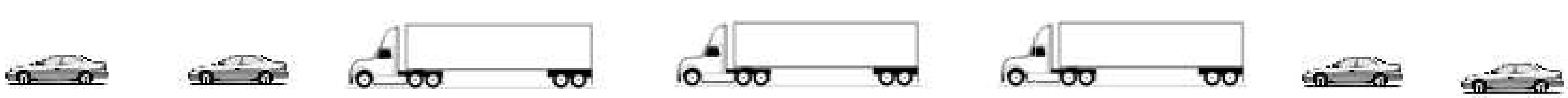
Fuel Saving for Truck CACC/Platooning

Truck 2 has highest savings at short D-Gap

Truck 3 savings decrease at short D-Gap

Truck 1 has savings at short D-Gap





Fuel Saving for Truck CACC/Platooning

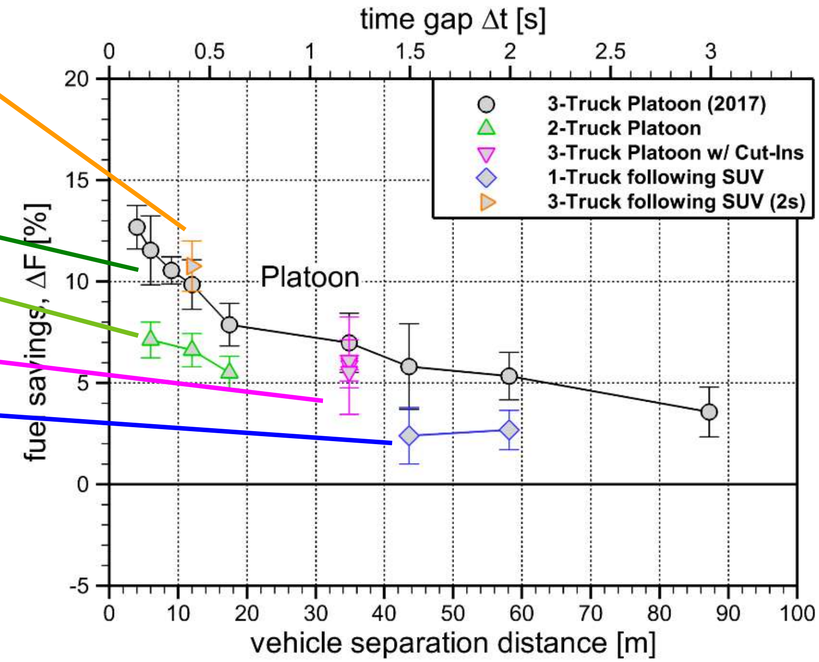
SUV leading 3-truck CACC

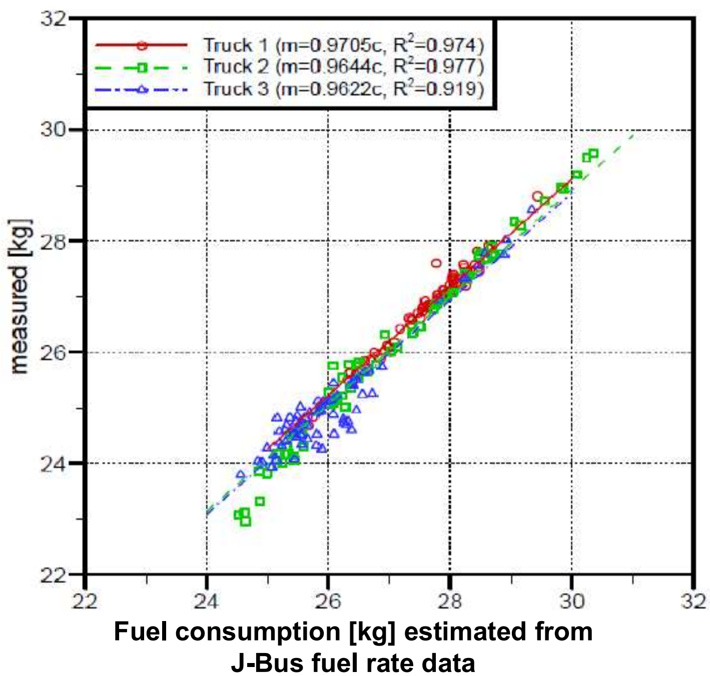
Average fuel savings of 3-truck CACC

Average fuel savings of 2-truck CACC, same D-Gap

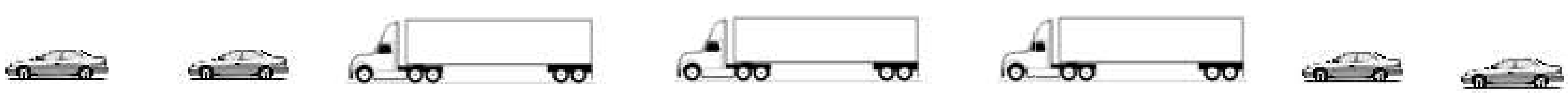
3-truck CACC with cut-in

1 truck following SUV

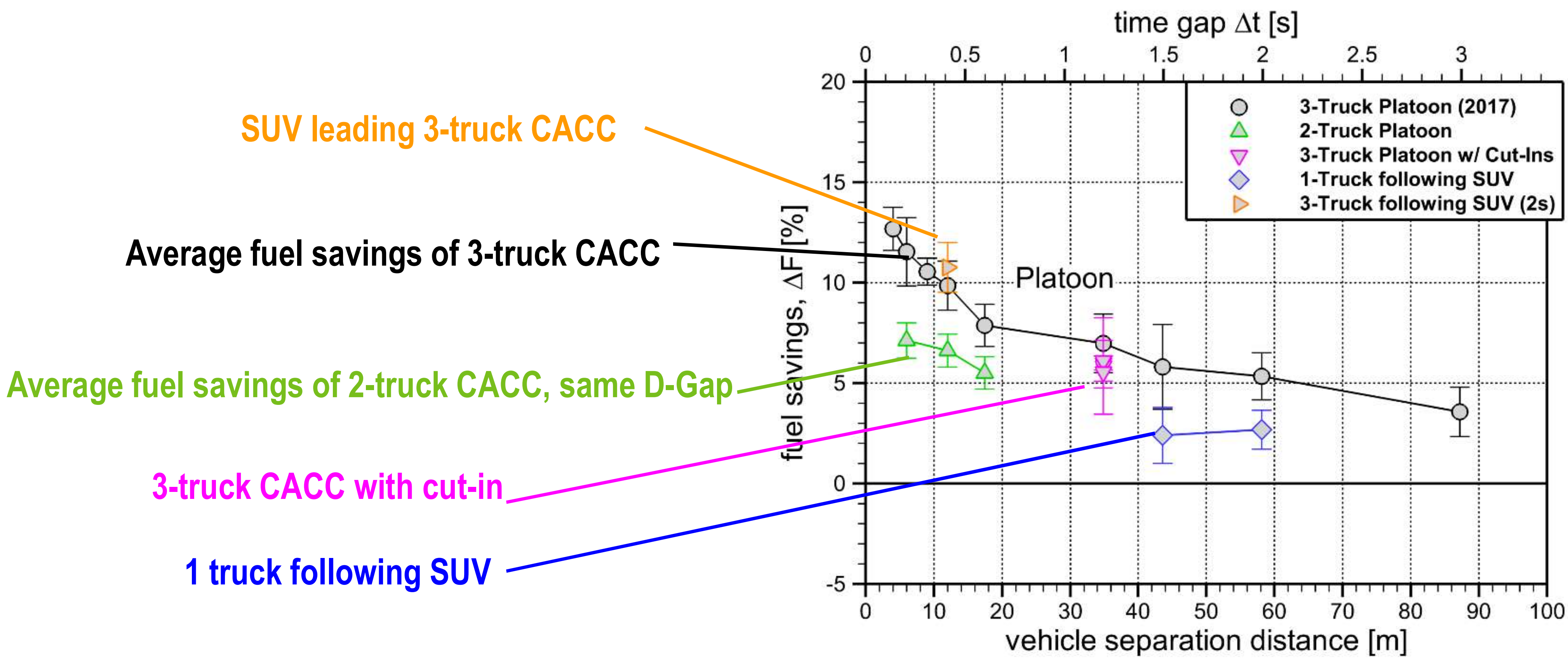


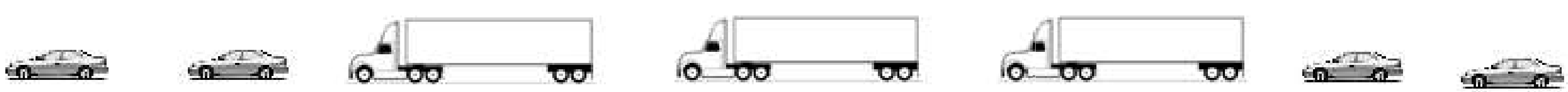


Fuel consumption: measured vs. estimated from J-Bus fuel rate



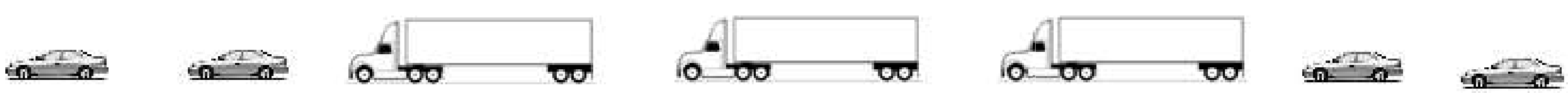
Fuel Saving for Truck CACC/Platooning





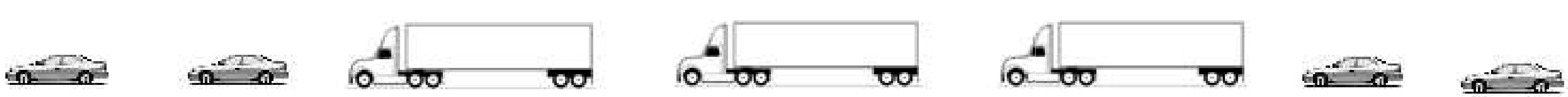
Factors Affecting Vehicle Energy Consumption

- Vehicle energy savings in real world traffic mainly affected by factors at three levels: (a) meso/macroscopic traffic patterns; (b) local vehicle following behavior; and (c) vehicle level: control & powertrain/drivetrain characteristics
- Local vehicle following behavior affect aerodynamic drag and speed
- Progressive market penetration of CAVs and Active Traffic Management (ATM) changes the traffic pattern significantly
- Field test of CAVs impact (for different market penetration) on energy savings is cost prohibitive
- Needs a reasonably accurate models to simulate fuel consumption



Factors Affecting Vehicle Energy Consumption

- **Main factors affecting fuel consumption at local traffic and vehicle levels:**
  - **Mass**
  - **Speed**
  - **Road grade**
  - **Acceleration/deceleration**
  - **Following distance in traffic**
  - **Position in CACC string/platoon**
  - **Vehicle geometry and shape (streamlined or not)**
  - **Control (automatic or manual) performance**
  - **Powertrain and drivetrain characteristics**

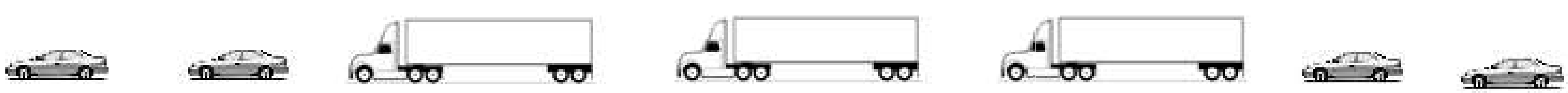


Highway and Roadway Automation

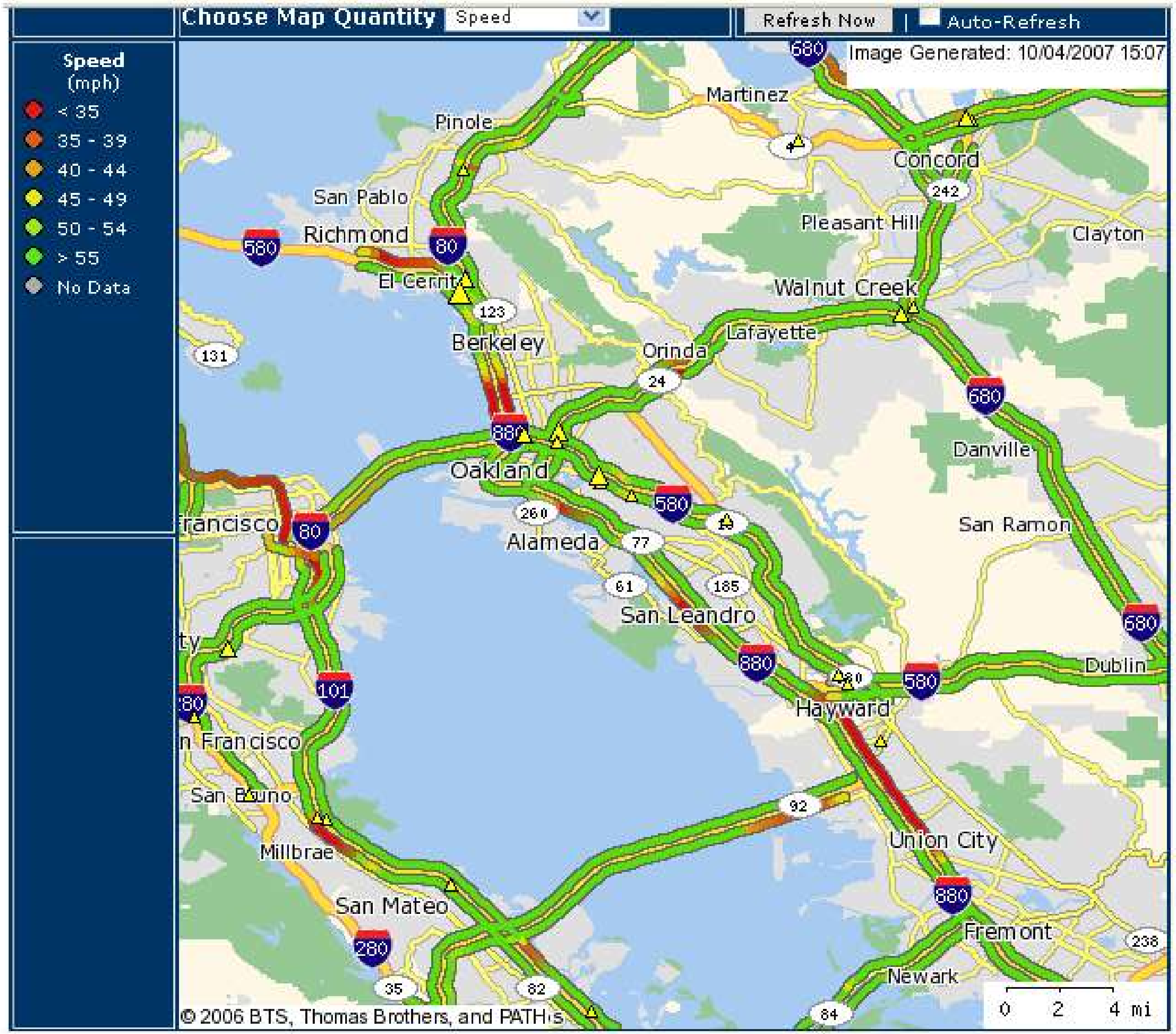
- Traffic Monitoring and Measurement
- Network Traffic Measurement and Control: PeMS
- Roles of V2V & V2I in Highway/Roadway Automation
- Active Traffic Management (ATM)
- Integrated Traffic Signal Control with CV and CAVs
- Challenges for Highway/Roadway Automation
- Towards Fully Automated Highway/Roadway System

Traffic Monitoring and Measurement

- Ground Sensors
  - Inductive loops (single, dual)
  - Roadside-vehicle wireless transponder
  - Video camera
  - Microwave/Laser/Infrared/ radar
  - WIM
  - Air tubes
  - …
- Probe Vehicle or Connected Vehicles (CV)
  - Cellphone or modem (wireless comm.) + GPS + speed etc
  - Driver report

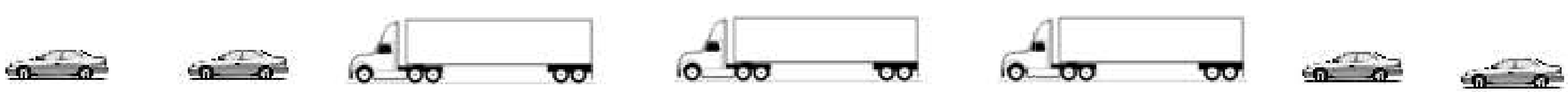


Traffic Monitoring and Measurement- PeMS



Traffic Monitoring and Measurement

- **Traffic State Parameter Estimation:**
  - Distance/time aggregate traffic parameters
    - Occupancy, Distance mean speed, Flow, Density
    - Link travel time
  - Onramp demand
  - Turning ratio
  - Onramp/off-ramp queue length
  - Time delay
  - Vehicle re-identification → ODs
  - Issues: Detector fault, communication fault, …

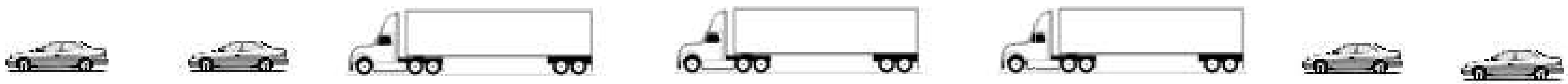


Active Traffic Management (ATM)

- Freeway:
  - Coordinated Ramp Metering (CRM)
  - Variable Speed Limit/Advisory (VSL/VSA)
  - Lane Management
  - Coordinated Onramp Merge
  - Incident/accident management

- Arterial Intersections
  - Active Traffic Signal Control (ATSC)
  - Coordinated Traffic Signal Control along an arterial corridor
- Network Level
  - Coordination of all sub-control

  Systems for overall system optimization



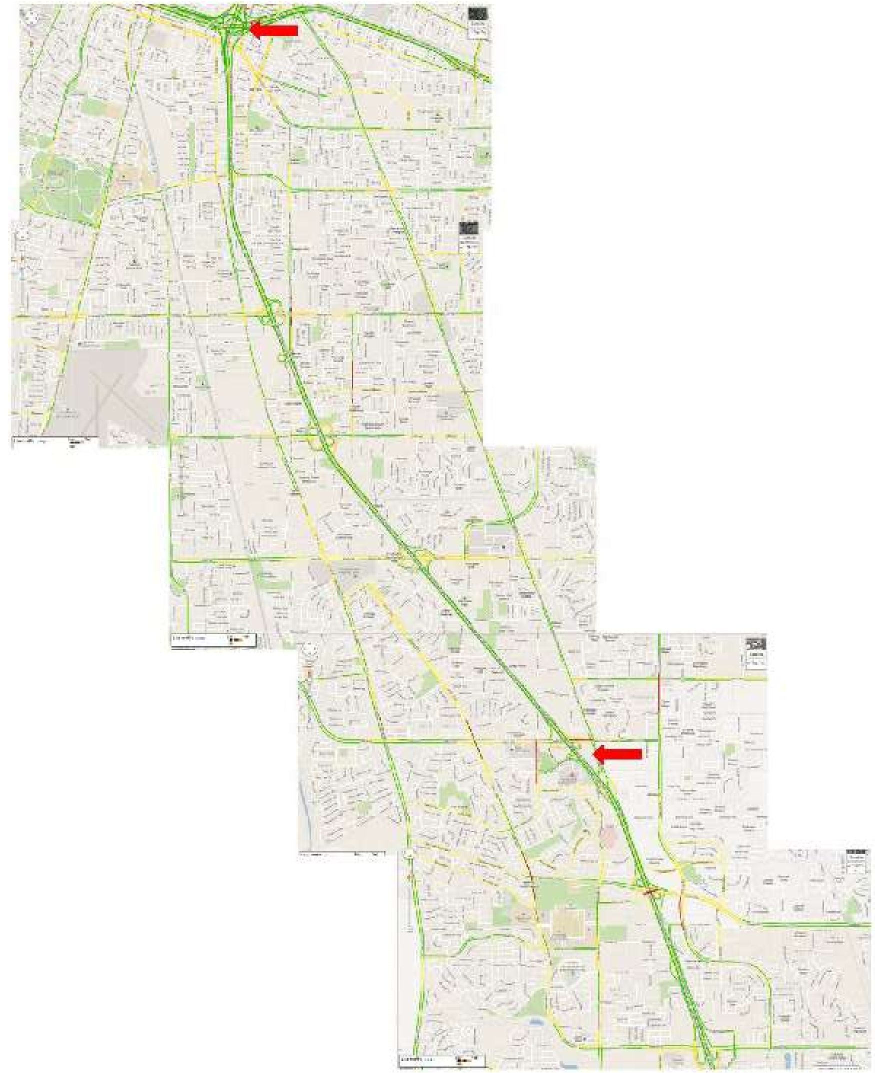
Active Traffic Management: CRM & VSA

- **Freeway Coordinated RM**
  - **SR99 NB, Sacramento, CA:**

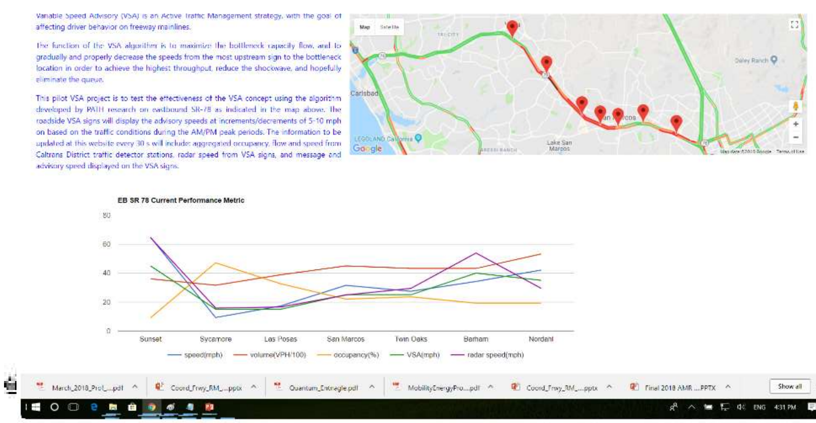
VMT increased by 5.39%,

VHT decreased by 1.64%,

Q (=VMT/VHT) increased by 7.25%.



- **Freeway VSA field test (2018)**
  - **SR 78 EB, San Diego, CA:**
    - **VMT increased by 2.72% on average.**
    - **VHT decreased by 6.28% on average.**
    - **Q increased by 8.71% on average.**



Active Traffic Management: Experiences

- **Coordination of Freeway Ramp Metering and Arterial Traffic Signals (ongoing)**
  - **I680 & Capitol, San Jose, CA: Coordination of all sub-control systems overall optimization**

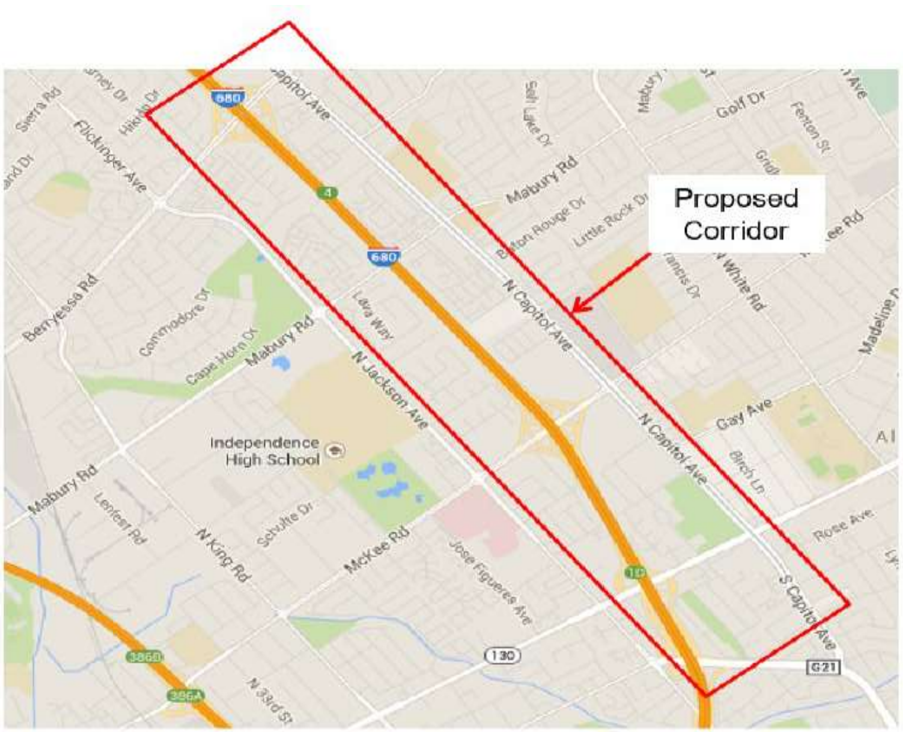
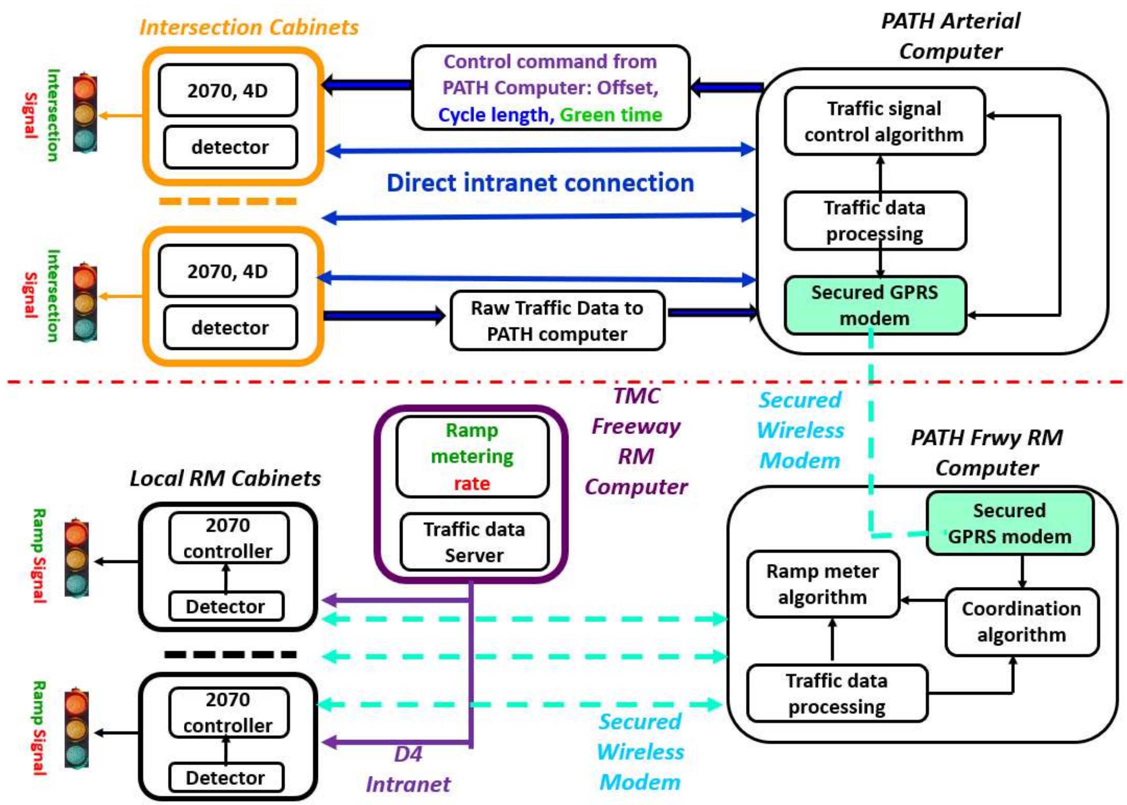
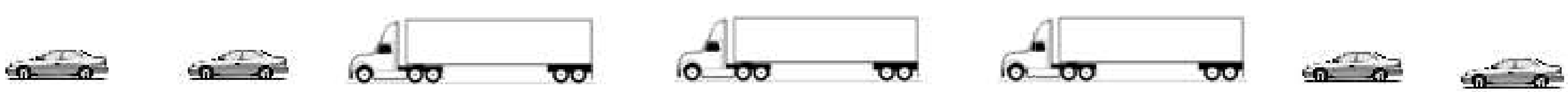


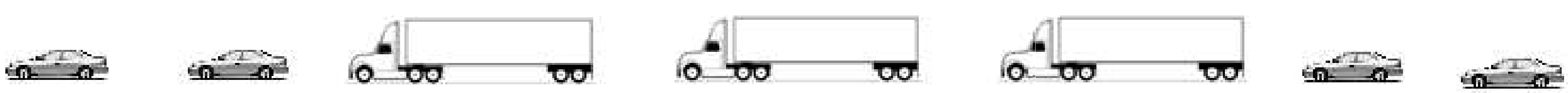
Figure 1 I680 (Capitol Expy. To Berryessa Rd.)



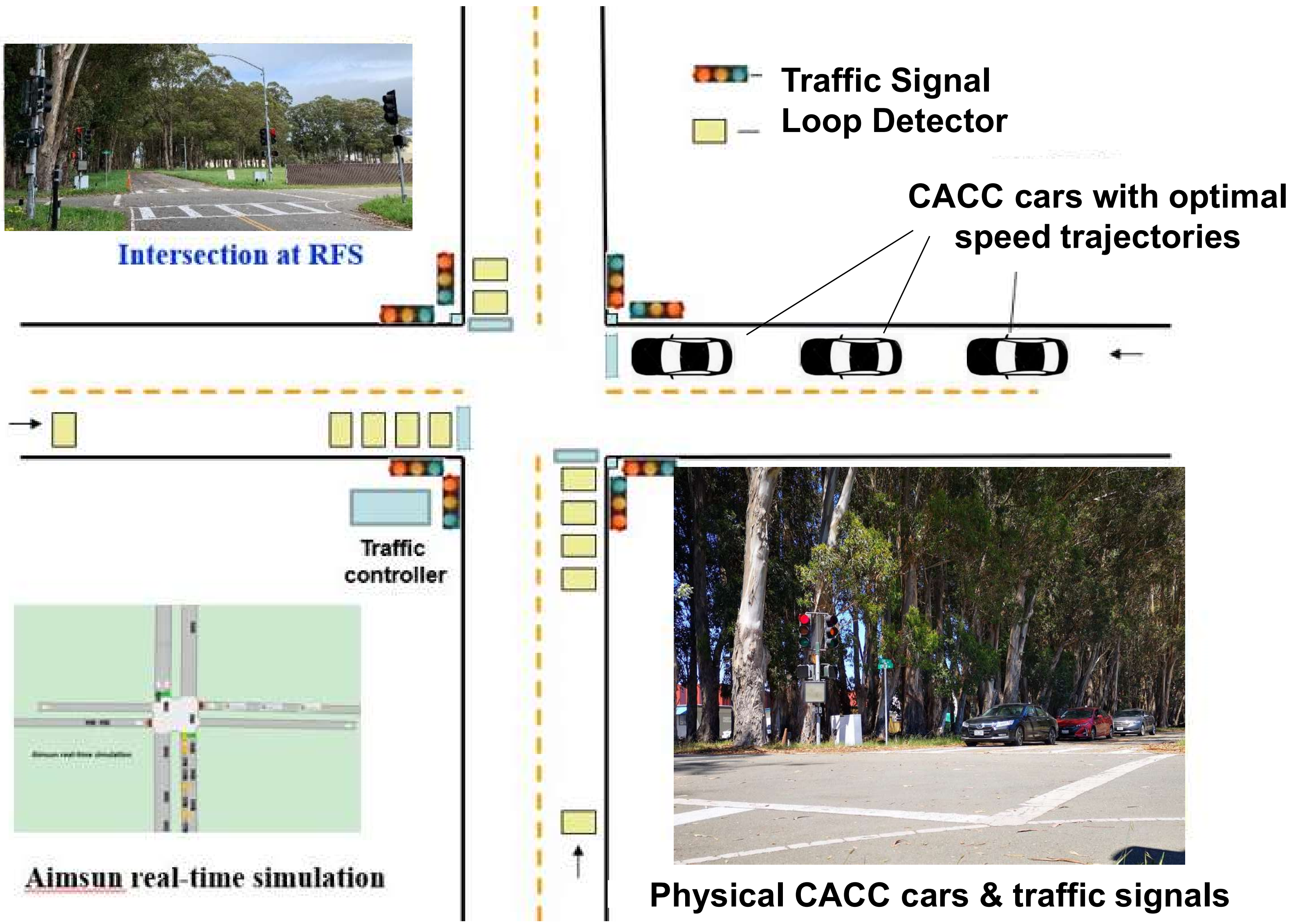


Integrated Traffic Signal Control with CAVs

- Intersection Active Traffic Signal Control
- Trajectory planning for CAVs: used as the set-speed for CACC
- Real-time simulation
  - Synchronized with traffic controller and the signal
  - To generate virtual traffic for signal activation
  - Repeatable test scenarios
- Physical CACC vehicles with V2I connection with 2070 controller
- Energy consumption measurement
  - Repeat 50~100 laps for each designed scenario
  - Gauge of actual fuel filled on each vehicle
  - On-vehicle fuel rate recorded if available from CAN Bus
  - Real-time simulation energy consumption of all traffic based on models



Integrated Traffic Signal Control with CAVs

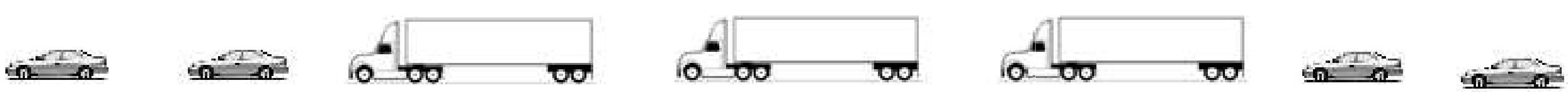


Integrated Traffic Signal Control with CAVs

Roles of V2V & V2I in Highway/Roadway Automation

Roles of V2V & V2I in Highway/Roadway Automation

- **Function: Real-time message passing**
  - **Reduce the Need to Sensors**
  - **Reduce time Delay**
  - **Better traffic state parameter estimation by fusion of CV data and road detector data**
- **Application**
  - **Traffic Monitoring and ATM**
  - **Integrated Intersection Traffic signal control and Safety**
- **Examples**
  - **Situation awareness for collision avoidance**
  - **Downstream congestion warning → shockwave reduction**
  - **VSL/VSA passed to vehicle for driver to follow**
  - **VSL/VSA used in CAV as set-speed for control**

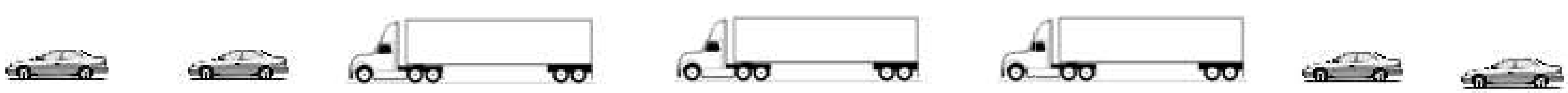


Roles of V2V & V2I in Highway/Roadway Automation

- **Limit of CV Data**
  - **CV data alone cannot measure flow nor density unless market penetration level is 100%**
- **Road sensor**
  - **Still necessary for freeway**
  - **Very important for intersection traffic and all target detection**
    - **For better safety**
    - **For integrated traffic signal control**

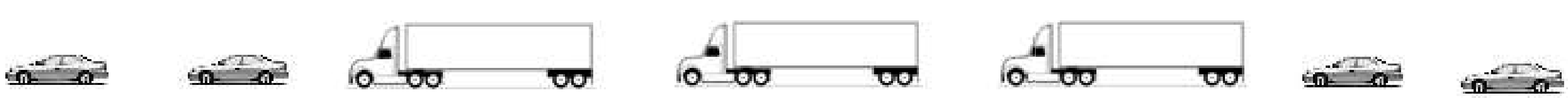
Roles of V2V & V2I in Highway/Roadway Automation

- Roadside and intersection sensor (radar + video camera)
  - Help in the situation vehicle sensor cannot see
- Dynamic road map broadcasting situation awareness ➔ collision avoidance
  - Road and lane geometry
  - Nearby all movement traffic
  - All vehicle position
  - Any moving object position including pedestrian
- Integrated traffic signal control
  - Driver warning initially
  - ADAS
  - CAV control eventually



Roles of V2V & V2I in Highway/Roadway Automation

- **Function:**
  - **Providing richer info ➔ Better perception for complicated traffic situation**
  - **Reduced vehicle onboard sensors ➔ reduced energy use**
  - **Reducing time Delay & improved highway capacity**
- **Application**
  - **Cooperative Driving: CACC & platooning**
  - **Situation awareness for collision avoidance:**
    - **Using DSRC passed other vehicle info**
    - **Using wireless passed roadside sensor information**
- **V2V & V2I is the only and eventual solution of automated vehicle deployment in urban area and in complicated traffic situation**
- **Autonomous vehicle must become *connected with VII***

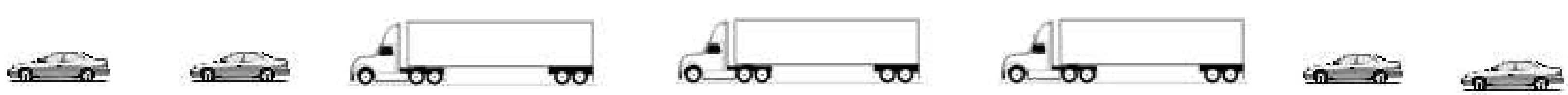


Challenges for Highway/Roadway Automation

- Capacity estimation for non-recurrent bottleneck
- Demand uncertainties
- Large scale system problem
- Integration of freeway and arterials
  - Open system - difficult to isolate
  - Limit onramp storage: e. g. US-101 near San Francisco
- Non-homogeneity of driver behavior
- User equilibrium approach for routing will no improve traffic
- Only system-wide optimal coordination (dynamic system equilibrium) can improve traffic in a messo and macroscopic level

Towards Fully Automated Highway/Roadway System

- V2V and V2I Communication system
- Automated vehicles technologies
  - Sensor technologies
  - Individual vehicle control and Cooperative Control
- Infrastructure systems
  - Sensor, communication
  - traffic control devices
- Institutional issues and driver acceptance
- Potential benefit
  - increased highway/roadway capacity, mobility and safety
  - reduced travel time, energy consumption, and emission
- Mixed traffic will last for long time with progressive market penetration of CAVs



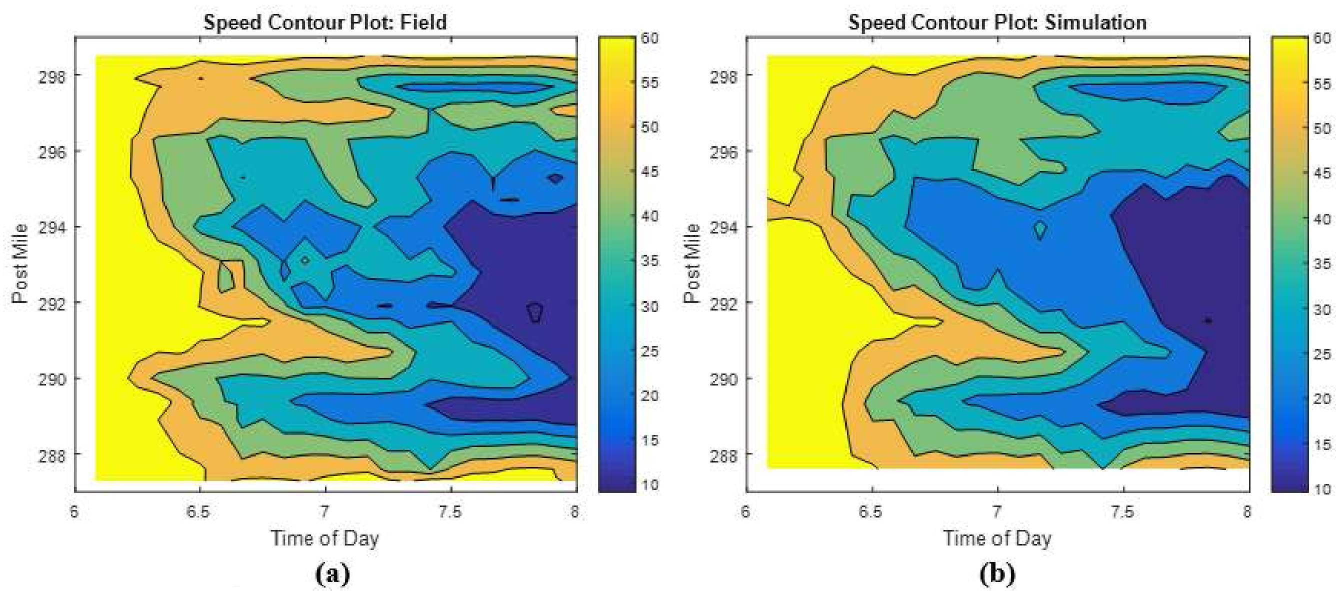
Simulation of Mixed Traffic with CV and CAVs

- **Traffic Flow GEH criteria**

Calibration of freeway flows.

Freeway: 5-min flows of SR-99 Northbound					
Detector Location (post-mile)	Target	Cases	Cases Met	% Met	Target Met?
Overall	GEH < 5 for > 85% of k	504	464	92.06%	Yes

- **Speed Cont**

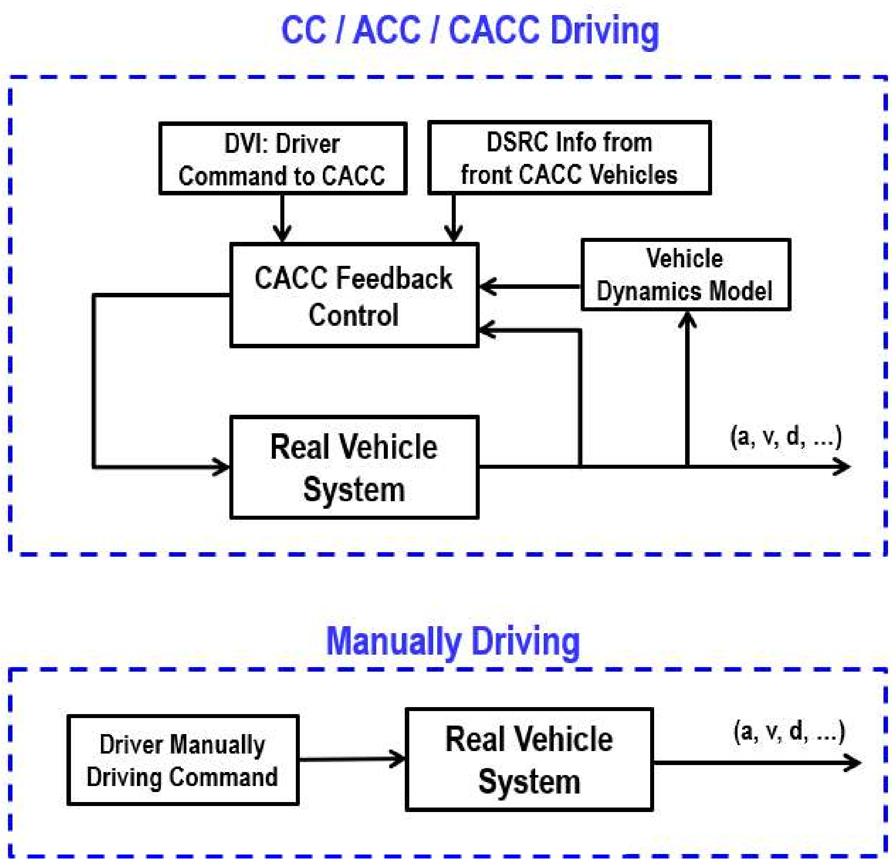


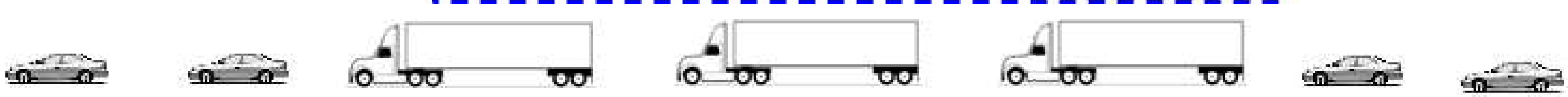
Comparison of contour plots of (a) field observed and (b) simulated speeds (mph).

Ref: X. Y. Lı **; Traffic**
Simulation ***Meeting*****,**
Washington D. C., 2017

Simulation of Mixed Traffic with CV and CAVs

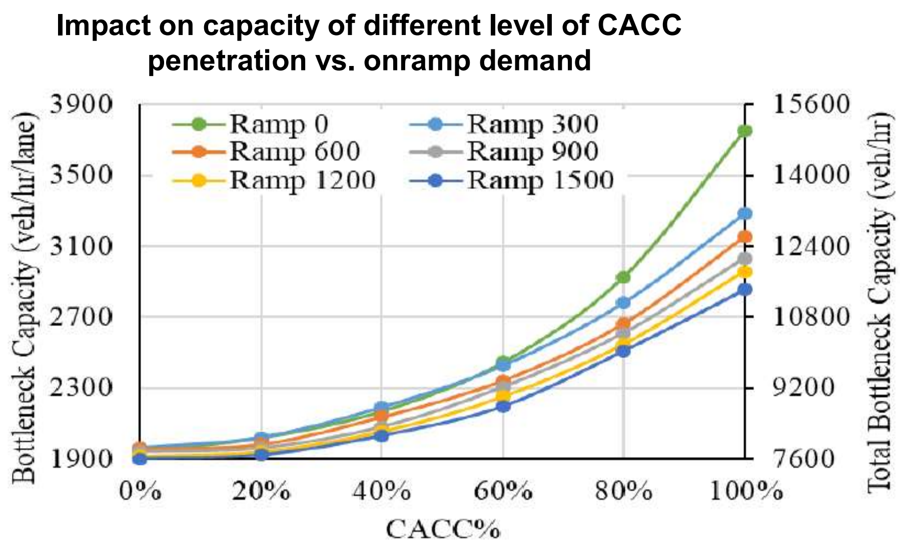
- **Modeling dynamic interactions with other vehicle for microscopic traffic simulation: to build simple vehicle following model to replace complicated feedback control system based on test data**

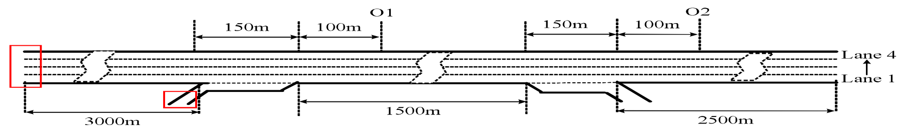




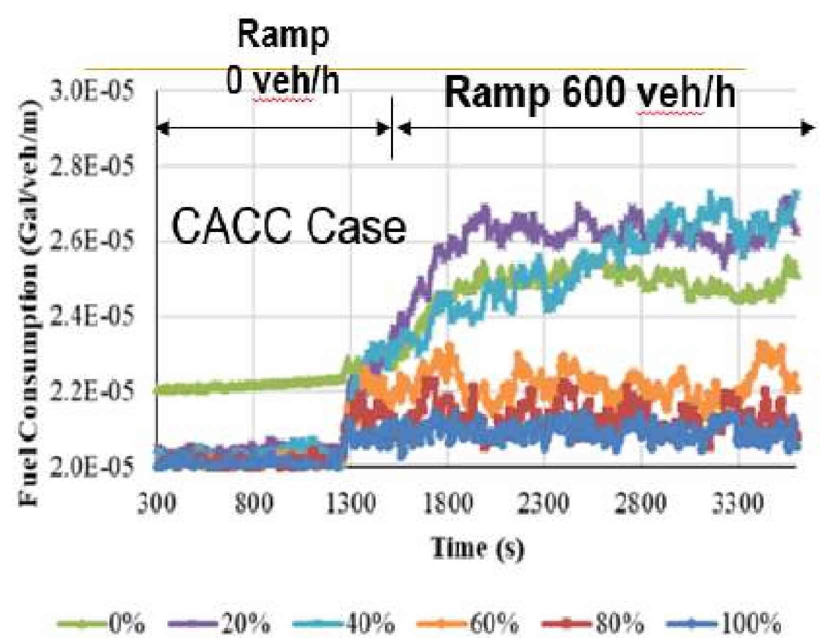
Simulation of Mixed Traffic with CV and CAVs

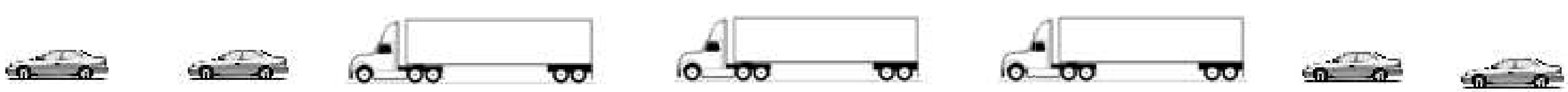
- Impact on Capacity



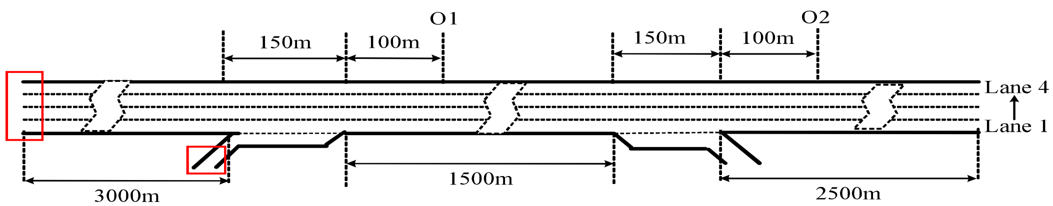


- Impact on Energy Saving
  - MOVES model for estimating the fuel saving
  - Plot shows the normalized fuel rate in gallon per vehicle per meter
  - Energy consumption drops with CACC% increases
  - Connectivity and coordination are important

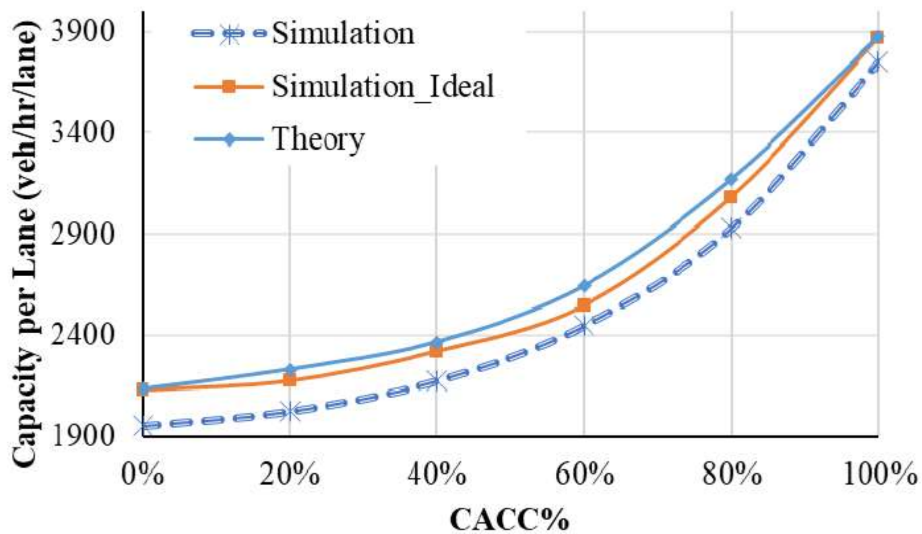




Simulation of Mixed Traffic with CV and CAVs

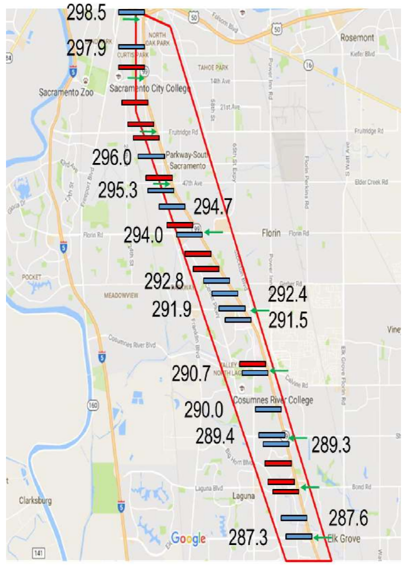


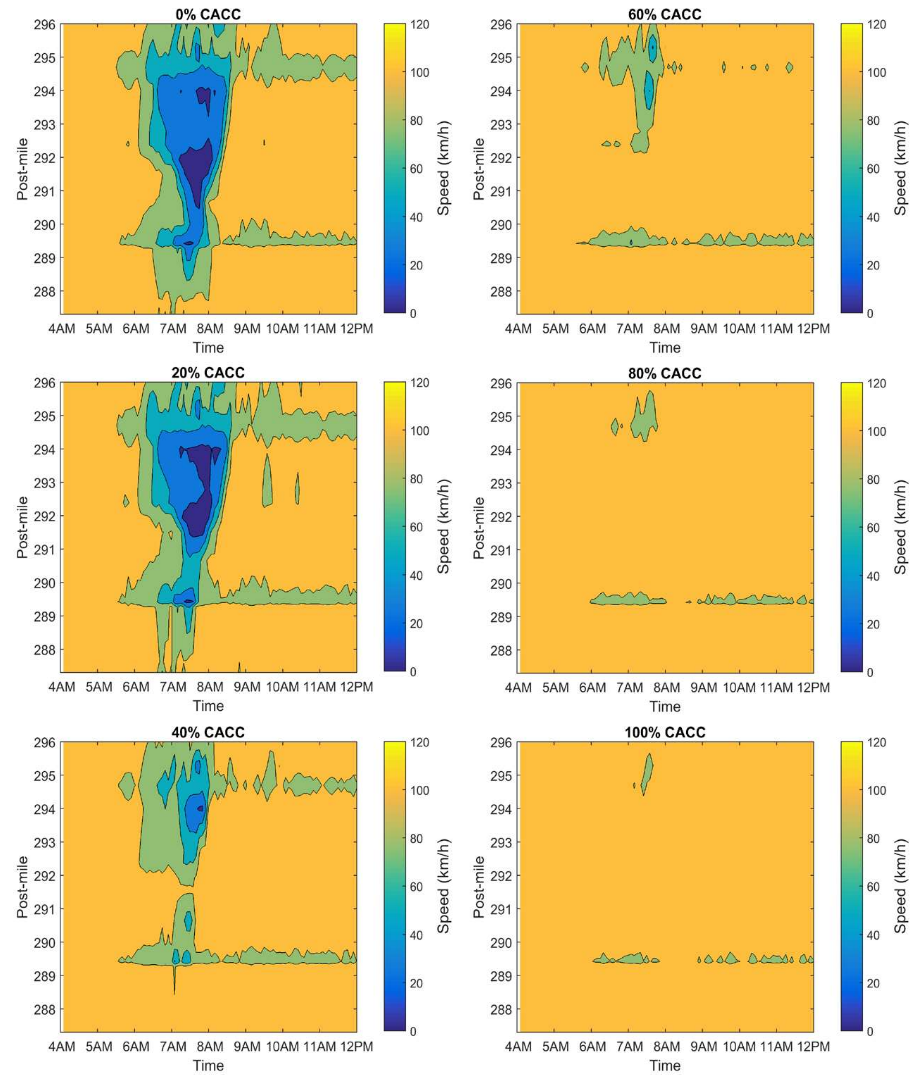
- Theory: calculated capacity
- Simulation_Ideal: simulated capacity for no lane changes and no randomness in drivers' behaviors
- Simulation: simulated capacity



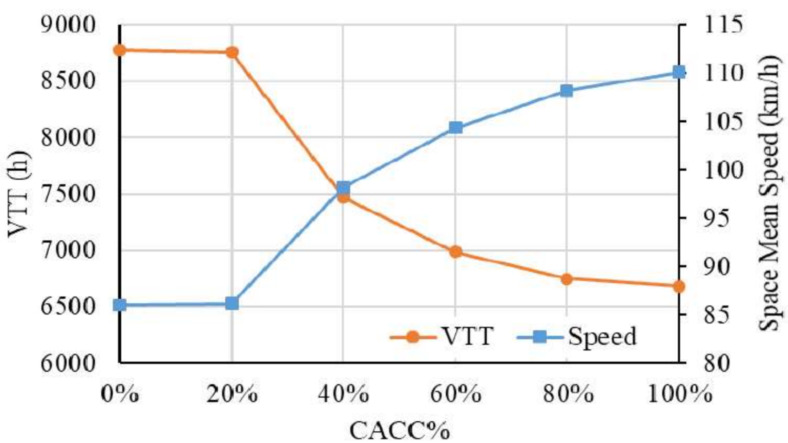
Simulation of Mixed Traffic with CV and CAVs

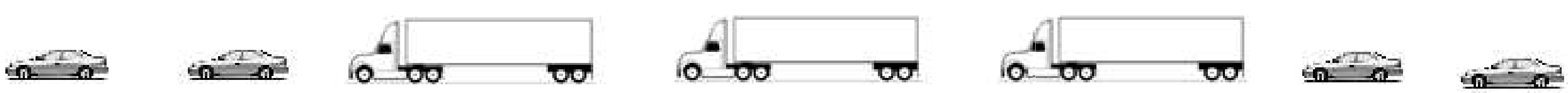
- VTT decreases and speed increases with the CACC market penetration.
- No significant change between 0% and 20% CACC case





CACC penetration impact on Space Mean Speed





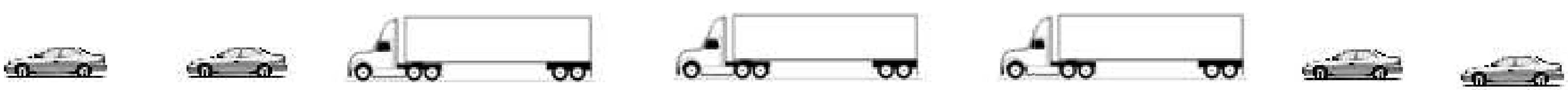
1997 Demo, I-15 HOV Lane San Diego

Automated Vehicle Merging, 2001

Transport Canada Test Track (2017)

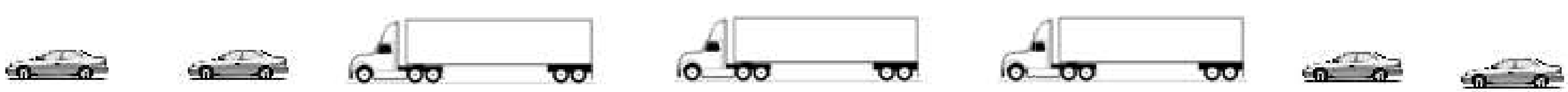
Truck Platoon (Nevada SR722, 2009)

Truck CACC on I-580 & Hwy4, 2017



Links of Some PATH Demos and Vehicle Tests

- **PATH 1997 Automated Vehicle Platoon Demo on I-15 San Diego**
  https://www.youtube.com/watch?v=h7tO-4FoKCo&t=67s
- **3 Connected Fully Automated Vehicle (CAV, Level 4) Merging (2000):**
  https://www.youtube.com/watch?v=CLKty9u-2z8
- ***3-Truck CACC fuel econ test at Transport Canada Test Track, Montreal, including 4m following:***
  https://www.youtube.com/watch?v=DnLlycxlees
- ***3-Truck CACC demo in Washing DC Sept 13-15 2017:***
  https://www.fhwa.dot.gov/research/truck_platooning/ (FHWA Website)
  https://youtu.be/7lyZ62SqU5E (video)
- ***3-Truck CACC on Highway 4 and Interstate 80, in 2016:***
  https://www.youtube.com/watch?v=IlRSNb6rJnI
- ***3-Truck CACC Demo with Public Traffic on Interstate Highway I-110 in LA, 2017*:**
- **https://youtu.be/BPdBmIVFKIQ**
- ***2-truck platooning test at 55mph with 3m in Crows Landing NASA airport, 2003:***
- **https://www.youtube.com/watch?v=E3eEvwz9W5E**



Links of Some PATH Demos and Vehicle Tests

- ***3-truck platoon with 4m constant gap at 55mph on SR722 Nevada in 2009:***
- **https://www.youtube.com/watch?v=hxXanXBVy7o**

- **5-Cadillac SUV CACC (Level 1) implementation 2015:**
- **https://www.youtube.com/watch?v=A0o4utksX9M**

- **Truck Driver Assistance 2005:**
- **https://www.youtube.com/watch?v=2tiFrmPybg0**

- **Cooperative Intersection Collision Avoidance System (CICAS) (2005):**
- **https://www.youtube.com/watch?v=RgqeqGj8_wI**

Thank You!