Vehicle and Infrastructure Communications

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Talking Freight Webinar

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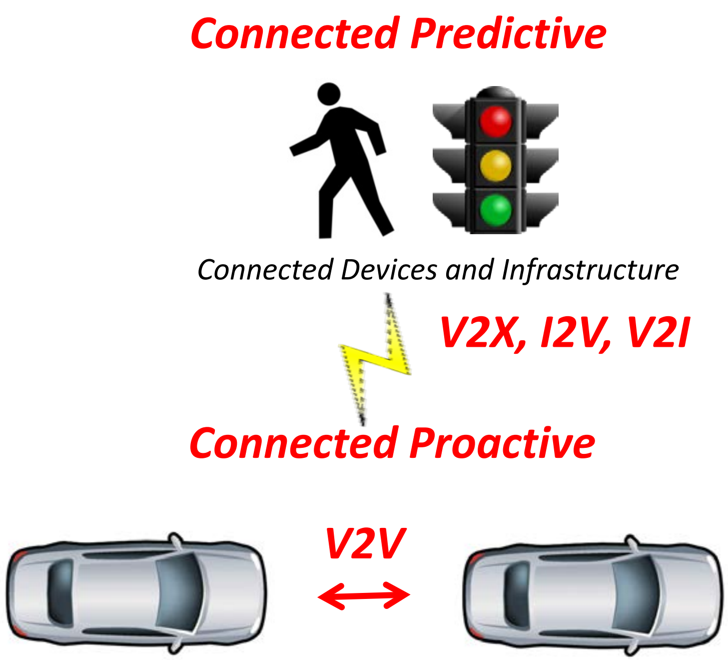
U.S. Department of Transportation

FEDERAL HIGHWAY ADMINISTRATION

DSRC Communications

DSRC – Dedicated Short Range Communications



DSRC Global Deployment

- Dedicated Spectrum
- Stable Standards based on IEEE 802.11p
- Strong industry-government cooperation

- Japan
  - ITS Connect
  - Commercial deployment from 2015
- United States
  - NHTSA NPRM – mass deployment by 2021
  - Commercial Deployment 2017 (Cadillac CTS)
  - Pilot Deployments and other federal, state & local initiatives
- Europe
  - Car2Car Communications Consortium (16 OEMs)
    - Commercial deployment by 2019
  - EC: “A European Strategy on C-ITS” – Nov. 2016
- Other regions
  - Several in trial phase (Australia, Korea, China, …)

DSRC Global Deployment

Requirements:

- **free and interference-free spectrum**
- **clear usage rules for interoperability**

- Japan: V2X in one 10 MHz channel at 760 MHz
  - Additional I2V spectrum available in 5.8 GHz.
  - Where can more spectrum be allocated?
- US: 75 MHz from 5.850-5.925 GHz
  - Seven 10 MHz channels
  - Will spectrum remain interference-free?
- Europe: 70 MHz from 5.855-5.925 GHz
  - Seven 10 MHz channels
  - Emerging protocol competition with cellular V2X?

Deployment is reality in Japan, has a clear path in US, and is a commitment of major automakers in Europe. All based on IEEE 802.11p

4G – 5G Wireless Communications

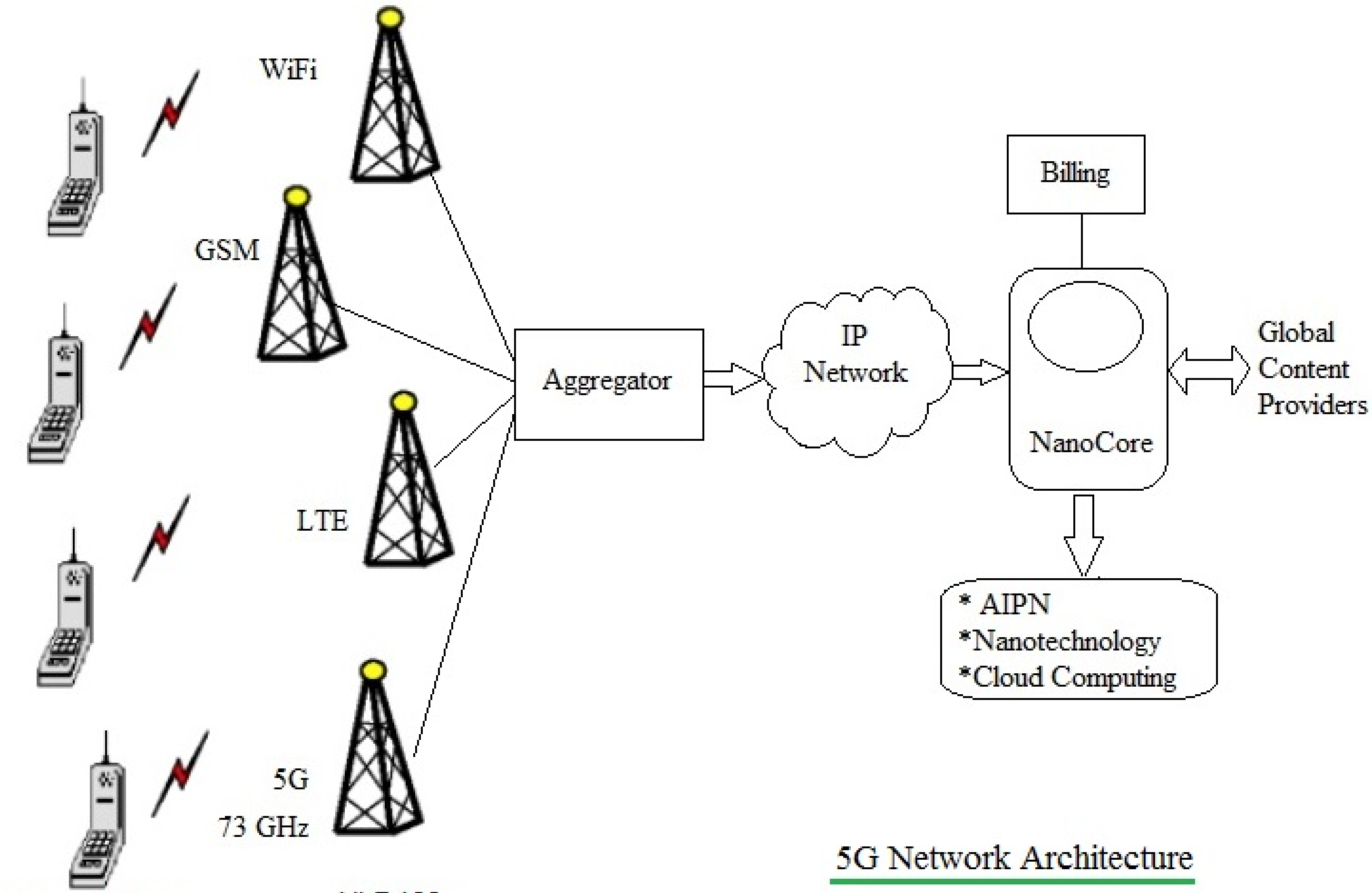
4G / LTE

- It was developed in the year 2010.
- It is fast and reliable.
- It provides speed up to 100mbps.
- It provides high performance like uploading and downloading speed.
- It provides easy roaming as compared to 3G.
- Use of a higher Layer Protocol (IP) as transport medium affords intelligence at every stage within the network relative to a service.

5G

- It is the next major phase of mobile telecommunication & wireless system.
- It is 10 times more faster than 4G.
- It has a expected speed of 1gbps.
- Lower cost than the previous version.
- It is expected to come after the year 2020.

4G – 5G Wireless Communications



5G Network Architecture

Comparison of DSRC and 4G – 5G

DSRC

Broadcast mode
300m nominal range
Device to device communications
Fast and reliable communications with minimal delay
Applicable to real-time control, mainly V2V
e.g. automated vehicles, active safety systems

4G – 5G

Non-broadcast mode
Unlimited range
Communications through server
Non-deterministic and long delay
Applicable to ‘slow’ applications, mainly V2I
e.g. speed harmonization, curve speed warning

Partial Automation for Truck Platooning (PATP) - Review

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STAKEHOLDERS

Owners & Fleet Operators

- Lower Cost

Drivers

- Workload, comfort & convenience

OEM's & Suppliers

- Market share, technology

Infrastructure Owners & Operators

- Roadway efficiency

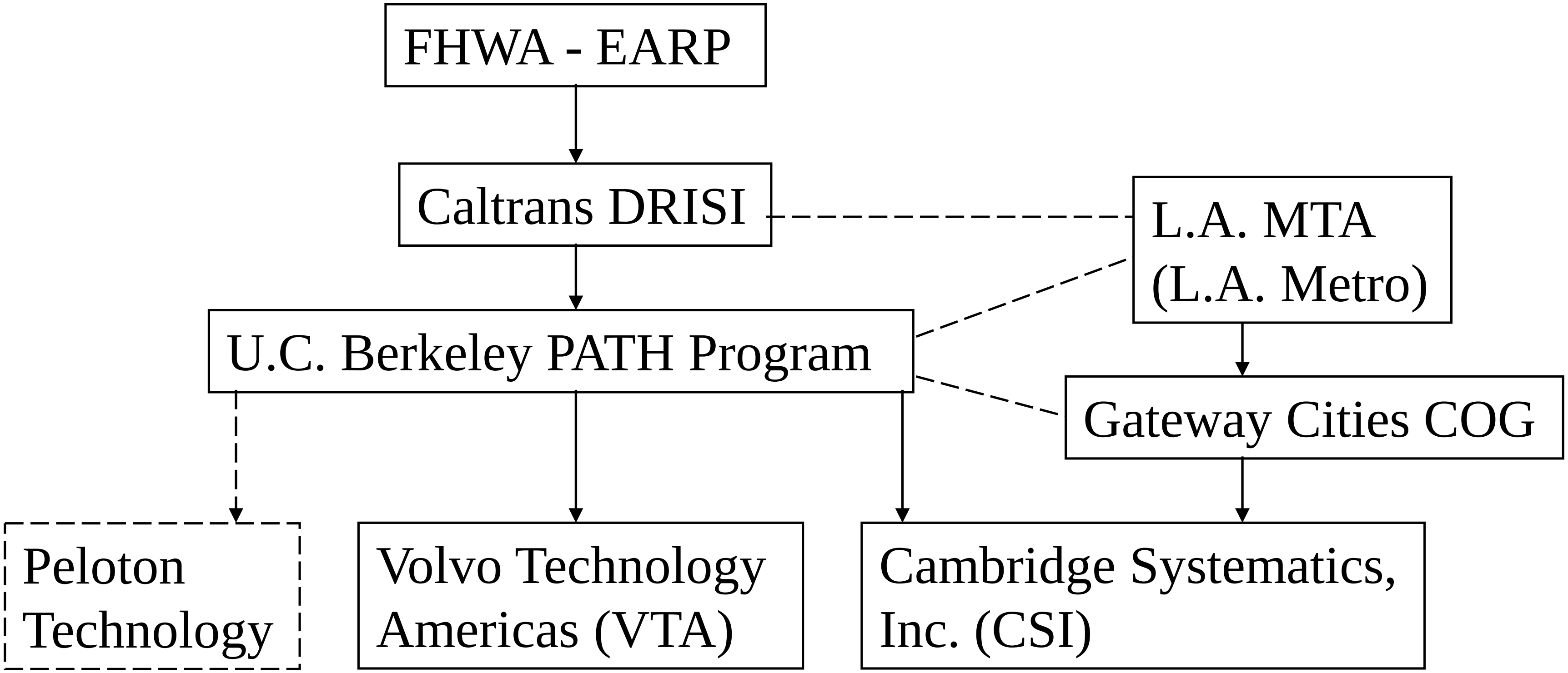
SAFETY IS THE OVERRIDING ATTRIBUTE FOR ALL

Exploratory Advanced Research Program – Caltrans Project

Partial Automation for Truck Platooning

- Period of Performance:
  - Phases I and II: 36 months
  - Phase III: 3 months (*optional*)

PATP Project Team



Project Team - Partners

- Caltrans Division of Research, Innovation and System Information (DRISI)
- UC Berkeley, Partners for Advanced Transit and Highways (PATH)
- Volvo Technology America, Inc. (VTA)
- Cambridge Systematics, Inc. (CSI)
- Los Angeles County Metro Authority (LA MTA)
- Gateway Cities Council of Governments (GC COG)
- Peloton Technology (unfunded team member)

Project Deliverables

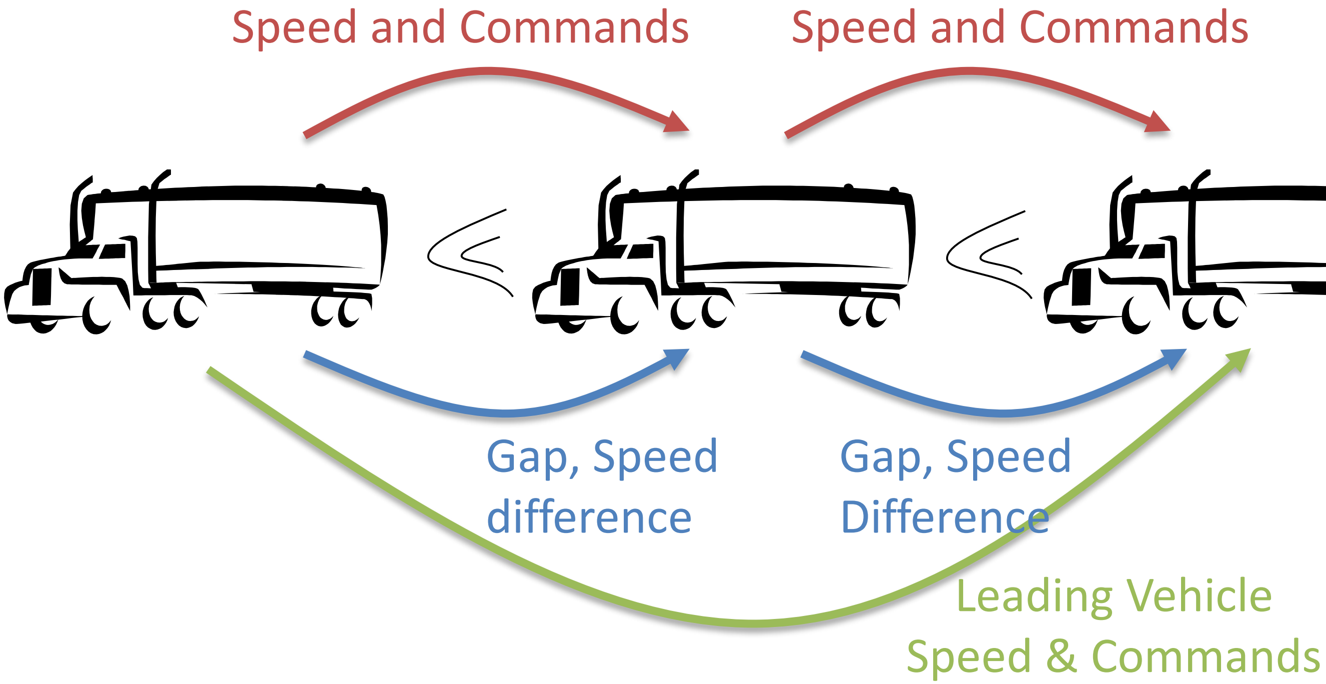
- **Simulation**
  - I-710 model and results of simulation studies using that model
  - Model of an intercity truck platooning application
- **Reports**
  - Industry needs assessment
  - Results of simulation
  - Test results (driver acceptance and perception of safety, ride quality)
  - Benefits estimates based on field tests (traffic and energy)
- **Public demonstrations**
  - Three truck platoon in Los Angeles area
  - Three truck platoon near FHWA TFHRC
- **Outreach briefing material about truck platooning**
  - Videos
  - Handouts

PATP Project Goals

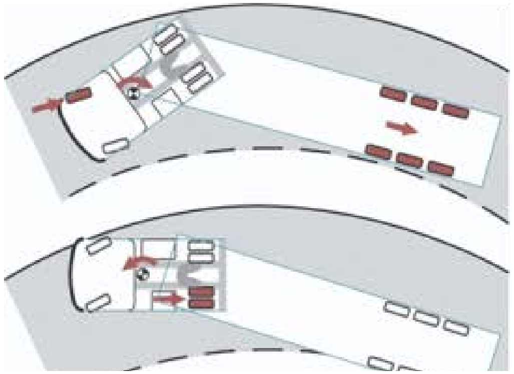
- Identify near-term opportunities for CACC to improve heavy truck operations
  - Energy savings from drag reductions
  - Traffic flow (stability and density increases)
  - Maintain/improve safety
- Assess acceptance of moderately short CACC gaps by truck drivers
- Measure energy savings at gaps chosen by drivers
- Provide data and demos to show benefits to industry and public stakeholders

Experimental System Operating Concept

- Three truck platoon
- 5.9 GHz DSRC Communication
- Longitudinal control only (throttle and brakes), driver steers the truck
- Vehicles already equipped with production ACC
- Lead truck either manually or automatically (ACC) driven
- Gap is based on time headway – consistent with driver preference



Volvo Technology: Active Safety Systems in Production



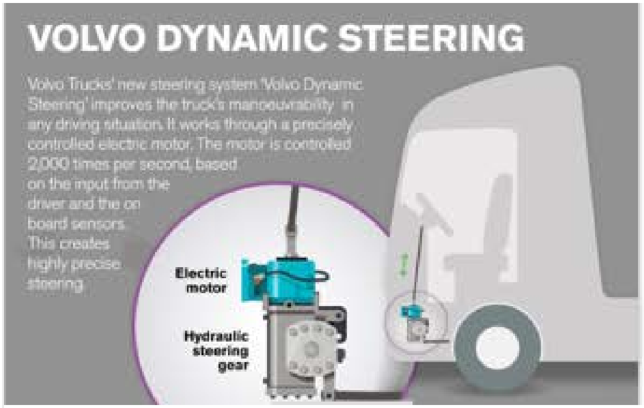
Electronic Stability Program

Forward Collision Warning – Automated Electronic Braking System

Adaptive Cruise Control

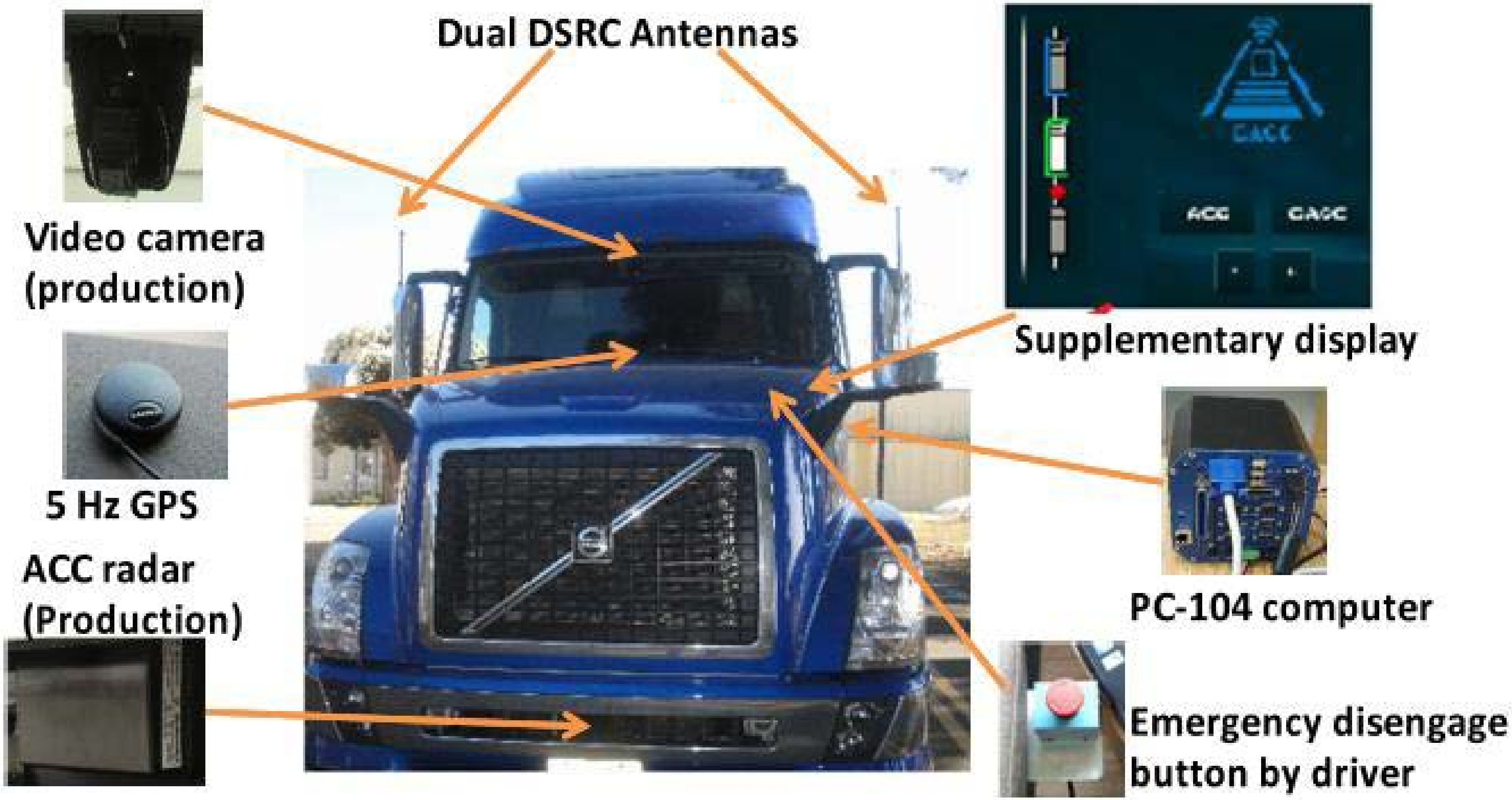
Lane Change Assist

Lane Keeping System



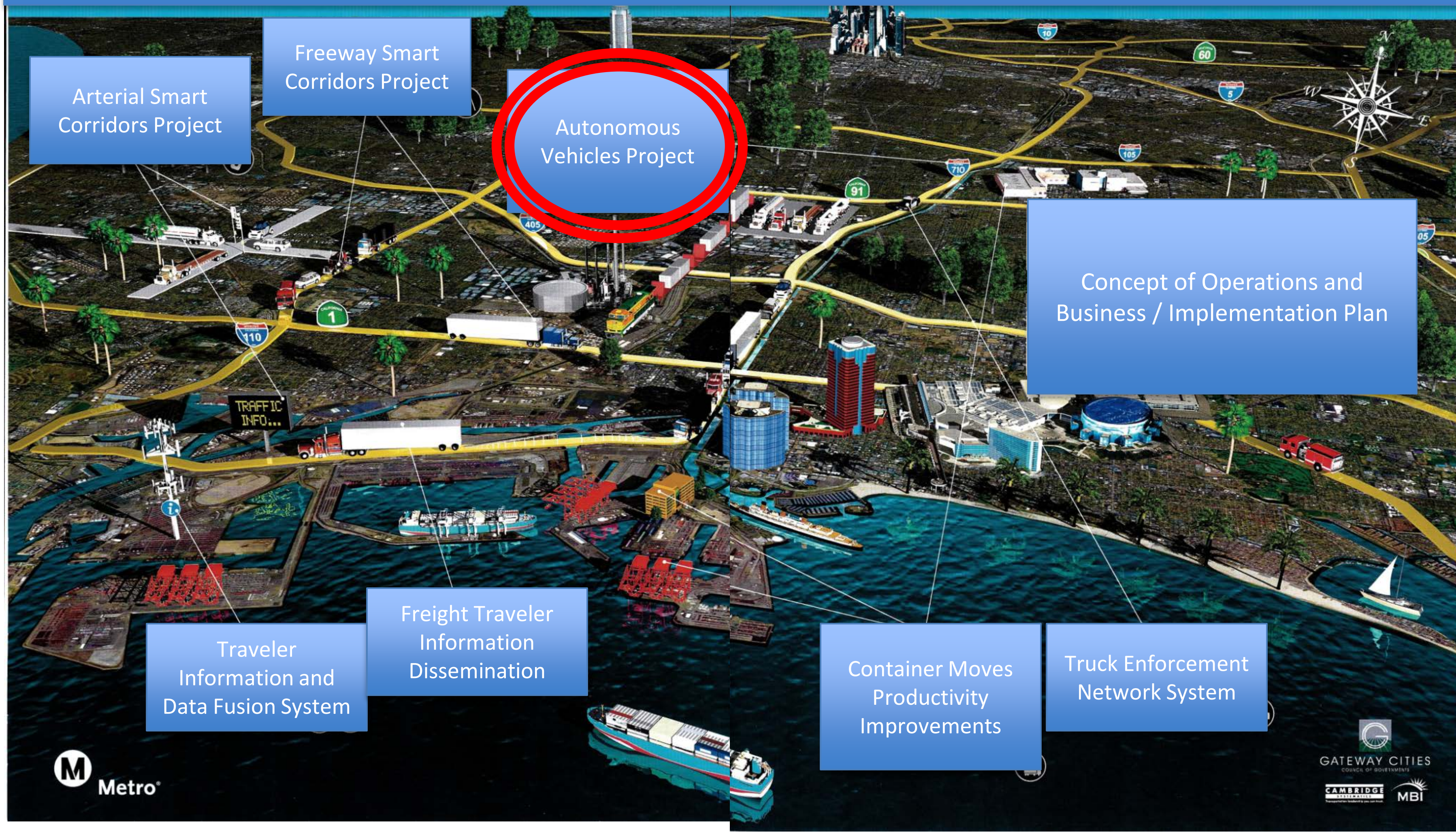
Volvo Dynamic Steering

Three Trucks Equipped for CACC



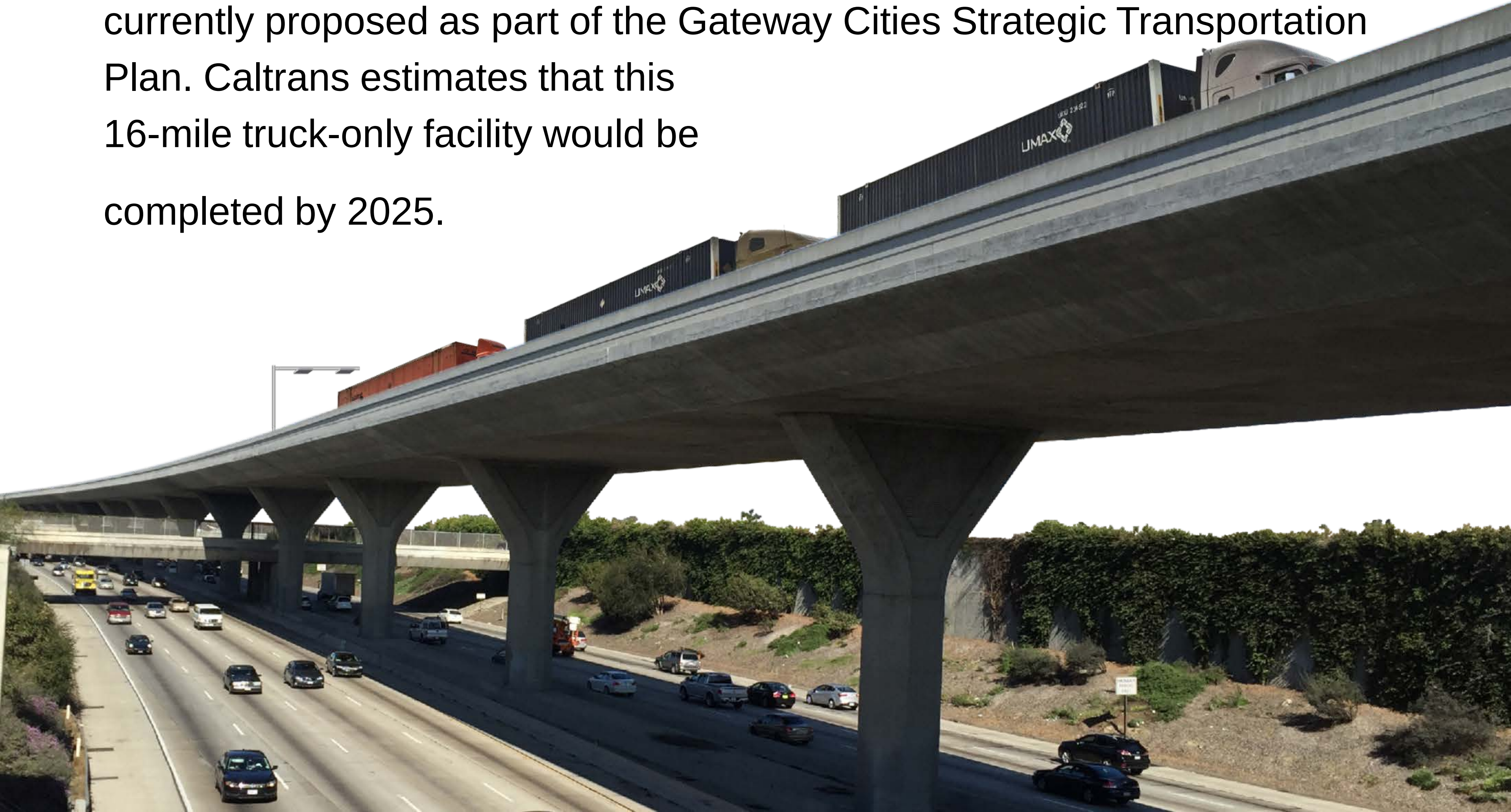
Gateway Cities Partnership and Role

Technology Projects for Gateway Cities Goods Movement



I-710 Freight Corridor Concept

A dedicated four-lane freight corridor parallel to the I-710 freeway is currently proposed as part of the Gateway Cities Strategic Transportation Plan. Caltrans estimates that this 16-mile truck-only facility would be completed by 2025.



Challenges CACC in Public Traffic

- Different vehicle types: dynamical capabilities varies a lot
- Manually driven vehicles: driver behavior differences
- Reliability in detection and communication
- Delays in truck dynamics
- Cut-in & cut-out by other manually driven vehicles
- Flexibility in maneuverability
- More reliable control for safety:
  - needs control to be more stiff
  - quick response
- Driver comfort, fuel economy & flexibility in maneuverability
  - control to be softer
- …

Human Factors Activities

- Developing Operating Concepts
  - CACC String Formation vs. Platoon Formation
  - Normal Operations: Cut-Ins and Platoon Dissolution
  - Faults, Failures, and Abnormal Operating Conditions
- Activity Diagrams Help to Define Scenario Subtleties
  - Operator Responsibilities / HMI Requirements
  - Vehicle Algorithms & Sensors Requirements
  - V2V Communication Message Content
- Human-Machine Interface (HMI)
  - Developing HMI Requirements and Concepts with Volvo
  - Volvo Driving Simulator Experiment
- Driver Gap Acceptance
  - 3-Truck On-the-Road Experiment

Truck CACC DVI Development

- DVI Development
  - System Transition Diagram (Driver's Perspective)
  - DVI "Portal" (Unique Screens) Map & Transition Diagram
  - Iterating with Volvo Designers
- Volvo Truck Simulator Experiment
  - Simulator Scenarios → Use Cases for DVI Development
  - Testing HMI for Joining/Leaving a CACC String
    - Local Coordination Instructions
    - Situational Awareness During Cut-Ins
  - Performance at Gap Settings from 1.5s to 0.6s
    - Lane Keeping / Workload / Fatigue Impact
    - Driver Preference

Simulator Experiment Segment Moment-By-Moment Scripting

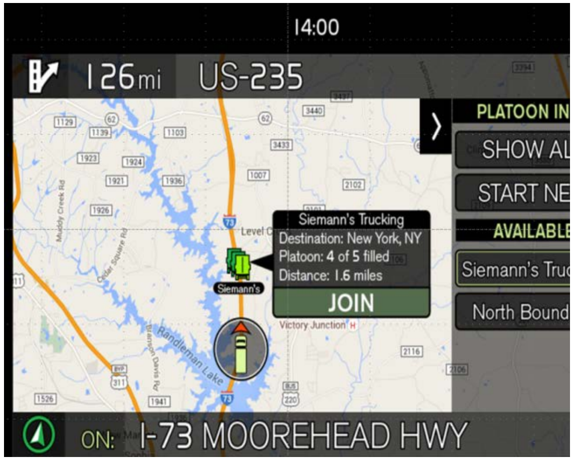
Scene Description

- Define scene requirements
  - Surrounding traffic (lane location, number/type of vehicles, speeds, autonomous [reacts to driver] vs. scripted agents)
  - Type and number of lanes
  - Topography of road (curves, straight, etc.)
  - Any traffic signs needed

Driver Info Display (DID)

- Volvo In-Dash DID
- Displays Factory ACC Status
- This box describes what happens with the ACC/CACC system during the segment

Secondary Info Display (SID)

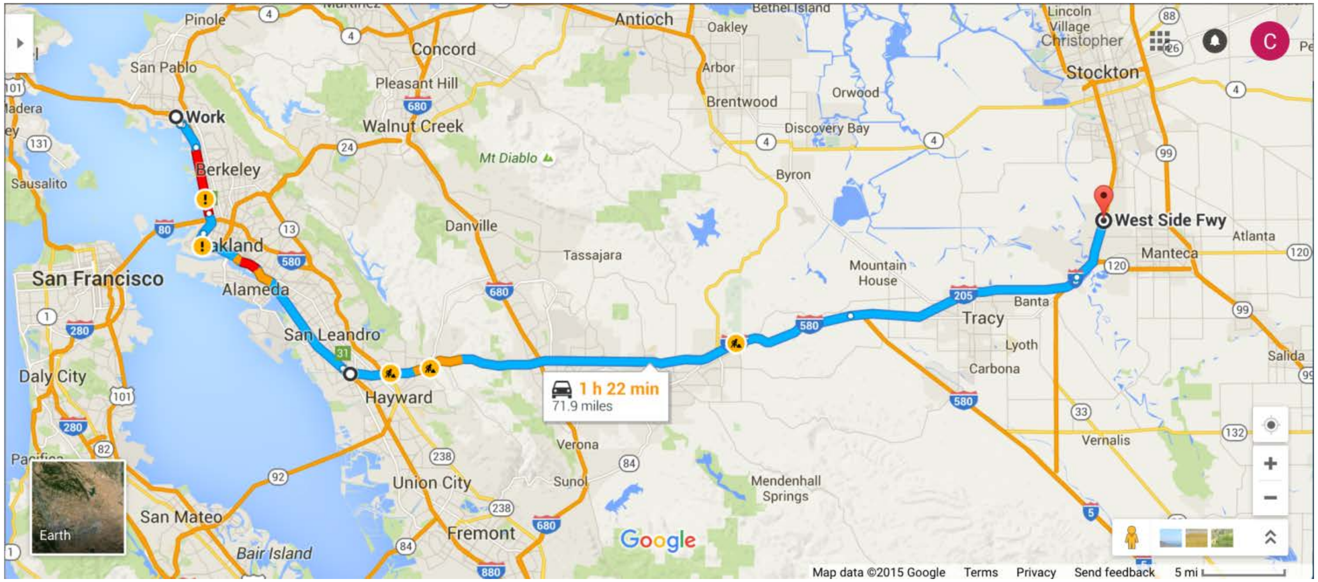


- CACC SID (10" Android Tablet)
- This box describes driver interactions with the SID as well as changes to the CACC status as described on the SID

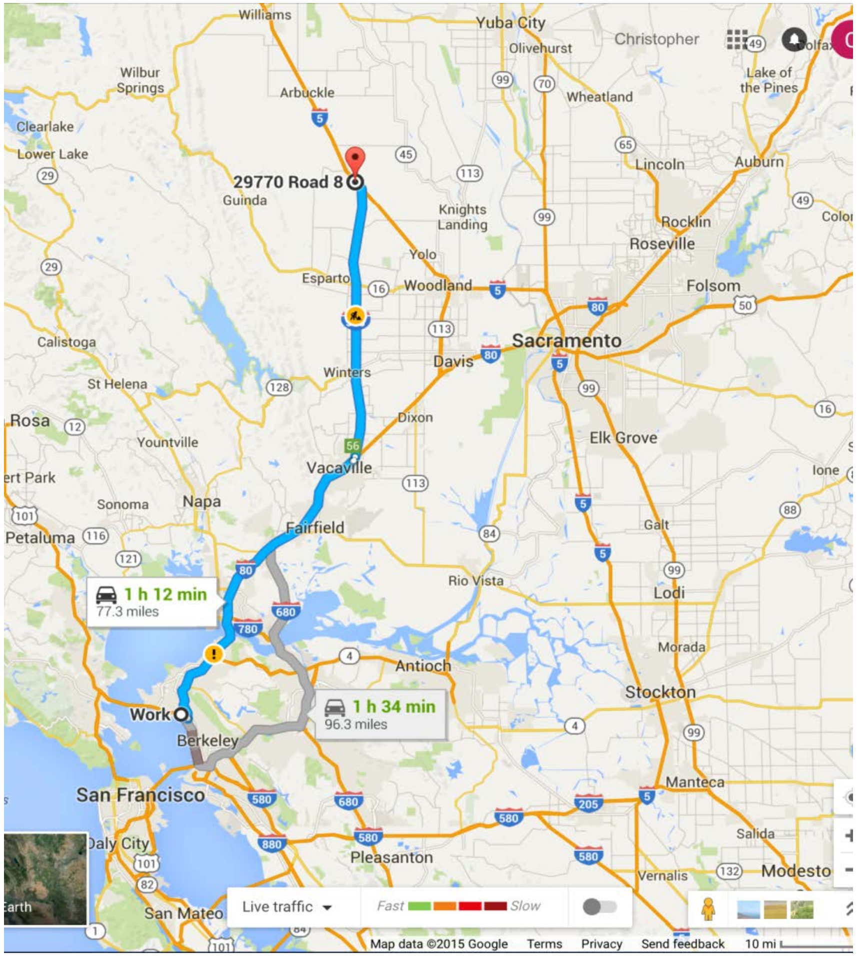
- Each slide describes segment starting and ending conditions and overall duration
- Travel speed and segment length
- Narrative of what happens during the segment
- Description of scripted vehicles or maneuvers

Truck CACC On-the-Road Experiment

- Testing Comfort at Gap Settings from 1.5 s to 0.5 (?) s
- 20-Mile Training / 48-Mile Route (Castro Valley to Manteca)
  - 3 Lanes, Driving in Middle Lane, Light Traffic, Significant Grades
- Each Driver will Drive in String Positions 2 & 3



Alternate Route



- Testing Comfort at Gap Settings from 1.5 s to 0.5 (?) s
- 30-Mile Training / 45-Mile Route
- Fairfield to Dunnigan
  - 3 Lanes, Middle Lane Driving, Light Traffic, Some Grades
- Each Driver will Drive in String Positions 2 & 3

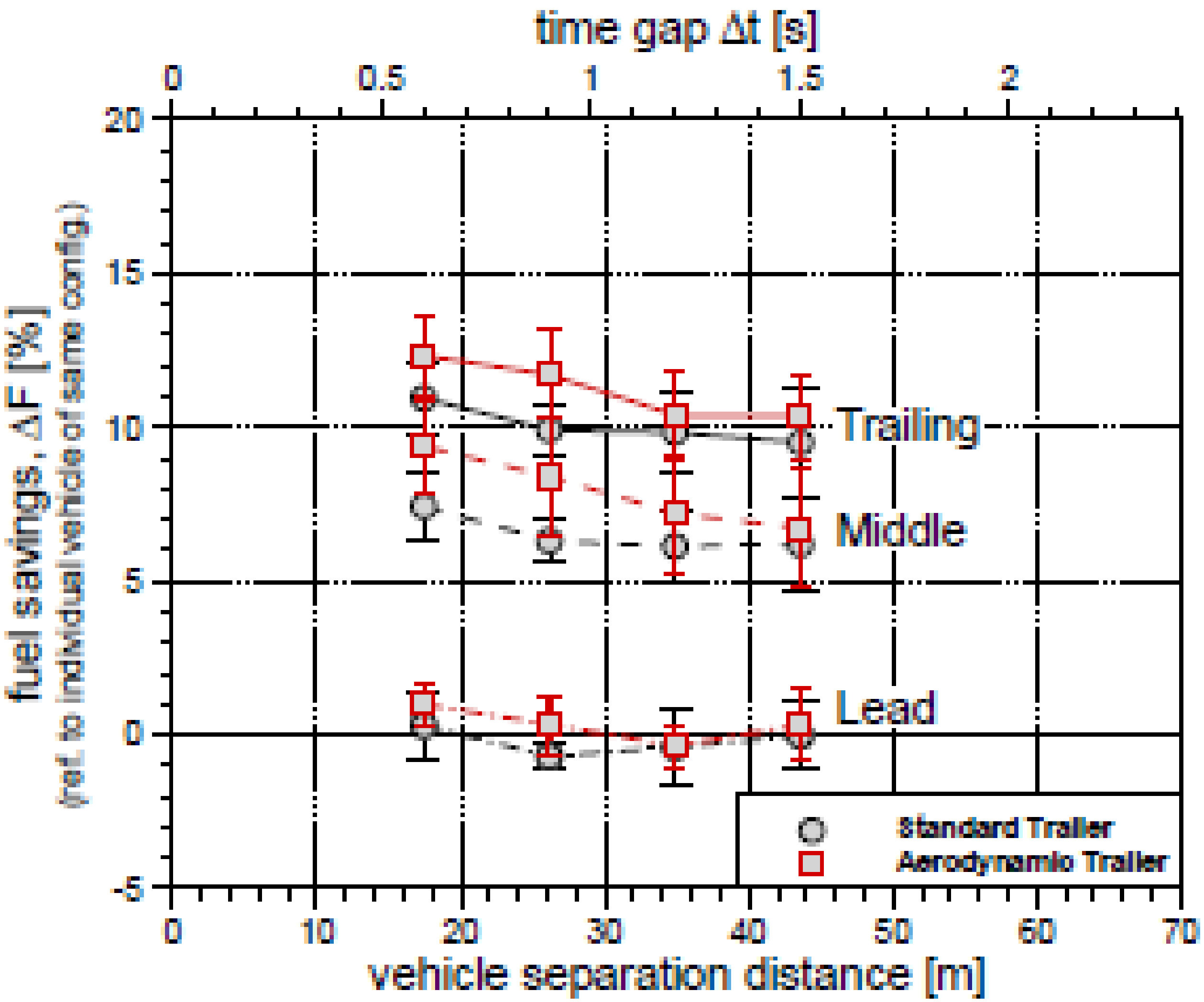
Test Track for Fuel Benefits

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

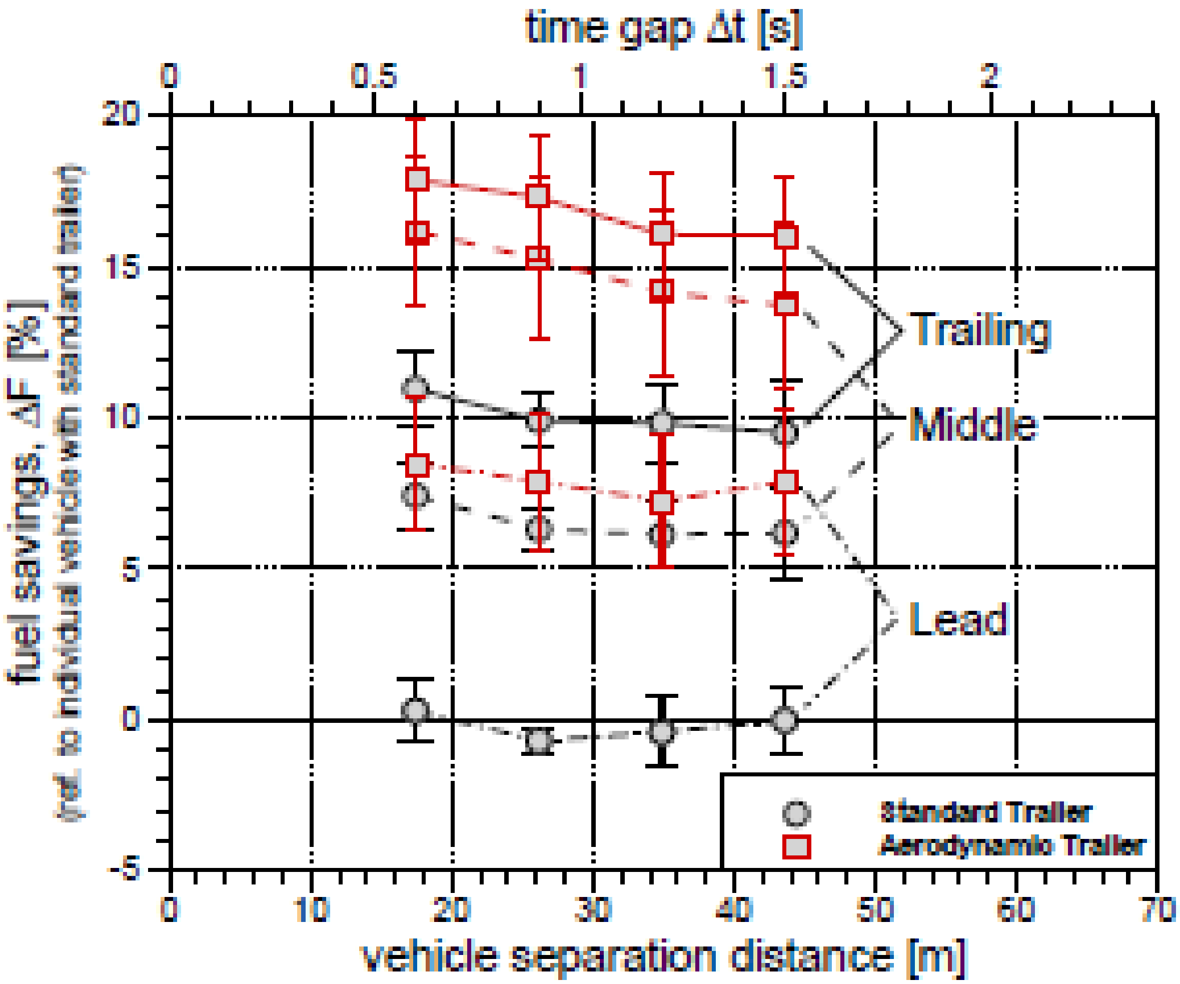
Boat Tails and Side Skirts

Auxiliary Fuel Tank

Fuel Savings – Individual



Fuel Savings – Combined



Accomplishments and Status

Reports and Studies (completed):

- Industry Needs and Opportunities for Truck Platooning
- CACC For Truck Platooning: Operational Concept Alternatives
- CACC For Truck Platooning: Opportunities for Infrastructure Support
- Enhanced Tractor-Trailer Interactions – Challenges and Opportunities

Human Factors (partially completed):

- Design of Human-Machine Interface (HMI) and Interactions is completed
- Driving Simulator experimentation is completed
- Driving Simulator is being instrumented and programmed for Level 1 automation
- Activity diagrams for determining time gap (following distance) preferences complete
- Subject selection for on-road tests is in progress

Vehicle Development (completed):

- Control Algorithm developed
- Three trucks instrumented
- Three truck platooning at low speeds (25mph) demonstrated on-site
- Three truck platooning at high speeds (65mph) demonstrated
- Fuel benefits tests completed

Heavy Truck Cooperative Adaptive Cruise Control System, Testing and Stakeholder Engagement for Near-Term Deployment

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Exploratory Advanced Research Program – Auburn University Project

Heavy Truck Cooperative Adaptive Cruise Control System – Testing and Stakeholder Engagement for Near-Term Deployment

- Period of Performance: 35 months
  - Phases I, II, and III

Driver Assistive Truck Platooning (DATP)

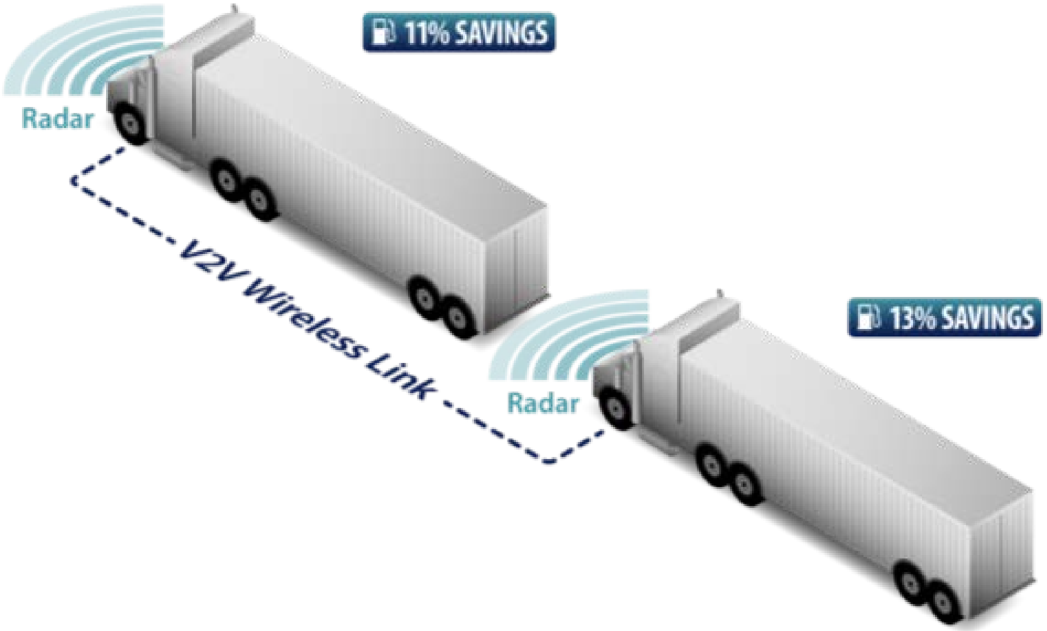
- Adaptation of Cooperative Adaptive Cruise Control (CACC) for two-truck pairing
- Data exchange between trucks allows for close following
  - resulting in significant fuel economy benefits
- Technology basis:
  - V2V communications, forward sensing (radar), positioning, actuation, and human-machine interface
- Driver roles:
  - Lead driver: normal driving
  - Following driver: steering
    - automatic longitudinal control

Project Team

- Auburn University
- Peloton
- American Transportation Research Institute (ATRI)
- Meritor-Wabco
- Peterbilt

Experimental System Operating Concept

- Two Peterbilt Trucks
  - GPS/IMU/Radar for positioning
  - DSRC Radios for V2V Communications
- Various Experiments
  - Analytical/Simulation Analysis
  - Test Track Validation
  - Interstate Validation

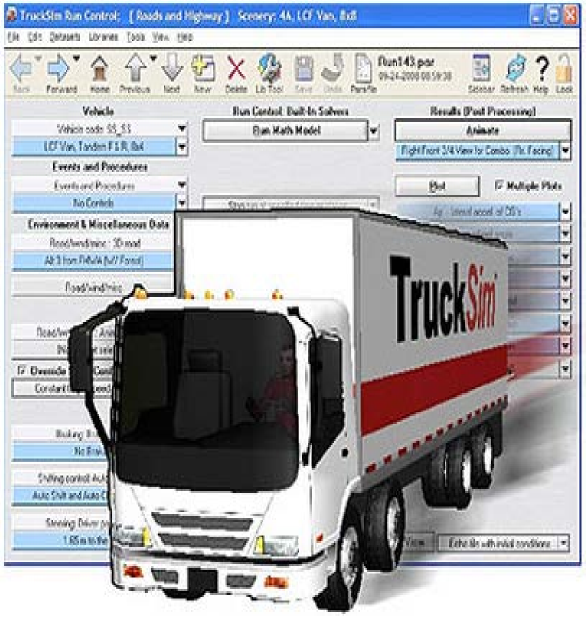


Phase I Analytical Results

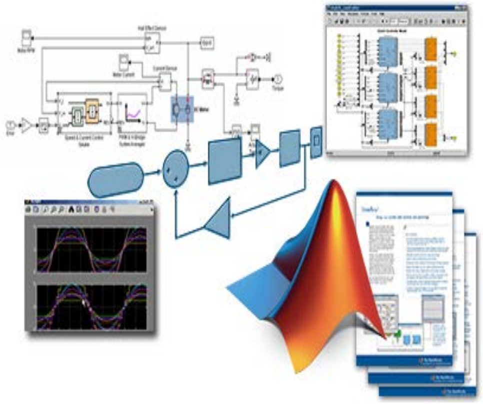
- Business Case Analysis
- Vehicle and Aerodynamics simulation/analysis
- Platoon formation modeling
- Traffic modeling

Vehicle Preparations and Sensor Research

- Vehicle Simulation
  - Simulate accurate vehicle fuel consumption at all points during a run when a time, velocity, and road grade profile are given
  - Study how different road profiles affect fuel efficiency of a heavy truck platoon
  - Combining powertrain, vehicle dynamics, and aerodynamics



- Aerodynamics Simulation
  - Changing the air drag coefficient to compare fuel consumption on different road and speed profiles for truck platooning
  - Testing different speed profiles will reveal the effectiveness of truck platooning in non-interstate applications



Traffic Flow and Mobility Impacts of DATP Usage

- Examined two-truck platooning within traffic stream
  - increasing levels of market penetration (20-100%)
  - range of headways (.5 – 1.5 seconds)
  - traffic at 100% current conditions, 115%, 130%
- Results
- DATP cause no delays compared to existing conditions
- Significant improvement in traffic flow at any headway lower than 1.25 seconds with market penetration over 60%.
- Phase Two
  - modeling operations on non-interstate highways
  - examining entry-exit effects

Phase Two (Completed)

- Two Peterbilt tractors equipped with DATP
- Testing
  - Track testing (see next slide)
    - variety of maneuvers and configurations
    - technical evaluations
  - On Road Testing
- Aerodynamics
  - model refinement based on track test results
- Platoon Formation
  - taking into account different fuel economy benefits for leader vs. follower
  - examining protocols for platoon formation based on braking ability
- Traffic Impacts
  - addressing entry/exit factors and non-interstate highways

FHWA-Auburn-Peloton Truck Platooning Track Testing

- Conducted at TRC Track in Ohio
- Objectives
  - Evaluate aerodynamics modeling results from Phase I of the project
  - Hold robust SAE Type II fuel economy track testing to quantify current system performance
  - On-track testing key to maintaining test consistency and avoiding interaction / disruptions by traffic
- Test Parameters
- Two truck platoons (identical Peterbilt tractors) plus control truck
- 65K pounds loading in 53 ft trailers with skirts
- Inter-vehicle distances: 30, 40, 50, 75, 120, 150 ft
- Speeds: 55-70 mph

Naturalistic Study of Truck Following Behavior

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Project Overview

- Goal: Support the development of automated truck platooning applications
- Partners
  - Turner Fairbank Highway Research Center
  - Volpe Center
- Period of Performance: 16 months
  - Begin: July 2014
  - End: October 2015
- Naturalistic Data Sources
  - Integrated Vehicle-Based Safety System (IVBSS) field test
    - 650,000 heavy truck driving miles
  - Safety Pilot Model Deployment
    - 380,000 heavy truck driving miles
  - Literature Survey

Key Research Questions

- How closely do trucks follow other vehicles on highways?
- How does following behavior vary by:
  - Type of truck
  - Speed
  - Road type
  - Road conditions
  - Weather
  - Visibility
  - Time of day
  - Etc.
- At what distances do vehicle cut-ins occur?
- What is the safety impact of different following gaps?
- Which elements of truck following behavior should be considered in the development of automation technologies, specifically platooning applications?

Accomplishments and Status

- Survey literature and naturalistic driving data
- Research and analysis plan
- Mining and analysis of naturalistic driving data
- Identification of data needs and resources
- Final reports and briefings - completed

Human Factors Issues Related to Truck Platooning Operations

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Project Description

- Conduct a literature review to document if any work has been conducted or proposed to look at human factors issues of other drivers in the presence of truck platoons.
- Develop a set of potential issues that drivers would face when in the presence of truck platoons.
- Design a driving simulation experiment with a larger number of subjects and scenarios. Use the test track experiments to develop the baseline driving simulation parameters.
- Conduct a driving simulator experiment on driver behavior in the presence of truck platoons.
- Synthesize results from the driving simulator test.
- Design a test track experiment where drivers would undergo a number of driving scenarios in the presence of truck platoons. The scenarios would vary several key aspects such as:
  - ➢ Driving maneuver (e.g., passing, following, leading, entry/exit, etc.)
  - ➢ Platoon operations (e.g., speed, intra-platoon truck gap, number of trucks, etc.)

Deliverables / Outputs

- **Literature Study**
- **Report on potential human factors issues related to truck platoons**
- **Driving Simulator Test Plan**
- **Driving Simulator Test Results**
- **Test Track Test Plan**

Questions?