Pathways to Automation: The Role of Vehicles and Infrastructure in a Future Transportation Environment

Planning Conference 2014
West Virginia DOT/FHWA/MPO

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Federal Highway Administration
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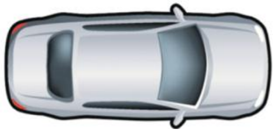
U.S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

Yesterday’s Vehicles

Yesterday’s automation technology

- Air bags
- Anti-lock braking system
- Electronic stability control
- Cellular connectivity (e.g., emergency crash notification)

Reactive



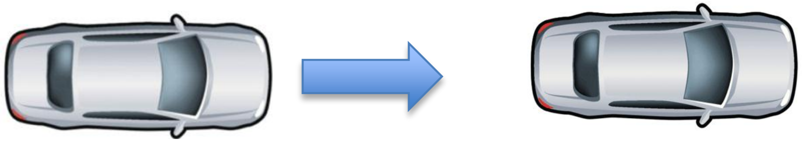
Standard Vehicles

Today’s Vehicles

Advanced automation technologies and features:

- Radar, Lidar, Sonar, Machine Vision
- Adaptive cruise control

Reactive ***Proactive***



Standard Vehicles *Automated Vehicles*

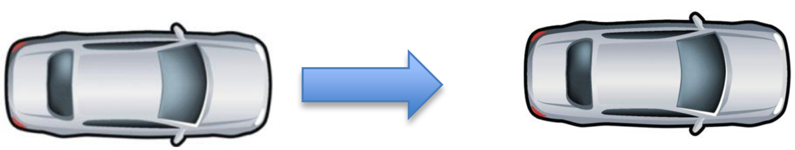
Today’s Vehicles… REALLY!

Advanced automation technologies and features:

- Radar, Lidar, Sonar, Machine Vision
- Adaptive cruise control
- **Automatic brake assist**
- **Lane change assist**
- **Lane centerIng**

Revolutionary Capabilities

Reactive ***Proactive***



Standard Vehicles *Automated Vehicles*

The Pathway Forward

- *“Automobiles with relatively modest "Level 2" features…will be the mainstay, accounting for 92% of autonomous vehicles in 2030.”*
- *“More advanced "Level 3" cars using high-resolution special maps…will gain only an 8% share while no fully autonomous "Level 4" car will hit the market [by 2030].”*

Jacques, Carole, “Self-driving Cars an $87 Billion Opportunity in 2030, Though None Reach Full Autonomy,” *Lux Research, Inc.* 20 May 2014.

The Pathway Forward

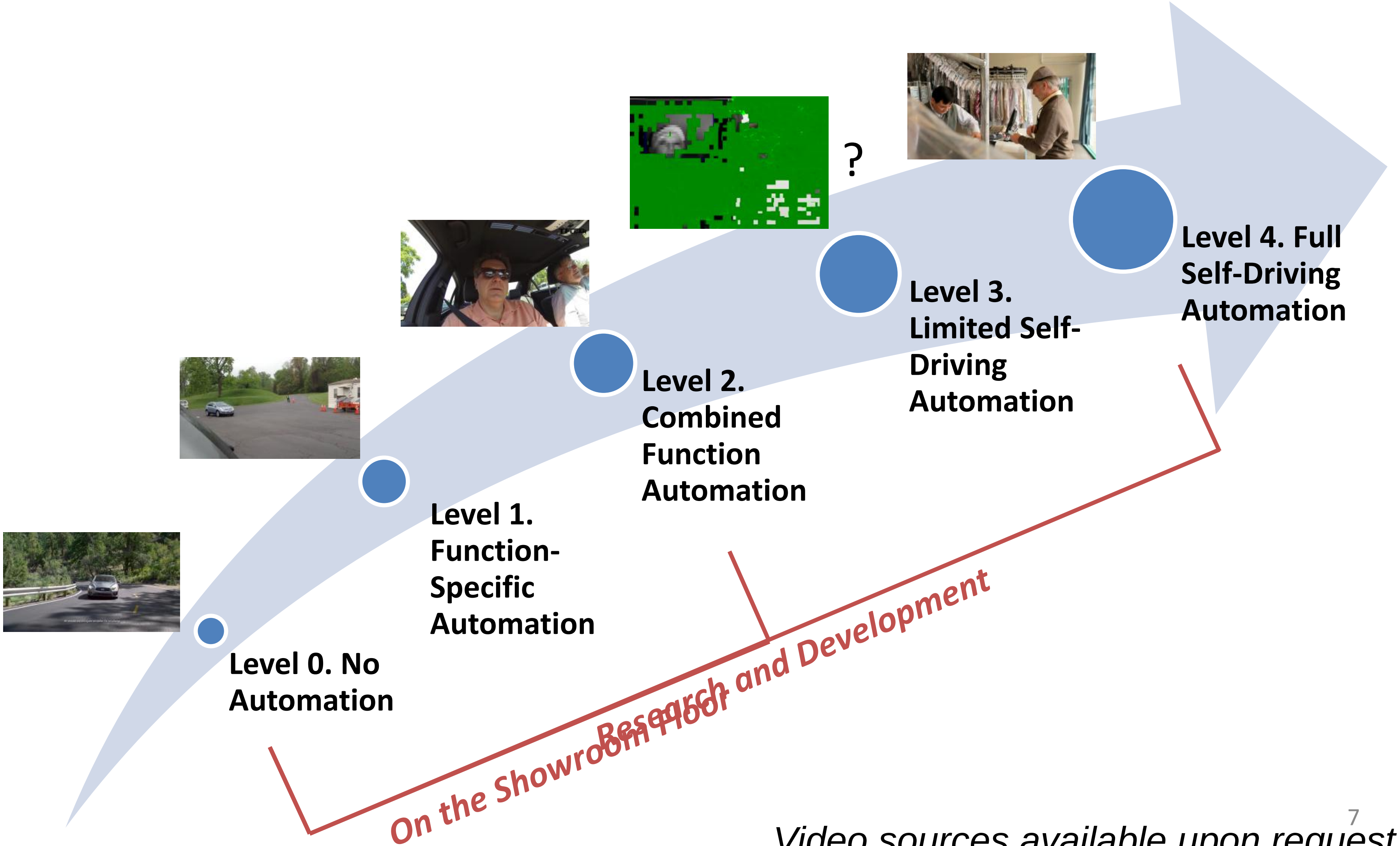
"Obviously it will take time, a long time, but I think it has a lot of potential"

Sergey Brin
Google Co-Founder

Markoff, John, "Google's Next Phase in Driverless Cars: No Steering Wheel or Brake Pedals," *The New York Times.* 27 May 2014.

How Do We Get There?

NHTSA’s Five Levels of Vehicle Automation



Video sources available upon request

The Bottom Line

Automated vehicle technologies that can save lives and improve the driving experience are *here today* and rapidly growing.

Automated vehicle technologies are **revolutionary**: *constituting or bringing about a major or fundamental change*[1]

[1]Merrian Webster Dictionary, www.merriam-webster.com

Challenges

Work Zone Location/Status

Sensing in Bad Weather

© King County, WA

Signal Phase and Timing

Source: gajitz.com

Incident Location/Status

© Randy Pench/ The Sacramento Bee

Bottleneck Status

System Demand at Special Events

© photos.com

Extreme Challenges

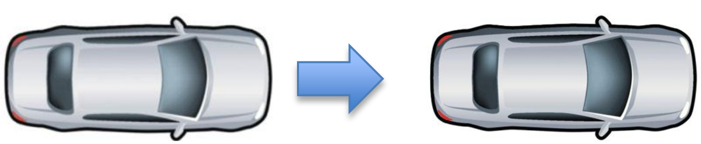
Source: City of Dayton, OH

Could Today's Automated Vehicles Have Avoided This Crash?

Advanced automation technologies and features:

- Radar, Lidar, Sonar, Machine Vision
- Adaptive cruise control
- Automatic brake assist
- Lane centering
- Lane change assist

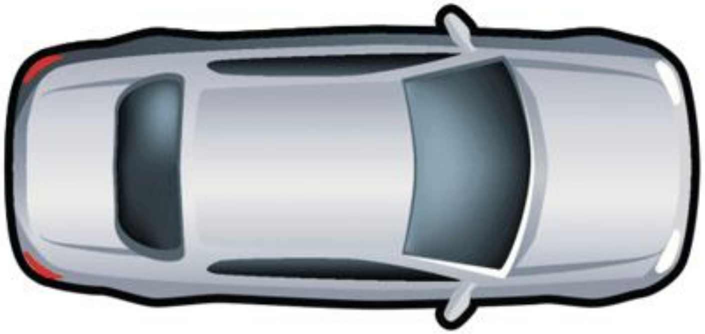
Reactive ***Proactive***



Standard Vehicles *Automated Vehicles*

Could Today's Automated Vehicles Have Avoided This Crash?

How to make today's proactive automated vehicles…



…even better?

…even better?

Through Wireless Connectivity!!

…and even more better?

Through Wireless Connectivity!!

With Connected, Automated Vehicles!!!

Let’s Build on What We Have…

- Current Automated Vehicle State of Practice
  - Cars In the market place
  - Cars On the roads

Reactive **Proactive**

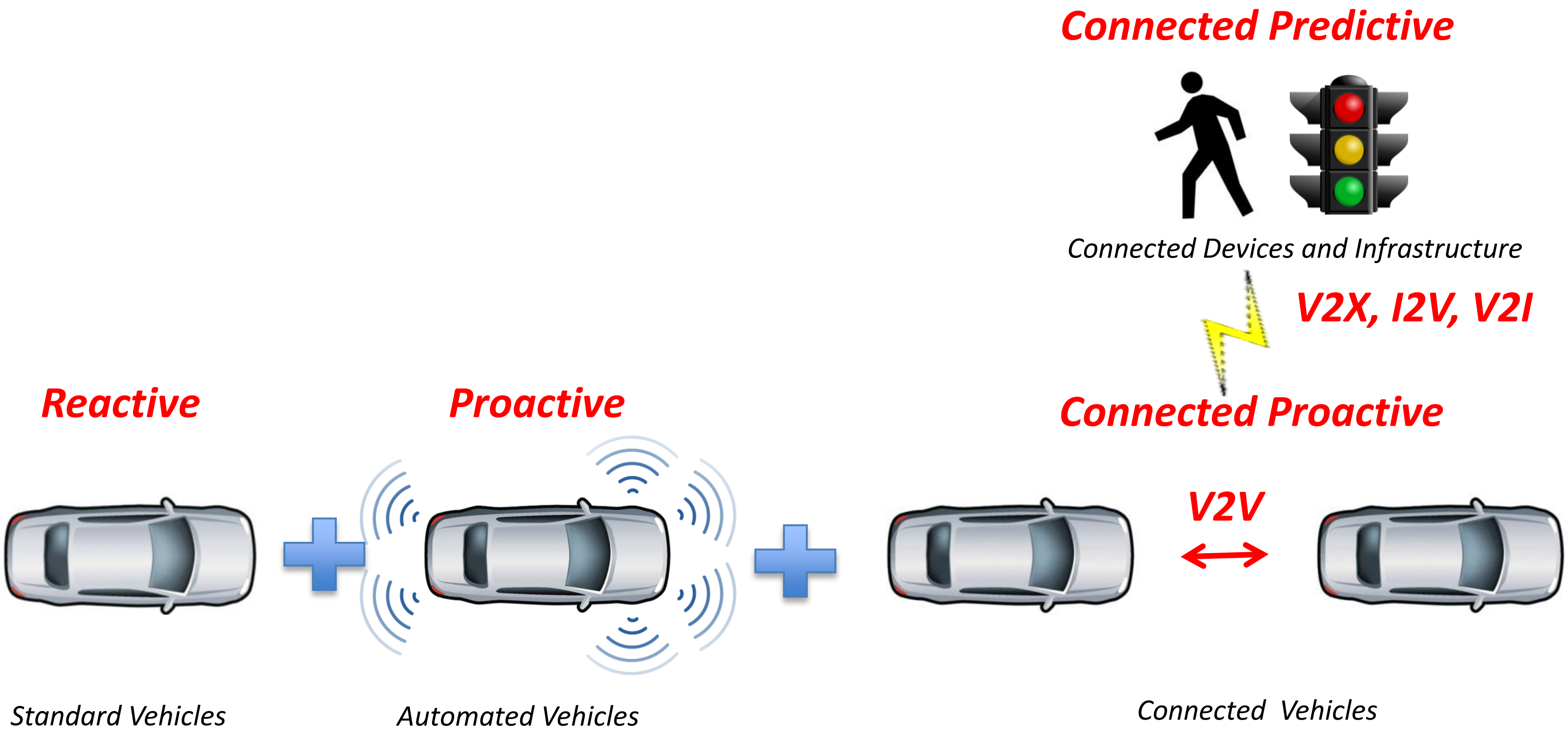
Standard Vehicles *Automated Vehicles*

Add Dedicated Short Range Communications (DSRC)

- Current Automated Vehicle State of Practice

+

- DSRC Connectivity:
  - US DOT’s Connected Vehicle Program (V2V, V2I, I2V, V2X)
    - Demonstrated in Safety Pilot, 2013
    - Collision Avoidance via Warning (V2V)



Include All Wireless Communications

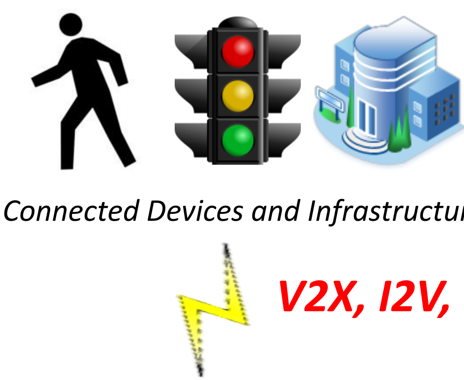
- Current Automated Vehicle State of Practice

+

- DSRC Connectivity:
  - US DOT's Connected Vehicle Program (V2V, V2I, I2V, V2X)
    - Demonstrated in Safety Pilot, 2013
    - Collision Avoidance via Warning (V2V)

+

- Cellular, Satellite, WiFi, etc.
  (V2V, V2I, I2V, V2X)



Next Comes Connected Automation

- Current Automated Vehicle State of Practice

+

- DSRC Connectivity:
  - US DOT's Connected Vehicle Program (V2V, V2I, I2V, V2X)
    - Demonstrated in Safety Pilot, 2013
    - Collision Avoidance via Warning (V2V)

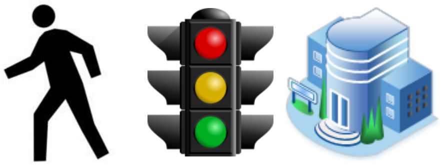
+

- Cellular, Satellite, WiFi, etc. (V2V, V2I, I2V, V2X)

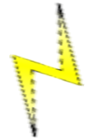
+

- Connected Automation
  - Cooperative Adaptive Cruise Control

Connected Predictive

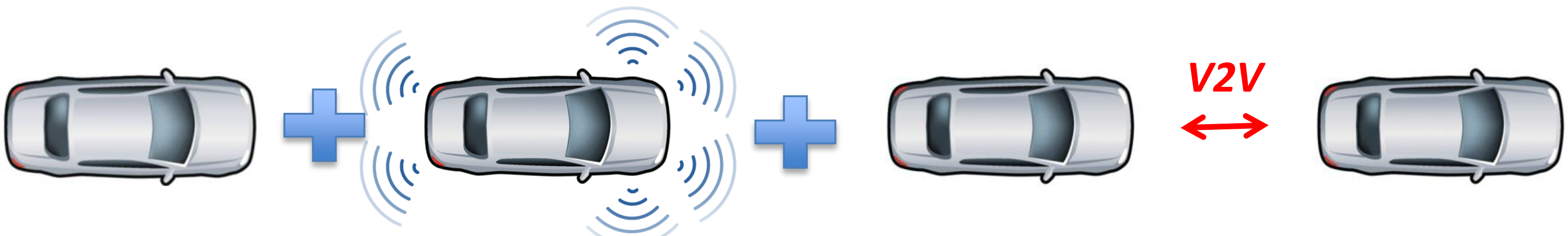


Connected Devices and Infrastructure



V2X, I2V, V2I

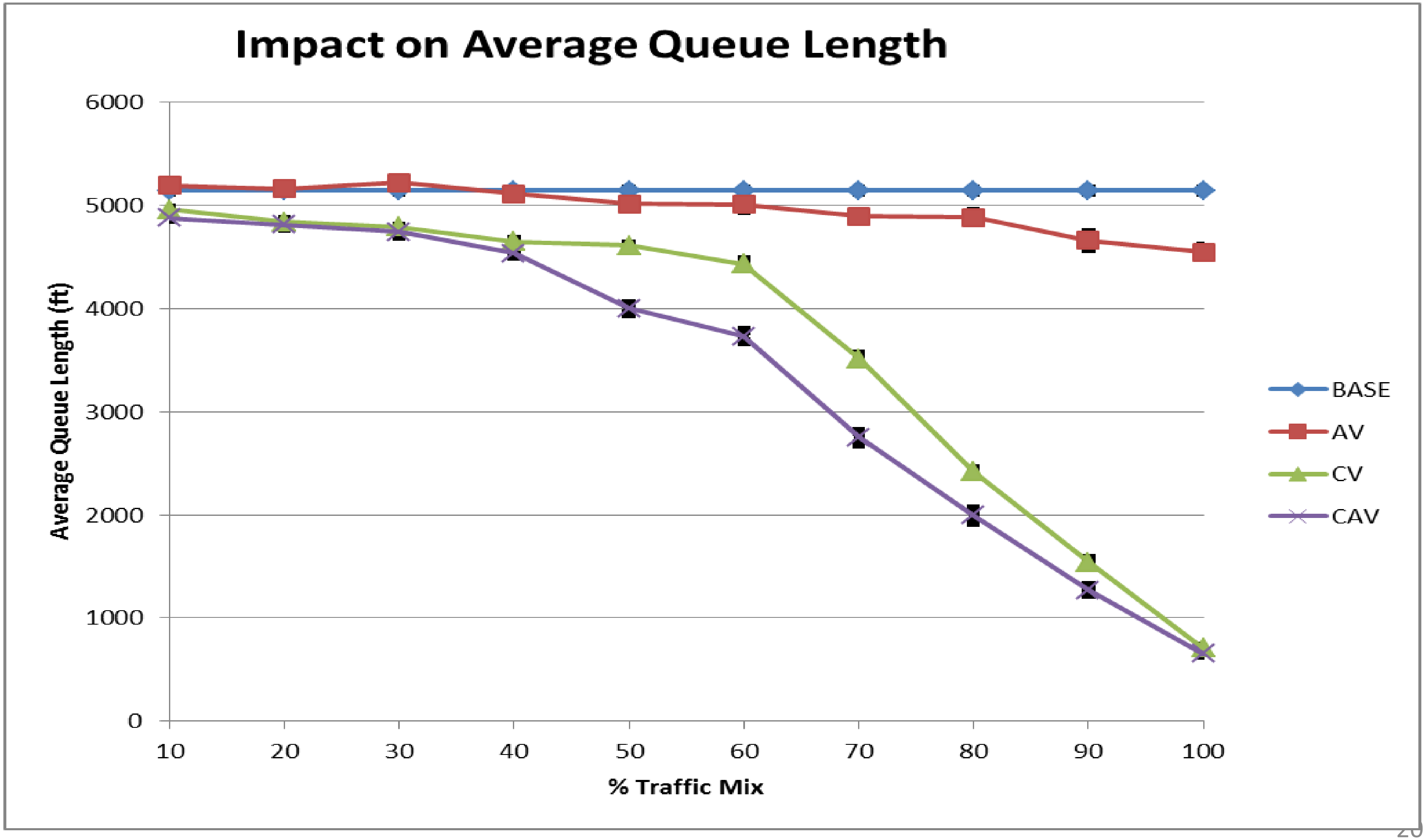
Reactive ***Proactive*** ***Connected Proactive***



Standard Vehicles *Automated Vehicles* *Connected, Automated Vehicles*

Advantages of Connected Automation

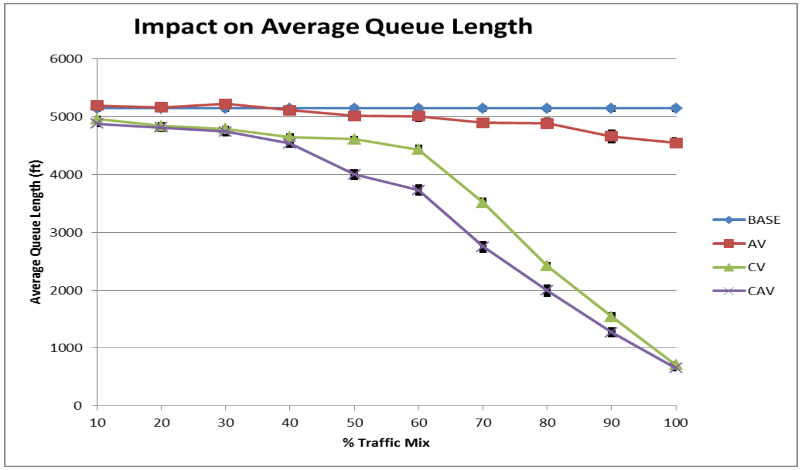
Impact of Queue Warning and Speed Harmonization on Queue Length



Source: Noblis IR&D

Advantages of Connected Automation

Impact of Queue Warning and Speed Harmonization on Queue Length



- AV technology has little impact on queue length
  - Without communications, AV's still travel at full speed until within sensing range of the queue
- CV technology provides major reductions in queue length
- Small synergies at mid-levels of market penetration

Source: Noblis IR&D

OK, So Now What?…

Connected Solutions

Connected Solutions Delivered By …

Research, Development, and Innovation

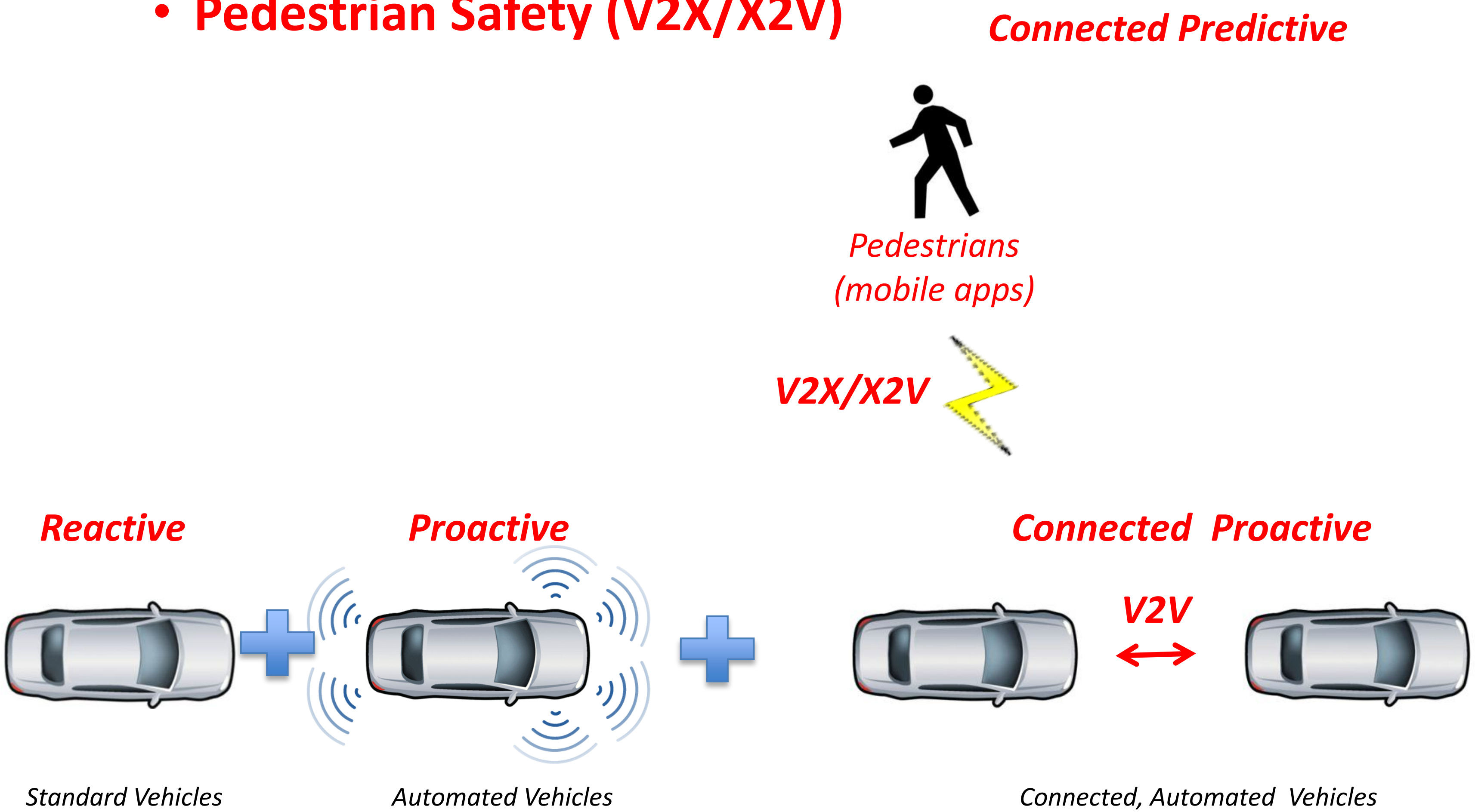
Connected Solutions Delivered By …

Industry, Government, and Academia Working Together

R&D Opportunities for Connected Automation

DSRC Connectivity:

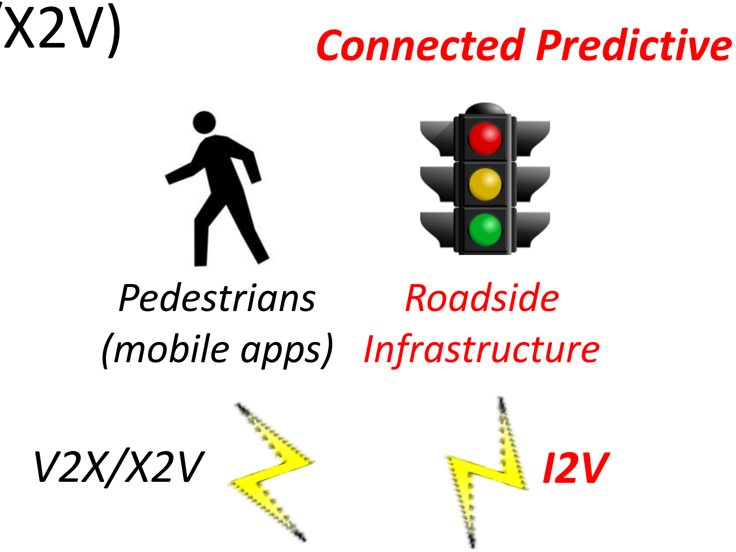
- **Pedestrian Safety (V2X/X2V)**

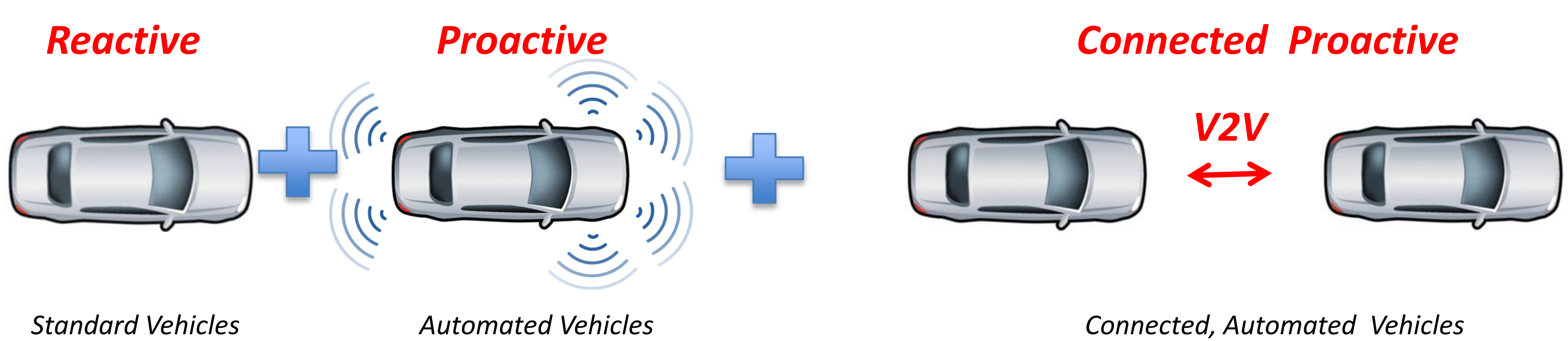


R&D Opportunities for Connected Automation

DSRC and Cellular Connectivity:

- Pedestrian Safety (V2X/X2V)
- **Eco-Driving (I2V)**

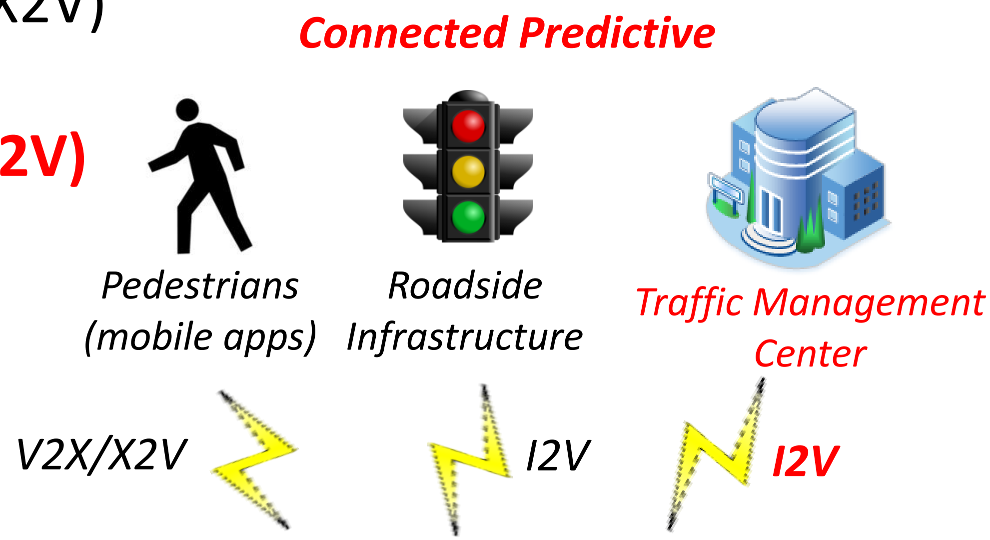


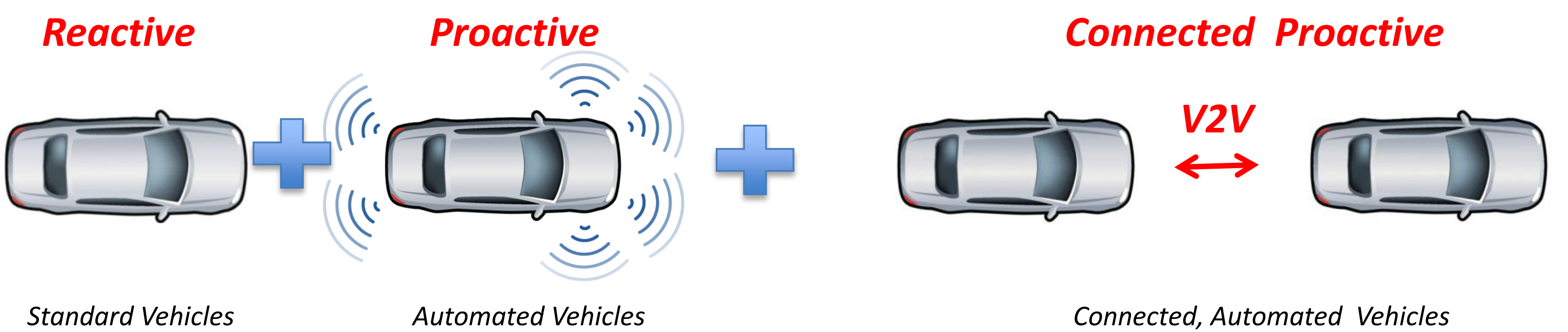


R&D Opportunities for Connected Automation

DSRC *and* cellular connectivity

- Pedestrian Safety (V2X/X2V)
- Eco-Driving (I2V)
- **Speed Harmonization (I2V)**

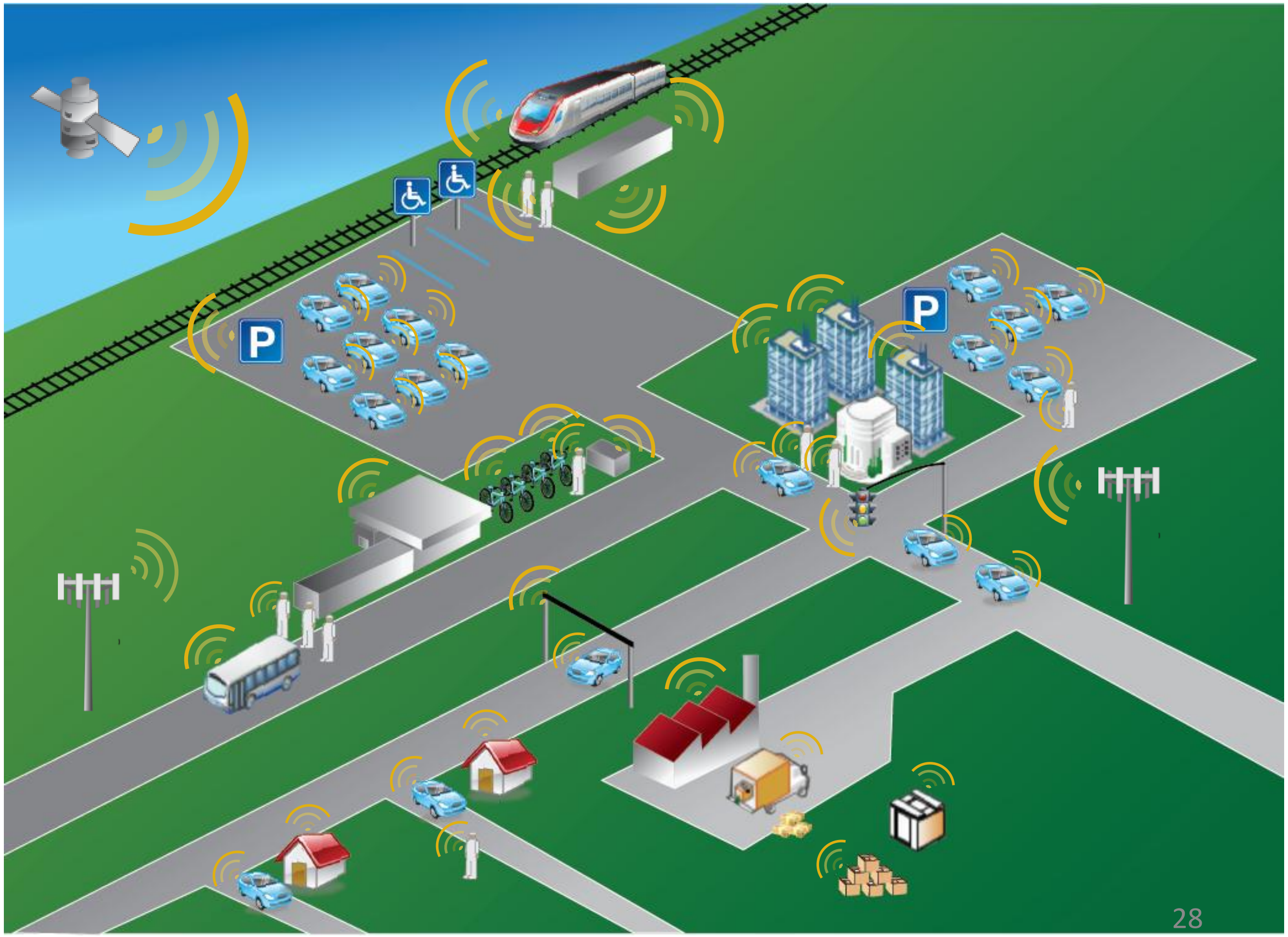




Vision: A Connected, Automated Transportation System

Connectivity-Enabled Information

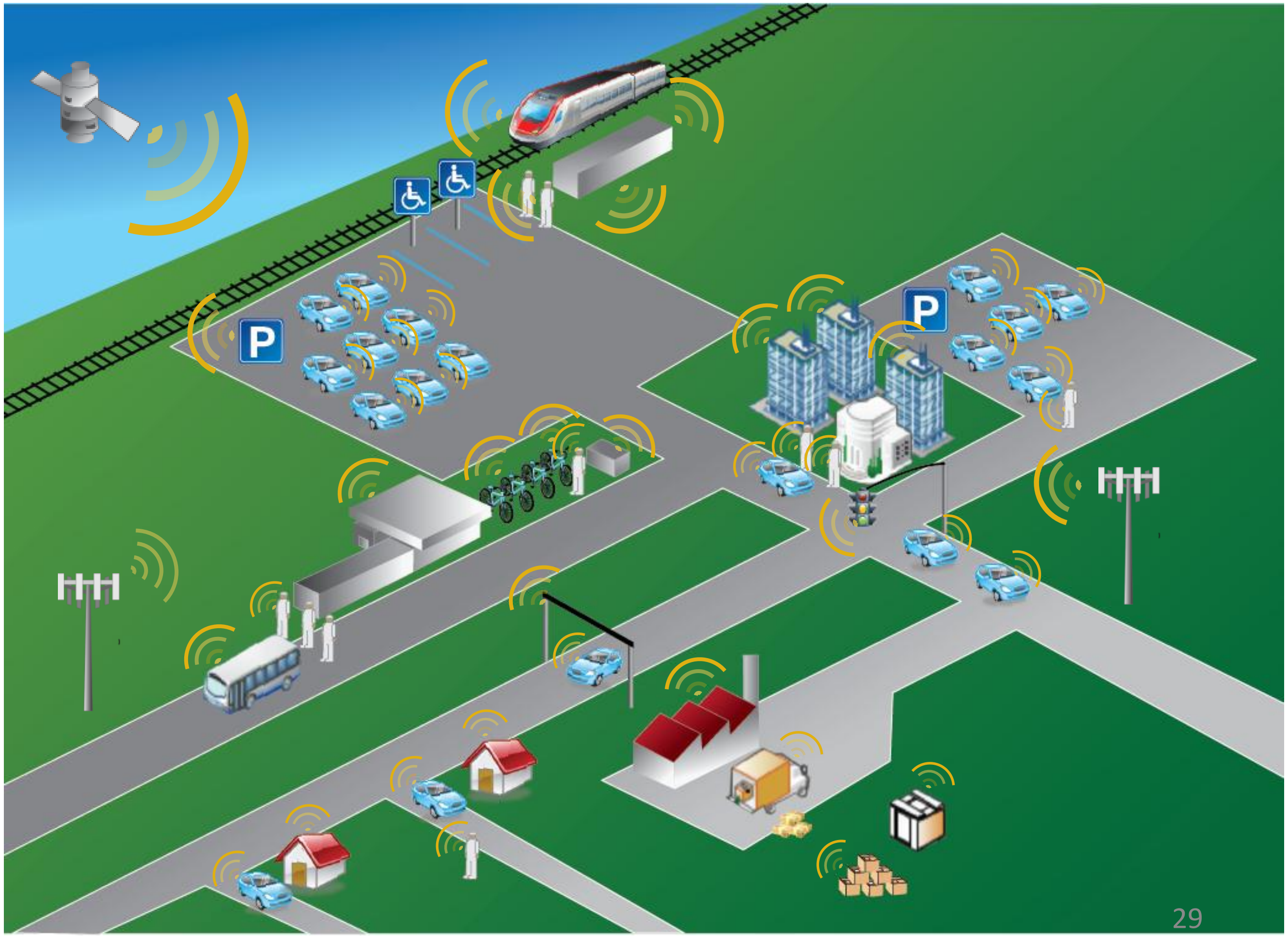
- Trip Planning and In-Route Information
- Bike Availability
- Access Information for Disabled Drivers
- Rideshare Information
- Bus, Truck, and Train Schedule Arrival and Departure Information
- Congestion, Incident, and Travel Time Information
- Toll Information
- Parking Availability
- Freight Dock Availability



Vision: A Connected, Automated Transportation System

Connected Vehicle and Traffic Control

- Speed Control/ Harmonization
- Signal Phase and Timing
- Demand Management/Tolling
- Fleet and Freight Management



FHWA Office of Operations R&D

SAXTON LABORATORY

Driving Future Highways

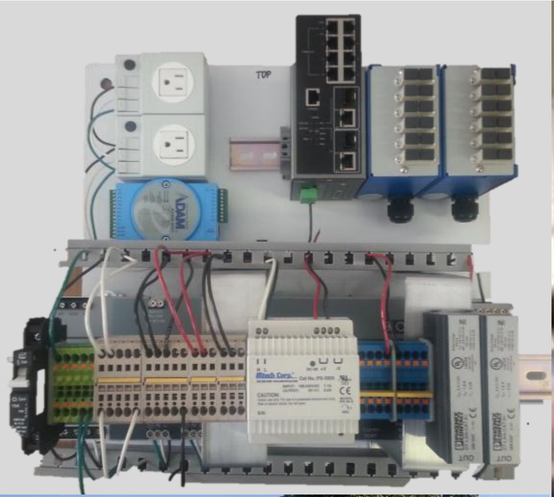
Turner-Fairbank Highway Research Center (TFHRC)

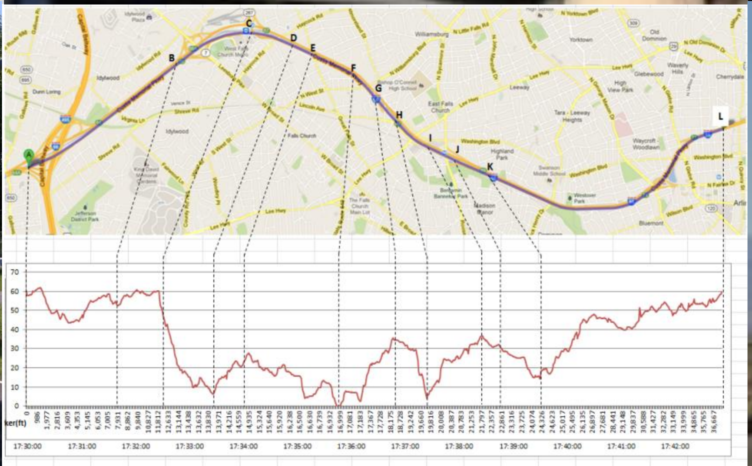
McLean, Virginia

Vision of the Saxton Lab

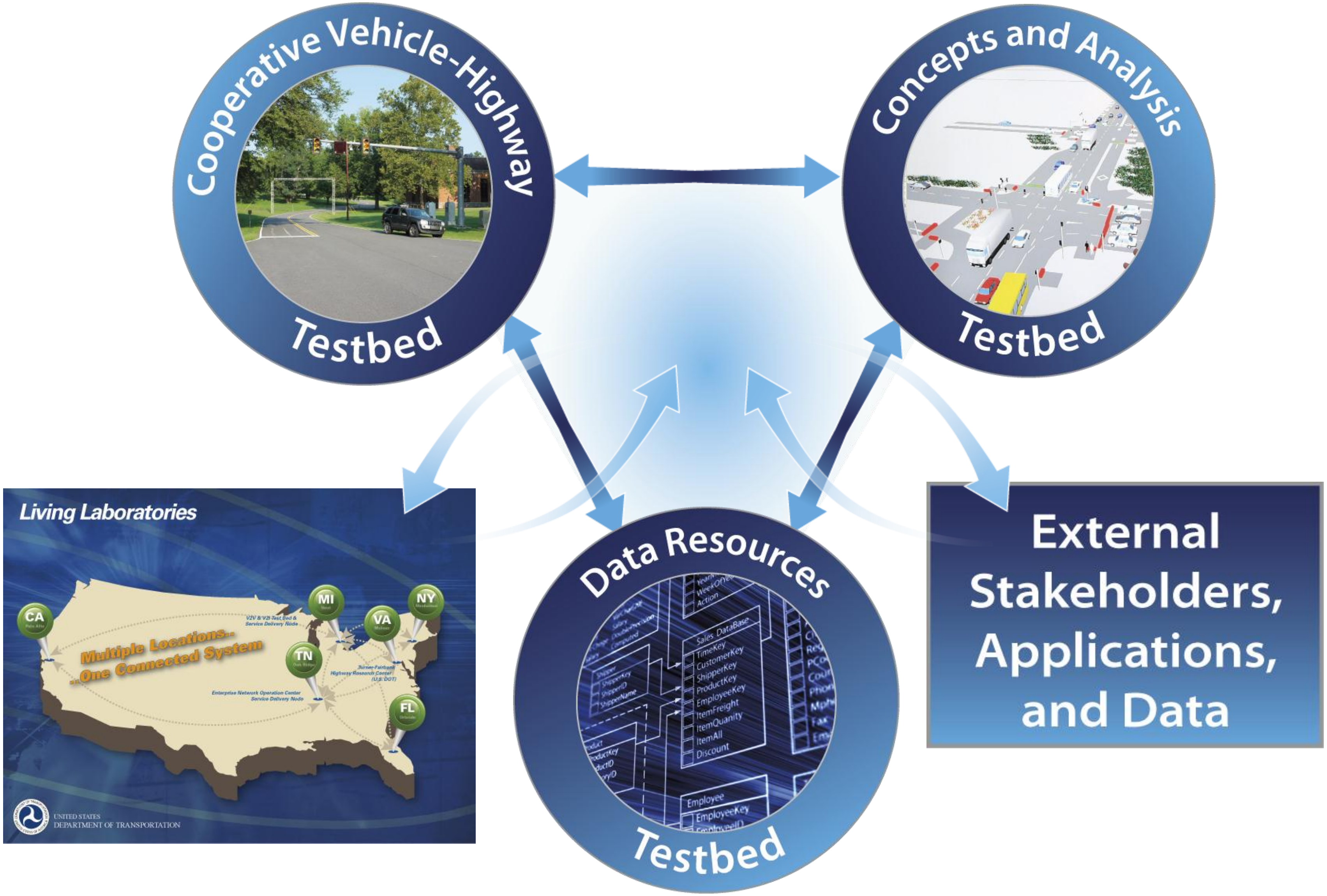
Operations R&D Focus Areas

Enabling Technologies	Concepts and Analysis	Operations Applications





Saxton Lab Capabilities



Saxton Lab Facilities

Connected Laboratory

- State-of-the-Art Simulation and Analysis Tools
- High-Bandwidth Internet2 Connectivity
- High-Capacity Data Servers
- Test and Development Bench

SMART Garage

- Enclosed vehicle laboratory
  - Vehicle exhaust system
  - Wireless connectivity

Saxton Lab Annex

- Additional Workstations

Saxton Lab Facilities

Connected Infrastructure

- Connected Traffic Signal
  - Roadside Communications and Traffic Control Infrastructure
  - Information Processing
- Connected Road
  - Wireless Pavement Sensors
  - High-Speed Cameras
  - Weather &GPS Base Station
  - WiMAX, DSRC and Cellular Comm.
- Connected Mobile Traffic Sensing System
  - Solar Powered
  - Microwave Vehicle Detection
  - Outdoor Pan/Tilt/Zoom Dome Cameras

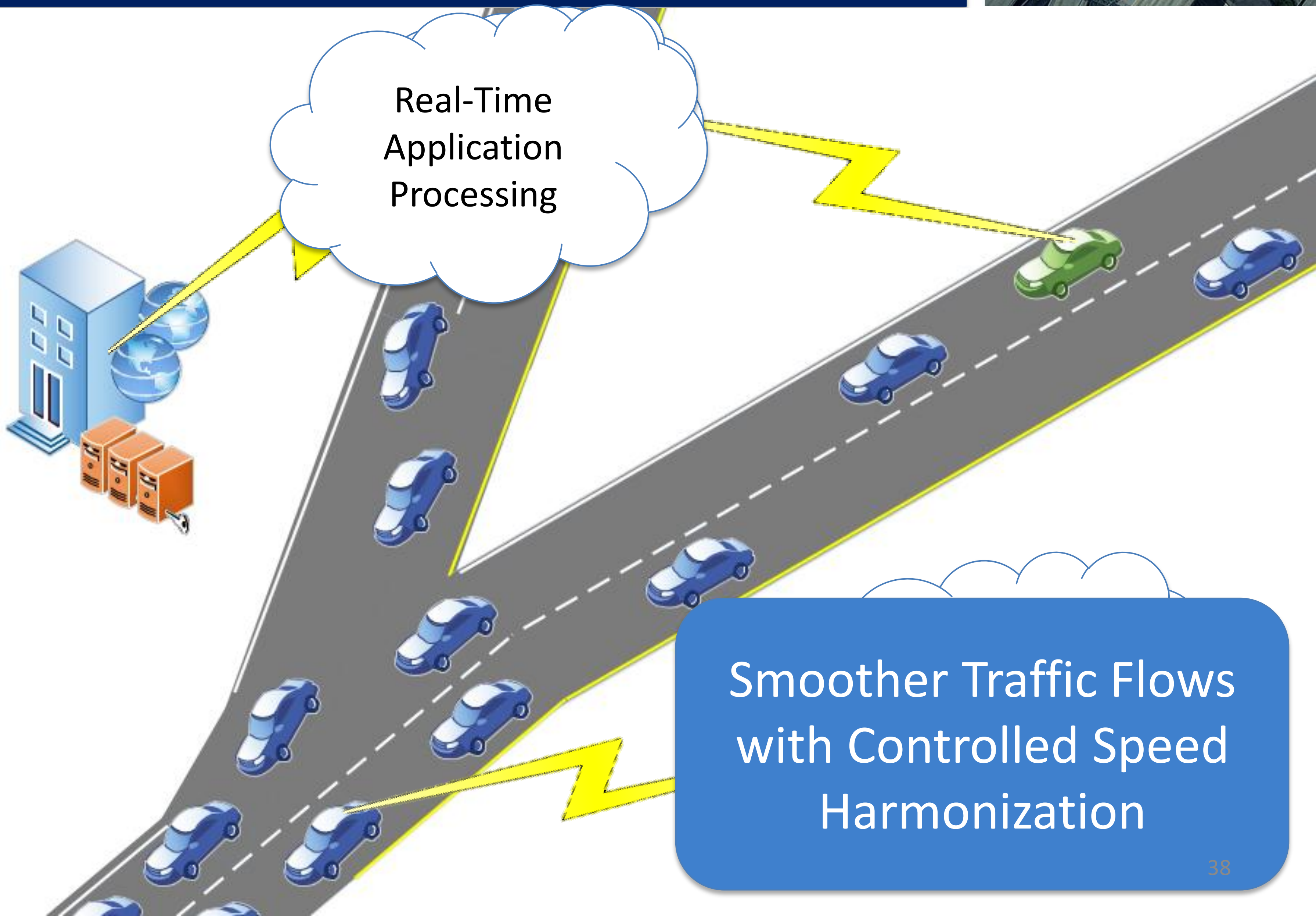
Connected Automation Research for Modeling and Analysis Fleet

- 5 vehicles equipped for V2V and V2I communications testing
  - Radar, Vision, and Ultra-Sonic Sensors
  - Front and rear-facing cameras
  - GPS, DSRC and Cellular Data Connectivity
  - Connected Vehicle Processors
  - On-board CV Data Collection and Processors
- 2 probe vehicles for communications testing
- 1 vehicle for automated eco glide path research
- 1 18-Wheel Tractor Trailer equipped with DSRC connectivity

Ongoing
Connected Automation Research

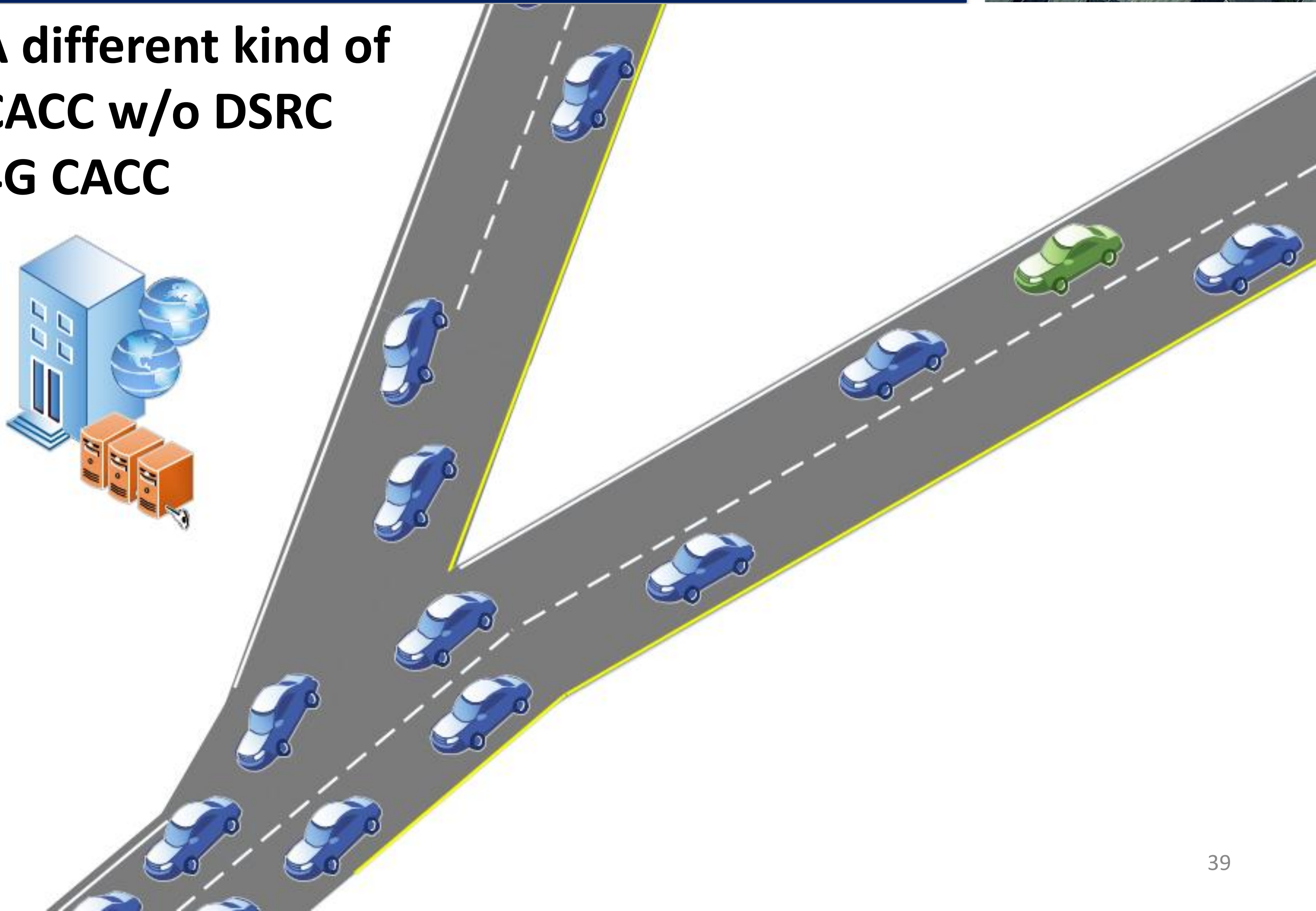
- TFHRC is conducting ongoing connected automation research now at the Saxton Lab and across the US
  - Automated Speed Harmonization
  - Automated Glide Paths at Intersections
  - Automated Truck Platooning

Automated Speed Harmonization Wireless Connectivity

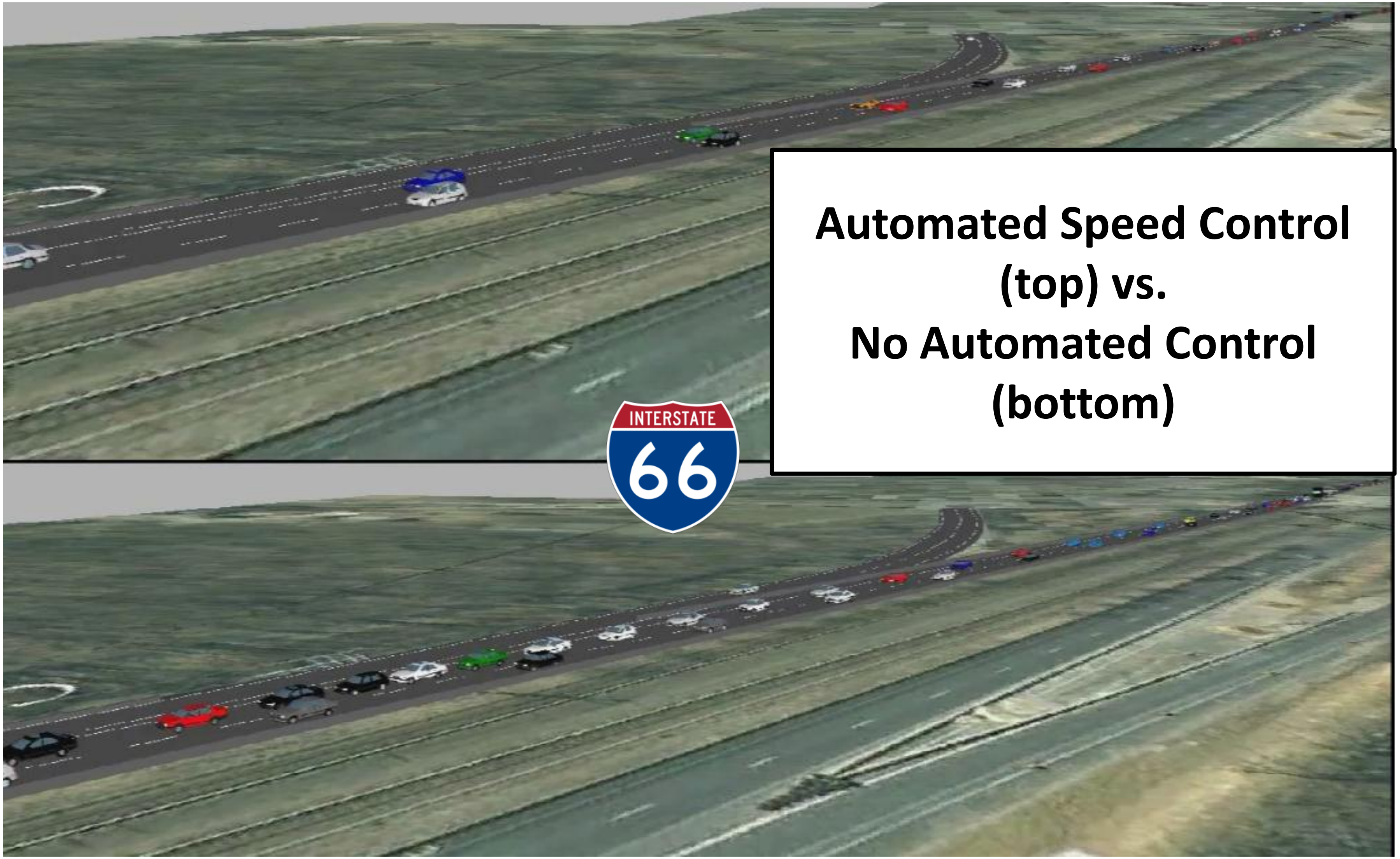


Automated Speed Harmonization Via 4G Wireless Connectivity

- **A different kind of CACC w/o DSRC**
- **4G CACC**



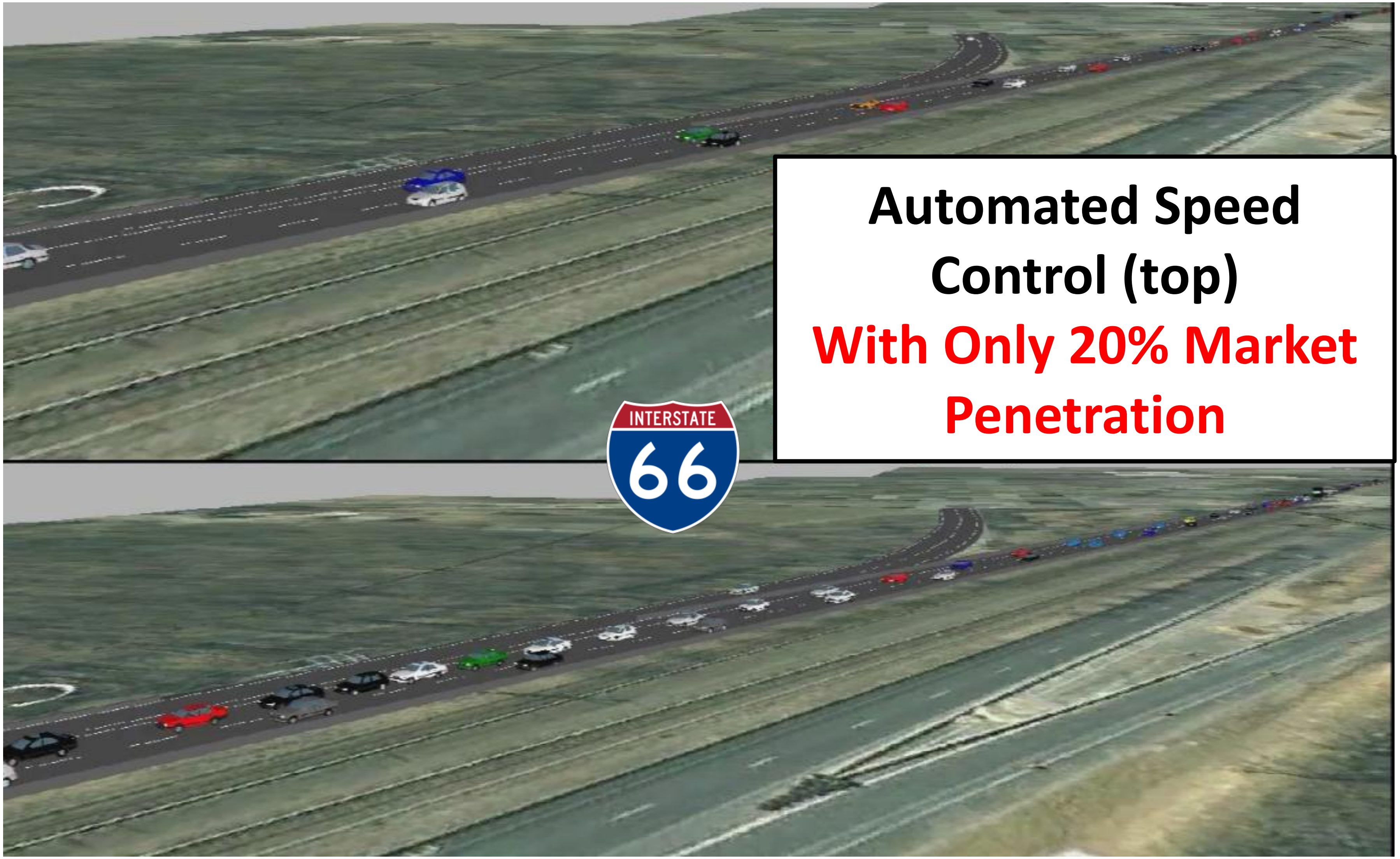
Automated Speed Harmonization Simulation Results



Automated Speed Control (top) vs. No Automated Control (bottom)

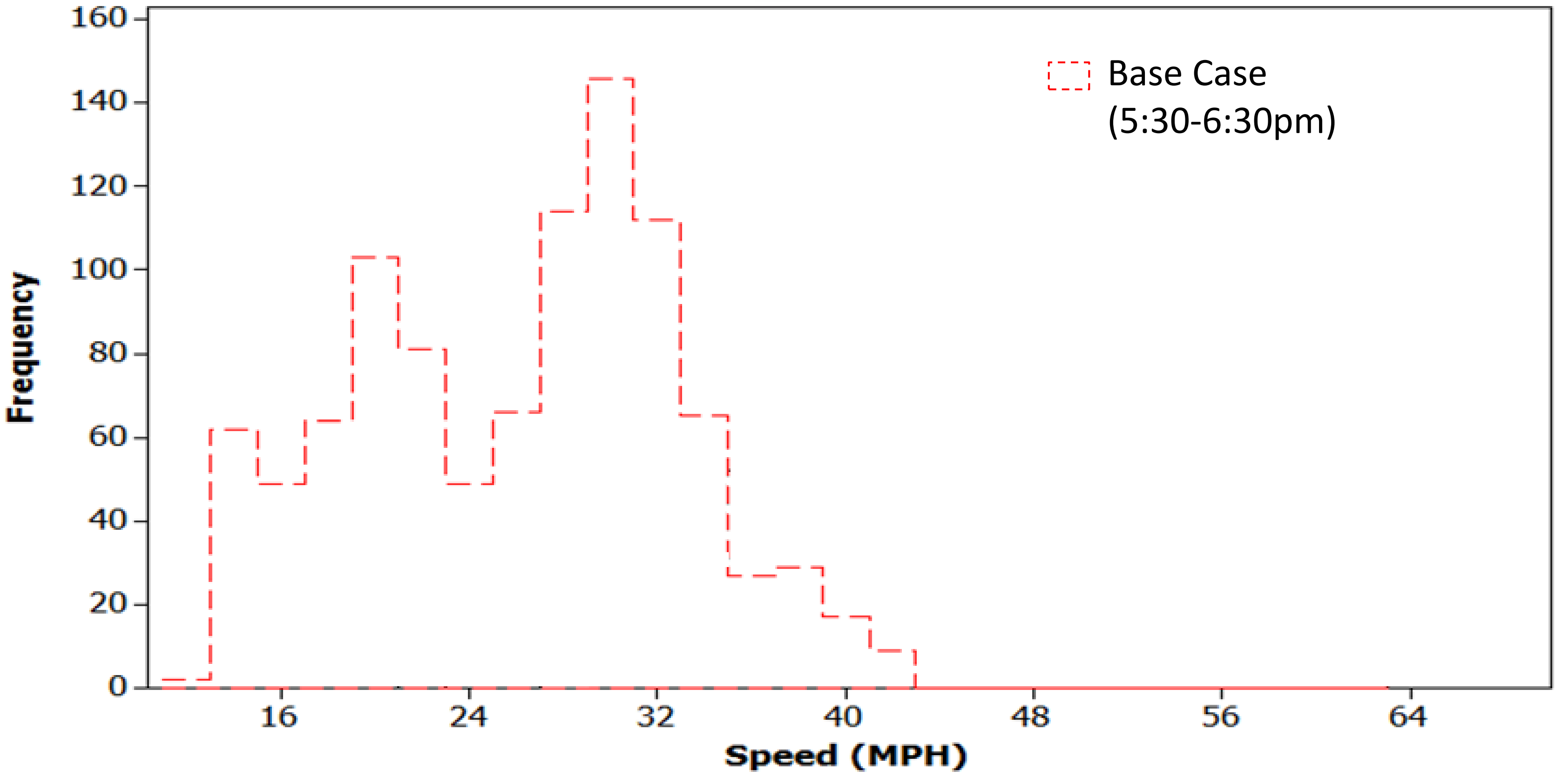
Source: VISSIM simulation for the Cooperative Vehicle Highway Systems to Improve Speed Harmonization Project

Automated Speed Harmonization Simulation Results



Source: VISSIM simulation for the Cooperative Vehicle Highway Systems to Improve Speed Harmonization Project

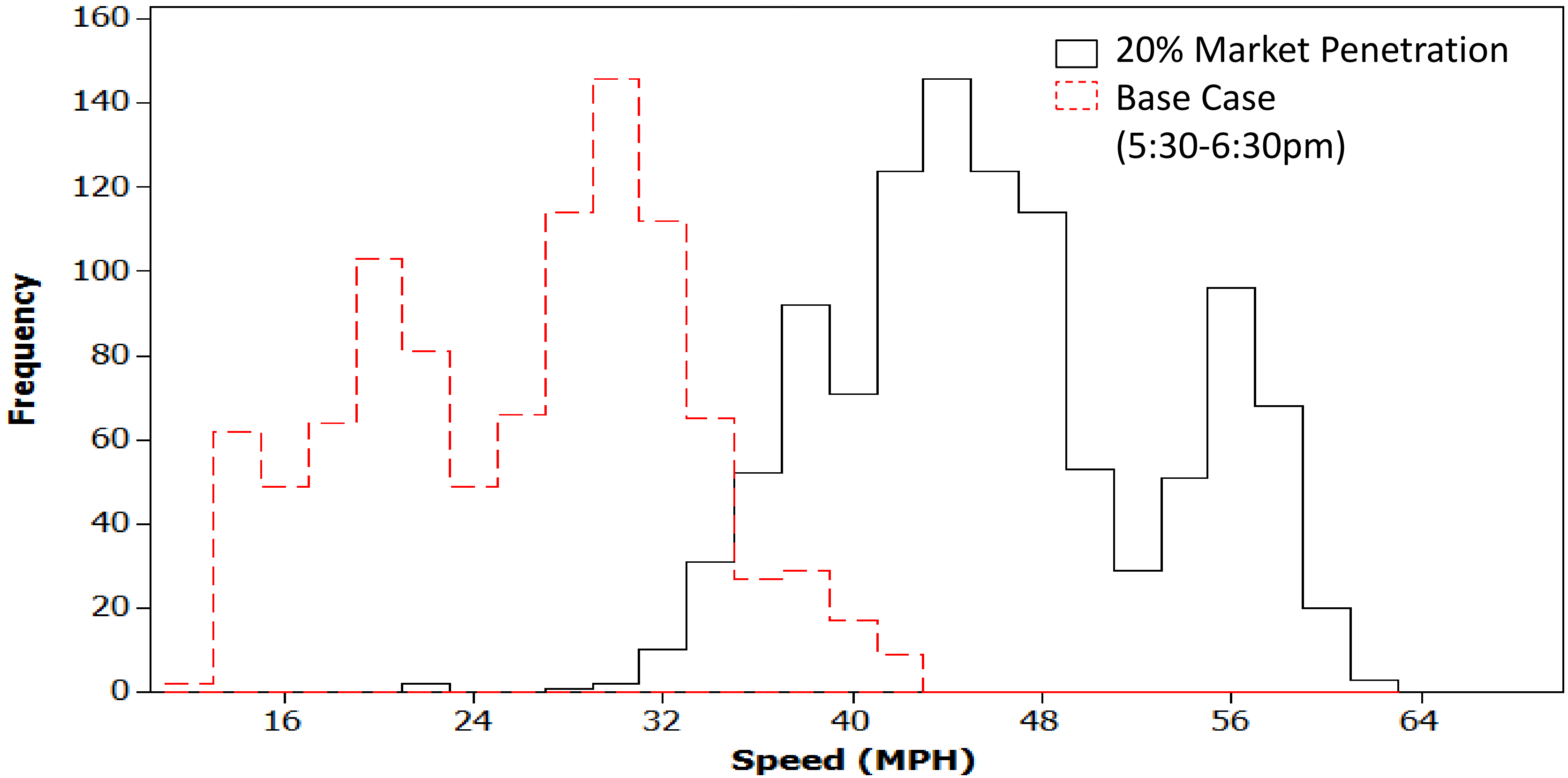
Automated Speed Harmonization: Baseline Condition



Source: Output from VISSIM simulation for the Cooperative Vehicle Highway Systems to Improve Speed Harmonization

Automated Speed Harmonization: Projected Benefits from Simulation

Higher Speeds during Congested Periods



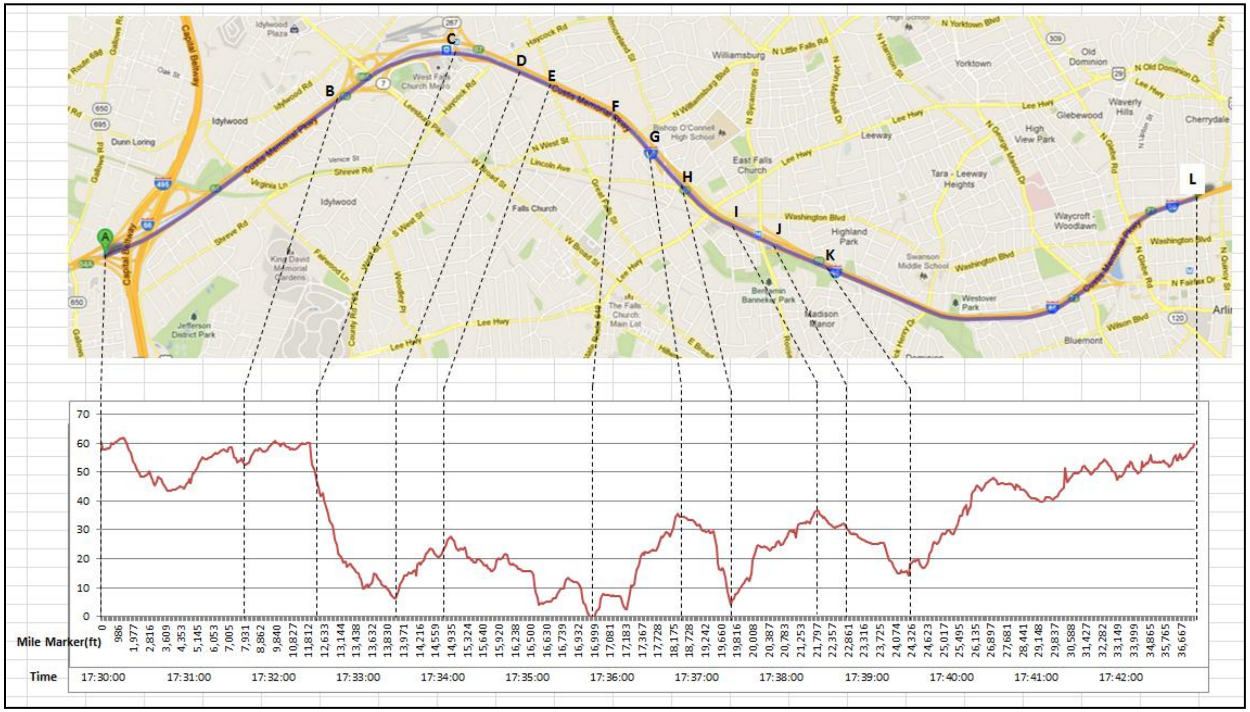
Source: Output from VISSIM simulation for the Cooperative Vehicle Highway Systems to Improve Speed Harmonization

Automated Speed Harmonization Field Testing in NOVA

- TFHRC/Saxton Lab Has Partnered with VDOT to deploy on I-66
- Deploying connected vehicle fleet
- Transmitting real-time speeds directly to cruise controls

Automated Speed Harmonization Field Testing in NOVA

– Developing, Testing and Demonstrating
– Using optimized variable speed targets in coordination with technology deployed in operating vehicles

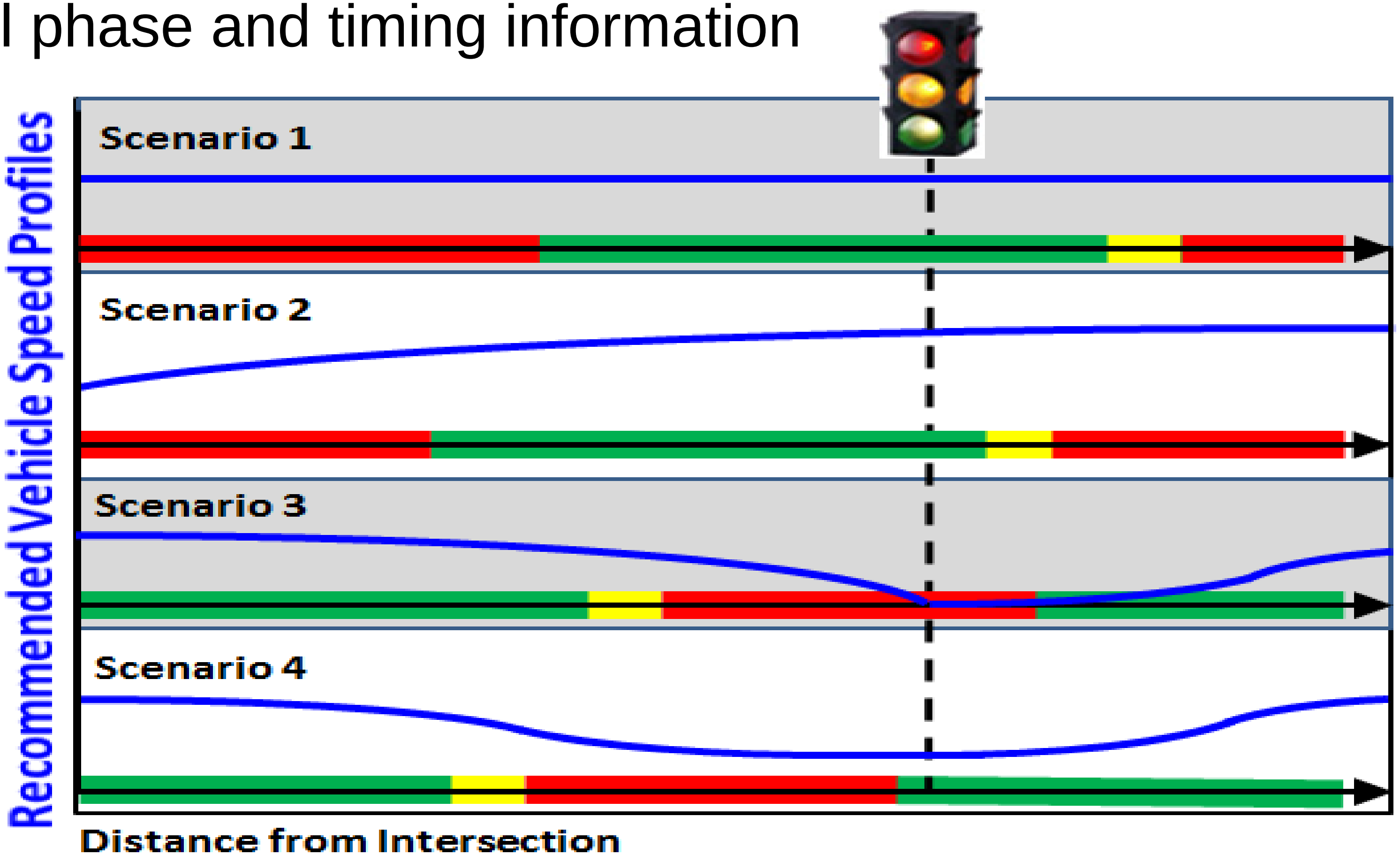


Benefits:

- Harmonize traffic speeds
- Reduce congestion
- Improve highway performance

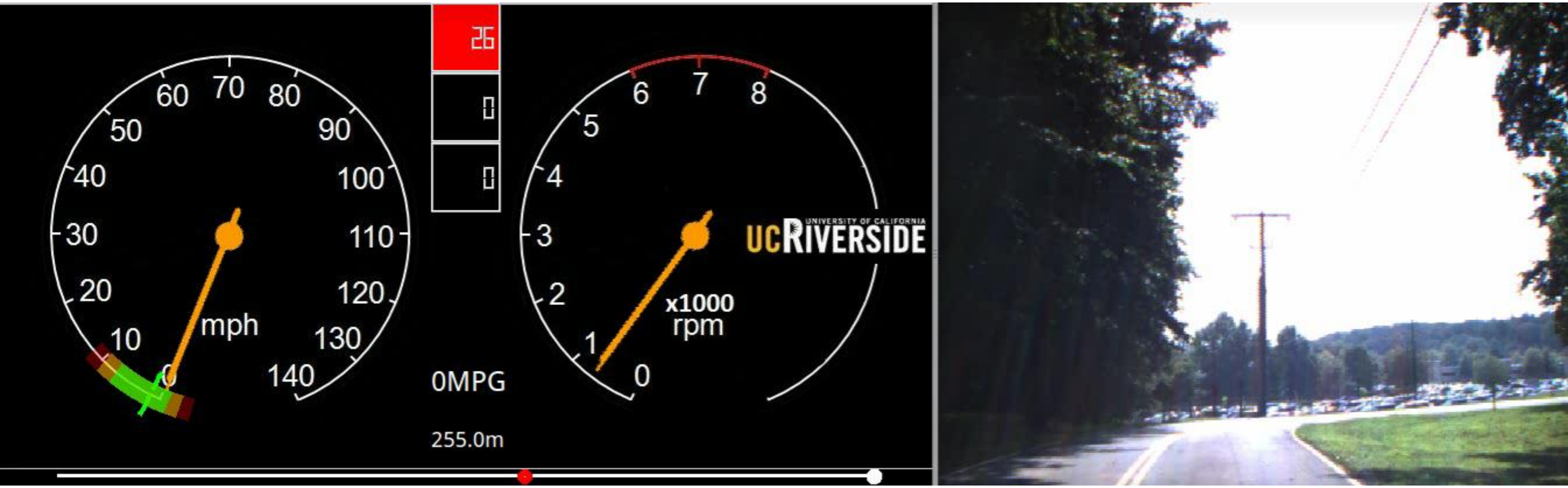
Automated Eco Glide Control Saves Fuel

Applications for the Environment: Real-time Information Synthesis (AERIS): Automatically controlling vehicle speeds approaching and departing intersections using real-time traffic signal phase and timing information



Manual Proof of Concept Test:

Scenario 4: Slightly Reduce Speed to Avoid Red Light



Eco Glide-Path Benefits at TFHRC's Intelligent Intersection

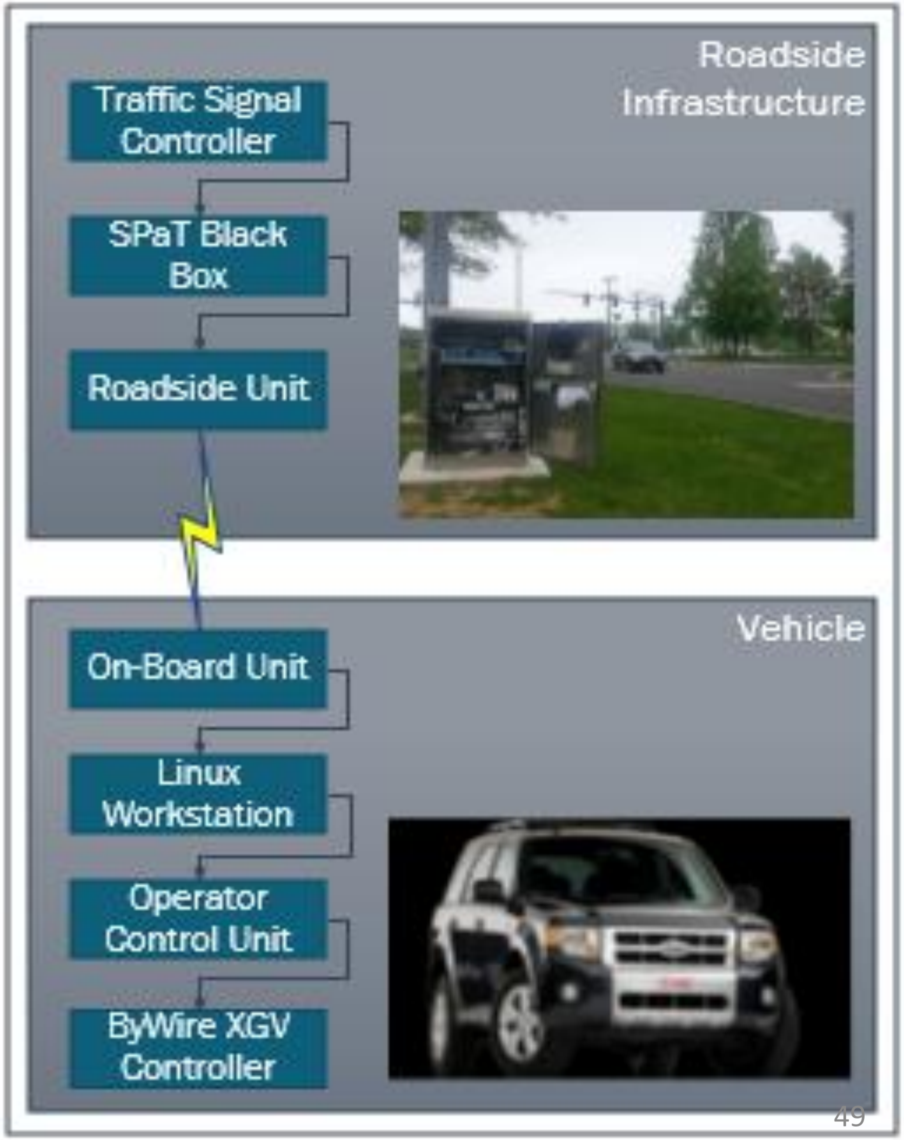
Potential Reduced Fuel Consumption

Speed (mph)	Average Fuel Savings (ml)	SD	Average % Improvement
20	13.0	-	2.5%
25	111	10.9	**18.1%**
30	76.0	15.7	11.2%
35	73.8	19.6	6.3%
40	107	14.6	9.5%

TFHRC is Automating Eco Glide-Path Vehicle Control via DSRC

- Developing a prototype application that can control a vehicle's speed using an automated longitudinal vehicle control system

- Minimizes driver distraction



Past TFHRC-Sponsored Field Tests of Automated Truck Platooning

Three Automated Trucks with Trailers (6 meter gap, ~0.25 seconds at 55 mph)	Three Automated Trucks with Trailers (4 meter gap, ~0.16 seconds at 55 mph)
	

Energy savings of 10-20%
Double capacity of truck-only lanes

Source: Partners for Advanced Transportation Technology (California PATH)

Ongoing TFHRC-Sponsored Truck Platooning Research

- TFHRC is leading partnerships with academia and the trucking industry
- Two projects addressing key questions:
  - Is platooning performance achievable with truck CACC in mixed traffic?
  - What are driver preferences for CACC time gaps?
  - What are the energy savings at the preferred time gaps?
  - What are the benefits in truck lane capacity, energy, and emissions?

Safe Automated Truck Platooning Possibilities

- Truck platooning may offer significant public and private sector benefits:
  - **Mobility**: Better travel reliability, speeds, and use of roadway resources
  - **Energy and Environment**: Lower emissions and fuel consumption
  - **Economic Competitiveness**: Lower operating costs
  - **Safety**: Fewer hazardous movements and better response to safety threats

Newest TFHRC-Led Projects

- High Performance Vehicle Streams
- Lane Change/Merge Options
- Human Factors Issues Related to Advanced Vehicle Control Functions
- Hardware in the Loop Simulation
- Real-Time Data for Connected Vehicles

High Performance Vehicle Streams

<u>Research question</u>: Can high performance vehicle streams of CACC-enabled vehicles provide order-of-magnitude performance benefits throughout a managed lane and without significant adverse impacts on other roadway elements?

<u>Objectives</u>: Develop concepts and assess through simulation the following:

- Strategies to cluster CACC-enabled vehicles with their peers to gain maximum traffic flow benefits
- Use of the opportunities posed by managed lanes
- Mix cars, buses, and trucks into streams using CACC

Lane Change/Merge Options

Research Question: Can traffic movements such as lane changes, weaves, merges, and de-merges be addressed with new operational concepts and technologies, including automated lateral control, and so enable the potential gains in throughput and performance that CACC promises?

Objective: Conduct foundational research on the traffic operations of lane changes, weaves, merges, and de-merges, based upon enabling technologies for automated operation and V2V and V2I communication.

Human-Machine Interaction

Research Question: Will evolving automation through CACC be acceptable to drivers and used as expected?

Objective: Investigate, through the use of a driving simulator and limited field testing, key human factors areas relating to CACC use, including:

- Workload, situational awareness, and distraction, and
- Platoon entry/exit operations

Hardware in the Loop Simulation

Research question: How do we assess the benefit and the performance of Connected Vehicles in a traffic network, given that the existing simulation software were not designed with Connected Vehicle features?

Objective: To develop a new tool to better evaluate the benefit and the performance of Connected Vehicles. Includes three major parts:

- Traffic simulation software
- Communication simulation software
- Hardware interface

Many new items, besides the conventional simulation items, will be added to this tool, which include OBE, RSE, SPaT, DSRC, GPS, Mapping, and engine emission, etc.

Real-Time Data from Roadway Sensors for Connected Vehicles

<u>Research question</u>: Can infrastructure systems recognize individual vehicle passages (and their *speed*) and broadcast data frequently (up to 10 times per second) in synchronization with GPS and vehicle systems, and also provide data to traffic management systems?

<u>Objective</u>: Develop and test a next generation traffic sensor, processing, and communication system

The Pathway Forward

Automated vehicle technologies are **revolutionary**

The Pathway Forward

Automated vehicle technologies are **revolutionary**

A connected, automated transportation system is the **next revolution**

We Want You:
Be a Part of the Next Revolution!

Universities

- Exploratory Advanced Research (EAR) Program
- National Science Foundation

Researchers

- National Research Council (NRC) Fellowships
- Eisenhower Research Fellows
- FHWA Student Internships
- Intergovernmental Personnel Act Agreements (IPA)

Industry

- Connected Vehicle PlugFests
- OEMs (Crash Avoidance Metrics Partners, LLC)

Government

- State and local DOTs

Opportunities for West Virginia

- FHWA 2015 Guidance for Connected Vehicles and Formation of a V2I Deployment Coalition
  - Open comment period until November 14, 2014: http://www.its.dot.gov/meetings/v2i_feedback.htm
- USDOT Connected Vehicle Pilots Deployment Project: http://www.its.dot.gov/pilots/
- AASHTO Connected Vehicle Field Infrastructure Footprint Analysis: http://stsmo.transportation.org/Documents/Executive%20Briefing.pdf

To Learn More

Visit

- FHWA Office of Operations Website: http://ops.fhwa.dot.gov/
- Turner-Fairbank Highway Research Center Website: http://www.fhwa.dot.gov/research/tfhrc/offices/operations/
- FHWA R&T Agenda: http://www.fhwa.dot.gov/research/fhwaresearch/agenda/challengeAreas.cfm?cid=2

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