



U.S. Department of Transportation

# FHWA Connected-Automated Vehicle Research Updates

Clayton S. Chen, PhD, PE, PTOE  
Turner-Fairbank Highway Research Center

Federal Highway Administration (FHWA), Office of Safety Research and Development (R&D)

June 13, 2019



U.S. Department of Transportation  
**Federal Highway Administration**

# U.S. Department of Transportation (USDOT) Automation Policy

- **Automated Driving Systems 2.0 (ADS 2.0): A Vision for Safety (September 2017)**
  - Clarifies Voluntary Safety Self-Assessment process.
  - Emphasizes motor vehicle safety.
- **Automated Vehicles 3.0 (AV 3.0): Preparing for the Future of Transportation (October 2018)**
  - Clarifies multimodal surface transportation.
  - Broadens considerations to reflect multimodal responsibilities (e.g., operations).



Source:  
USDOT

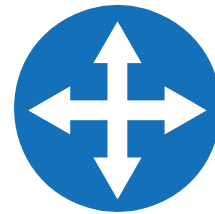
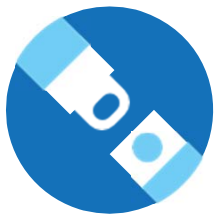
More information on AV 3.0 is available on the [National Highway Traffic Safety Administration \(NHTSA\) website](#).



# Preparing for the Future of Transportation

## Principles:

- Prioritize safety.
- Remain technology neutral.
- Modernize regulations.
- Encourage a consistent regulatory and operational environment.
- Prepare proactively for automation.
- Protect and enhance the freedoms enjoyed by Americans.



# Infrastructure Focus Areas

## Highway Infrastructure Categories

### Traffic Control Devices

Barriers  
Channelizing Posts  
Pavement Markings  
Traffic Signs  
Traffic Signals  
Work Zones

### Pavements and Structures

Asset Management  
Condition and Performance  
Design  
Innovative Technologies  
Maintenance  
Materials

### TSMO\* and ITS\* Infrastructure

Connected Vehicle (CV)  
Roadside Equipment  
ITS Roadway Equipment  
ITS Roadway Payment  
Equipment  
Parking Management  
Systems  
Transportation  
Management Centers  
Digital Infrastructure

### Multimodal Infrastructure

Bicycle/Pedestrian  
Infrastructure  
American Disabilities Act  
Accessibility  
Multimodal Traffic Control  
Devices  
Curb design  
Street design  
Parking



# Research Approach and Highlights

Exploring how to ensure safe, accessible, and efficient integration of automation.



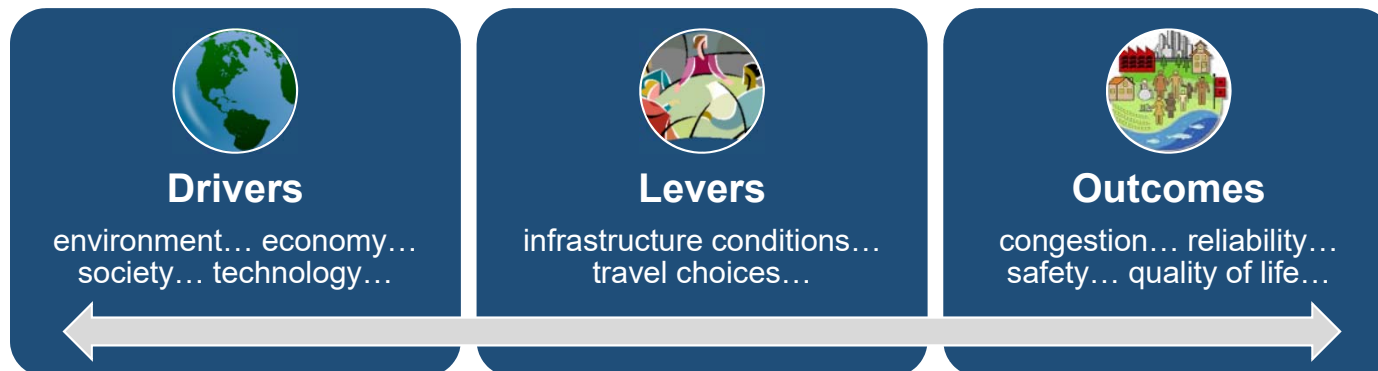
U.S. Department of Transportation  
**Federal Highway Administration**

# Scenario Planning for Connected and Automated Vehicles

**Purpose:** Equip agencies with information and tools to consider the uncertainties of CV/AV deployment.

- Created scenarios of potential CV/AV deployment.
- Conducted workshops to refine test scenarios.
- Assessed overarching scenario impacts and implications.

**Outputs:** Produce practitioner guidance/guidebook, qualitative assessment of impacts, and policy implications arising from future described in scenarios.



# System and User Costs

**Purpose:** Identify and analyze the potential system and user costs associated with the deployment of CV/AV technologies.

## Outputs:

- **Methodology:** Develop methodology to build on current CV/AV implementation scenarios as the framework for estimating costs to the government and users.
  - Establish statistical techniques and quantitative analyses.
  - Address costs to government (Federal, State, and local), private sector, and users.
- **Analyses:** Identify a list of costs and quantify their impacts using original thought and six scenarios from the Scenario Planning effort.
- **Tool Development:** Develop a user-friendly basic tool through which estimates of costs can be calculated.



# Impacts of AV on Highway Infrastructure

**Purpose:** Evaluate the interaction of vehicle automation and road infrastructure.

**Goal:** Develop practicable documentation and inform internal and external stakeholders about AV-related infrastructure needs.

**Objectives:** Assess and understand the demands and potential impacts of AVs on our current infrastructure assets and the potential needs and impacts of AVs on the future design of new infrastructure.



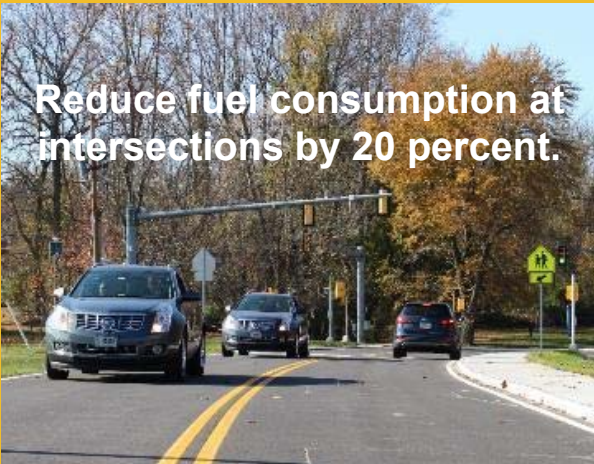


# Cooperative Automation Research Mobility Applications (CARMA) Research Program



Safely improve the operational efficiency and maximize capacity of our Nation's urban and rural roadways

Reduce fuel consumption at intersections by 20 percent.



Save Fuel by 10 percent.



Double capacity of existing lanes.



Source: FHWA.

RESEARCH FOCUSED ON ARTERIAL AND FREEWAYS



U.S. Department of Transportation  
Federal Highway Administration

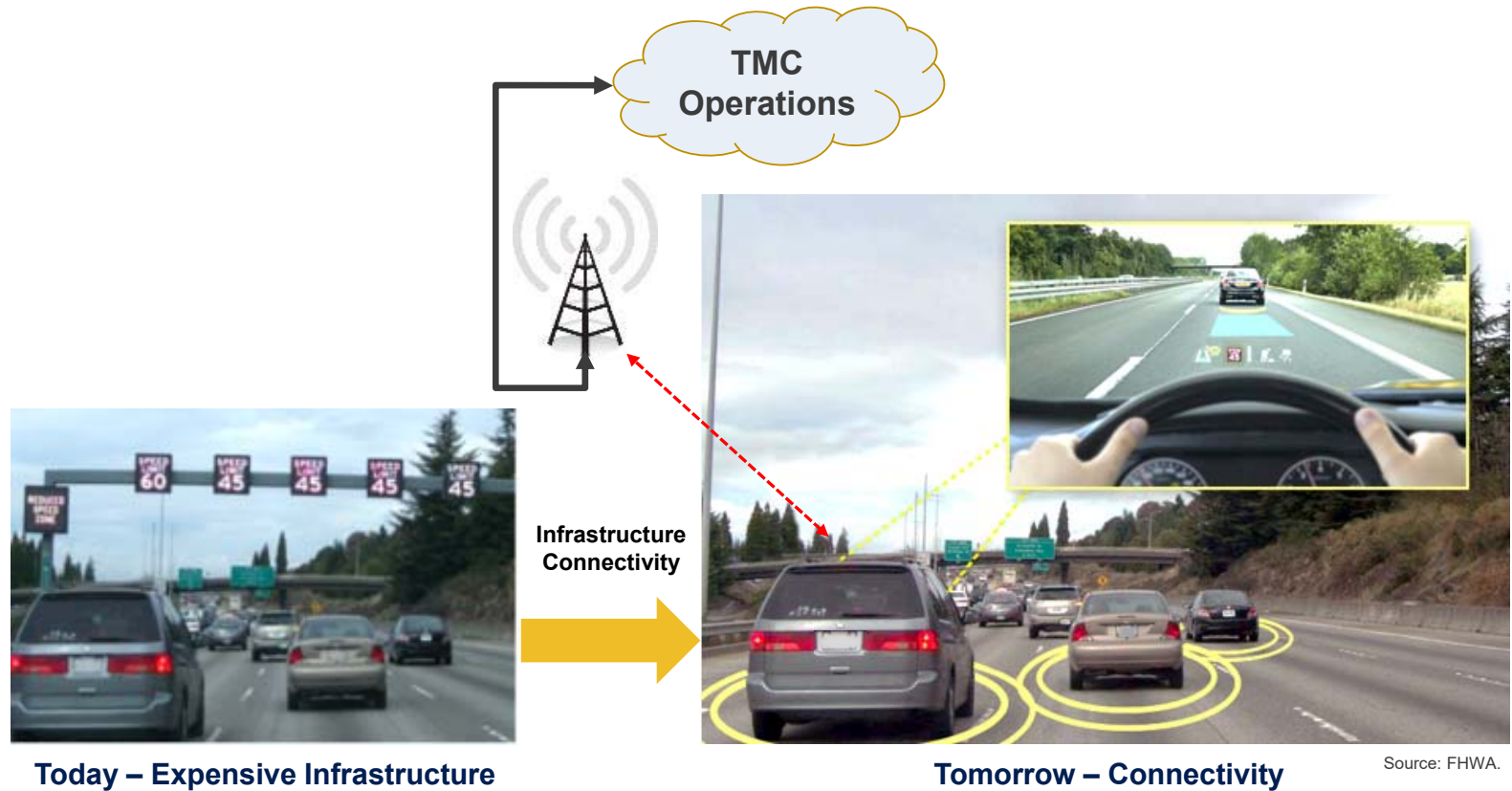
<https://highways.dot.gov/research/research-programs/operations/CARMA>



- Introduction to Cooperative ADS.
- New Uses Cases for TSMO.

# Connectivity

Important for Managing Our Transportation System



TMC: Traffic Management Center.



# TSMO OVERVIEW

## Transportation Systems Management and Operations

### Strategies:

- Work Zone Management.
- Traffic Incident Management (TIM).
- Special Event Management.
- Road Weather Management.
- Transit Management.
- Freight Management.
- Traffic Signal Coordination.
- Traveler Information.
- Ramp Management.
- Congestion Pricing.
- Active Transportation and Demand Management.
- Integrated Corridor Management.
- Access Management.
- Improved Bicycle and Pedestrian Crossings.
- Connected and Automated Vehicle (CAV) Deployment.



# EVOLUTION



## CARMA1 (2014–2016)

- Initial proof of concept.
- Collection of individual applications.
- Simulink/dSpace running on MicroAutobox.
- Demonstration of several applications:
  - Developed platooning algorithm.
  - Modified eco-approach and departure (EAD) algorithm.
  - Modified speed harmonization algorithm.
  - Modified lane change and merge algorithm.



## CARMA2 (2016–2018)

- Society of Automotive Engineers (SAE) Level 1 (L1) automation (speed control) and Level 2 (L2) capable.
- Built on top of Robot Operating System.
- Flexible – can be installed on several types/modes of vehicles.
- Acceptance of third-party plugins for research applications (guidance algorithms).
- Inclusion of simple applications:
  - Cruising with adaptive cruise control (ACC).
  - Cooperative lane change.
  - Mixed platoons.
  - Signalized intersections.
  - Speed harmonization.

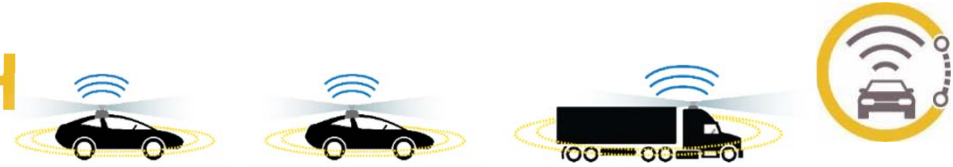


## CARMA3 (2018–2020)

- SAE L2 automation (speed and steering control) and Level 3 (L3) capable.
- More sophisticated vocabulary of vehicle-to-vehicle (V2V) cooperation.
- Enhanced lane change and merge/weave.
- Enhanced platooning (cars and trucks).
- Emphasis on infrastructure interactions for TSMO.
  - Work zones, TIM, weather events, etc.
- Emergency vehicle applications and interactions.



# CARMA 3 APPROACH



Advancing Cooperative ADS research with FHWA and FMCSA fleet and partnerships

CARMA  
PLATFORM



Source: FHWA.

- Expand cooperative automation capabilities.
- Develop proofs of concept to support TSMO use cases.
- Collaborate with Infrastructure Owner-Operator (IOO)/Original Equipment Manufacturer (OEM) community.



© 2018 Getty Images.

- Leverage Autoware open-source software (OSS) development.
- Enable ADS L2 and L3 capabilities.
- Engage ADS community.

Autoware™  
PLATFORM





# Truck Platooning

**Objective:** Investigate the potential benefits of Level 1 truck platooning.

**Findings** (California Department of Transportation/California Partners for Advanced Transportation Technology):

- Fuel savings – platoon average of 5–6 percent.
- Mobility impacts – average speed for all traffic increased.

**Ongoing:**

- Human Factors studying the impact on other road users.
- USDOT developing a Truck Platooning Roadmap.

**Planned:**

- USDOT will provide a Broad Agency Announcement for assessment of inservice truck platoons.
- USDOT will collaborate with FMCSA on future L2 operations.



Source: FHWA



# Human Factors in Automation

**Purpose:** Investigate critical human factors and safety automation issues related to light and heavy automated vehicles.

- Driver Acceptance of Cooperative Adaptive Cruise Control.
- The Effects of Vehicle Automation on Driver Engagement.
- Lateral Control Systems Study.
- Driver Adaptation to Vehicle Automation (L1 and L2).
- Human Factors Issues Related to Truck Platooning Operations.

<https://highways.dot.gov/research-programs/safety/human-factors>



Source: FHWA



U.S. Department of Transportation  
Federal Highway Administration

# New L2/3 Automated Vehicles



Source: FHWA

## **Safety/Human Factors research vehicle**      **Operations research vehicle**

- The two Lexus RX 450h SUVs shown above have L2 vehicle automation (ACC and lane centering).
- L3 capability will be added soon with software to allow autonomous driving in certain situations.
- The Human Factors vehicle has an eye tracker to assess driver attention and distraction.





# Virtual Reality (VR) Bike and Ped Simulator



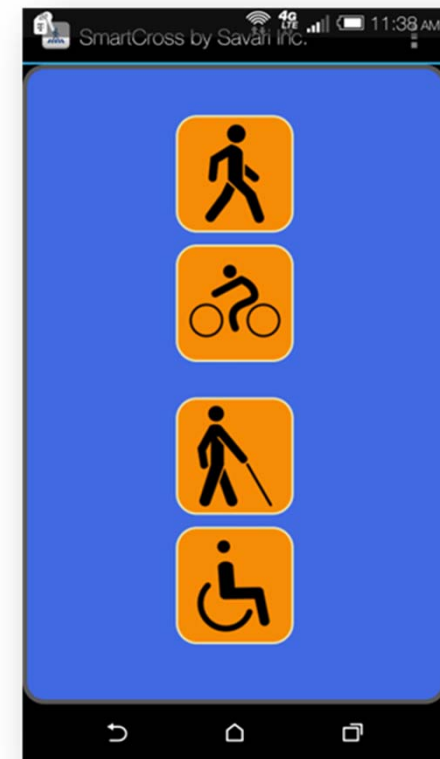
Source: FHWA

- Uses learning technology taken from the gaming industry.
- Includes a Highway Driving Simulator for Multiplayer/Multimodal Simulation Environment.



# SmartCross – Traffic Signal Interface on the Smartphone

- Developed by a Small Business Innovation Research (SBIR) project.
- Enables pedestrians to safely navigate busy intersections using mobile application.
- Allows users to request pedestrian walk phase directly from their smartphone.



Source: FHWA



U.S. Department of Transportation  
Federal Highway Administration

SBIR: <https://www.sbir.gov/>

# Machine Vision System to Support Vehicle-to-Infrastructure (V2I) Safety Applications

- Developed by a SBIR project. Phase 1: Proof of Concept.
- Develop an onboard vehicle machine vision system to identify and interpret specialized roadside static signage.
  - Standard-resolution camera can see and read static signs (i.e., MAP message via Roadside Equipment [RSE]).
  - Onvehicle logic will interpret the signage and execute appropriate function.
- Build a protocol for machine readable signs.



# Accessible Transportation Technologies Research Initiative (ATTRI)

## Enabling the Complete Trip



Source: FHWA

## Current ATTRI Applications in Development



Source: FHWA

[http://www.its.dot.gov/research\\_areas/attri/index.htm](http://www.its.dot.gov/research_areas/attri/index.htm)



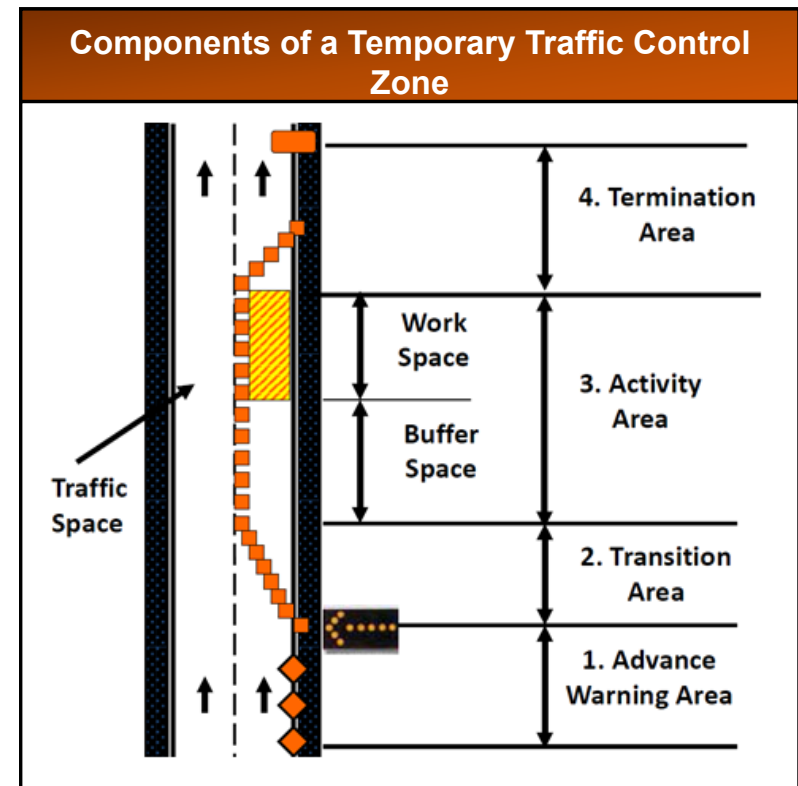
U.S. Department of Transportation  
Federal Highway Administration

# Data For AV Integration

Voluntary data exchanges to accelerate the safe integration of AVs.

## WORK ZONE DATA EXCHANGE

- **Purpose**
  - Adoption of a basic work zone data spec to be voluntary.
- **Outcomes within 6 months**
  - Active work zone to provide data feed.
  - Feed to be used in a meaningful way.
- **Big Picture Outcome**
  - Repeatable approach to harmonize local data.



Source: FHWA



U.S. Department of Transportation  
Federal Highway Administration

ITS JPO Enterprise Data: [https://www.its.dot.gov/research\\_areas/enterprise.htm](https://www.its.dot.gov/research_areas/enterprise.htm)

# V2I Deployment Benefits Tool

**Vision:** Improve safety and mobility via voluntary deployment.

**Objective:** Create a decision-support tool to select V2I applications.

## **Status:**

- Phase 1 Framework–Completed in October 2018.
- Phase 2 Prototyping–Kickoff in December 2018 will deliver:
  - A proof-of-concept working tool.
  - Partnership with IOOs for testing.
  - A draft Concept of Operations for the full tool.
  - A stronger business case for further customization and commercialization.



# CV Pooled Fund Study (PFS)

**Purpose:** CV PFS—a partnership of transportation agencies to facilitate the development and evaluation of CV applications.

**Goal:** Prototype and test practical infrastructure-oriented applications that lead to deployment.

## **Outputs:**

- Development and demonstration of CV technology, algorithms, tools, and applications.
- Preparation for field deployments.
- Development and deployment documentation.
- Lessons learned and identification of challenges from field deployments.

**Members:** 27 Core Members—Virginia DOT (VDOT) (Lead), Associate Members, and Liaisons.



# CV PFS Program – I

Reports: The CV PFS Website [http://www.cts.virginia.edu/cvpfs\\_research/](http://www.cts.virginia.edu/cvpfs_research/)

## **Phase I (7/2009–8/2012)**

- CV Traffic Signal Control Algorithm.
- Pavement Maintenance Support Algorithm.
- Evaluation of Signal Phase and Timing Data.
- CV Certification Program.
- Aftermarket Onboard Equipment.

## **Phase II (9/2012–1/2016)**

- Traffic Management Centers in a CV Environment.
- 5.9 GHz Dedicated Short Range Communications (DSRC) Vehicle-Based Road and Weather Condition Application.
- Surveying/Mapping for CV Applications.





# CV PFS Program – II

## **Phase III (2/2016–12/2018)**

- Basic Infrastructure Message Development and Standards Support for CV Applications.
- 5.9 GHz DSRC Vehicle-Based Road and Weather Condition Application, Phase 2.
- Multimodal Intelligent Traffic Signal System, Phase 1 and 2.

## **Phase IV (5/2018–12/2020)**

- Multimodal Intelligent Traffic Signal System, Phase 3.
- Using Third Parties to Deliver V2I.
- Connected Traffic Control System (CTCS).
- V2I Queue Advisory/Warning.



# Testing and Pilots



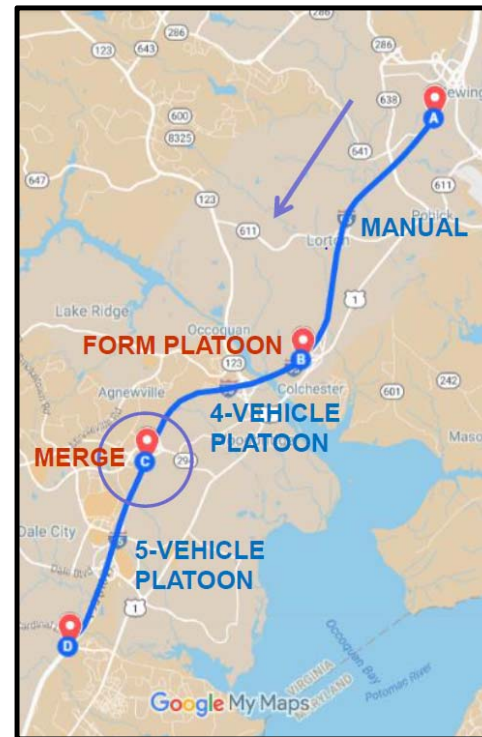
U.S. Department of Transportation  
**Federal Highway Administration**

# Cooperative Automation Testing

## Cooperative Automated Vehicle Testing with VDOT and Transurban

**Objective:** Investigate a combination of speed harmonization, platooning, and cooperative merging on a VA I-95 managed lane.

**Findings:** Initial tests and simulation studies showed a 50-percent increase in capacity is possible on the managed lane.



Original Photo © 2018 Google®



Source: FHWA

Google Maps Image of the Sites for the Cooperative Automated Vehicle Testing



# Cooperative Automation USE CASES

TSMO PROOF OF CONCEPT  
TESTING AND EVALUATION



U.S. Department of Transportation  
Federal Highway Administration

## 1

### Basic Travel



#### Example scenarios:

- Engage in a platoon defined by a geofence.
- Leader maintains safe time gap.
- Followers maintain interplatoon time gap.
- Platoon size of two to five cars per lane.
- Possible maneuvers with other Cooperative ADS-equipped vehicles.

## 2

### Work Zones



#### Example scenarios:

- Reduced command speed entering work zone.
- Defined by a stationary geofence.
- Lane change assignment prior to entering work zone.
- Maintain safe time gap throughout the work zone.
- Possible maneuvers with other CADS-equipped vehicles.

## 3

### Weather



#### Example scenarios:

- Reduced command speed entering low visibility weather.
- Defined by a dynamic geofence.
- Engage in larger time gap.
- Maintain lane guidance.
- Possible maneuvers with other CADS-equipped vehicles.

## 4

### TIM



#### Example scenarios:

- Reduced command speed entering traffic incident event.
- Determined by infield geofence.
- Lane change to provide space for first responders.
- Possible maneuvers with other CADS-equipped vehicles.

# CV Pilots Sites



- Reduce the number and severity of adverse weather-related incidents on the I-80 corridor in order to improve safety and reduce incident-related delays.
- Focus on the needs of commercial vehicle operators in the State of Wyoming.



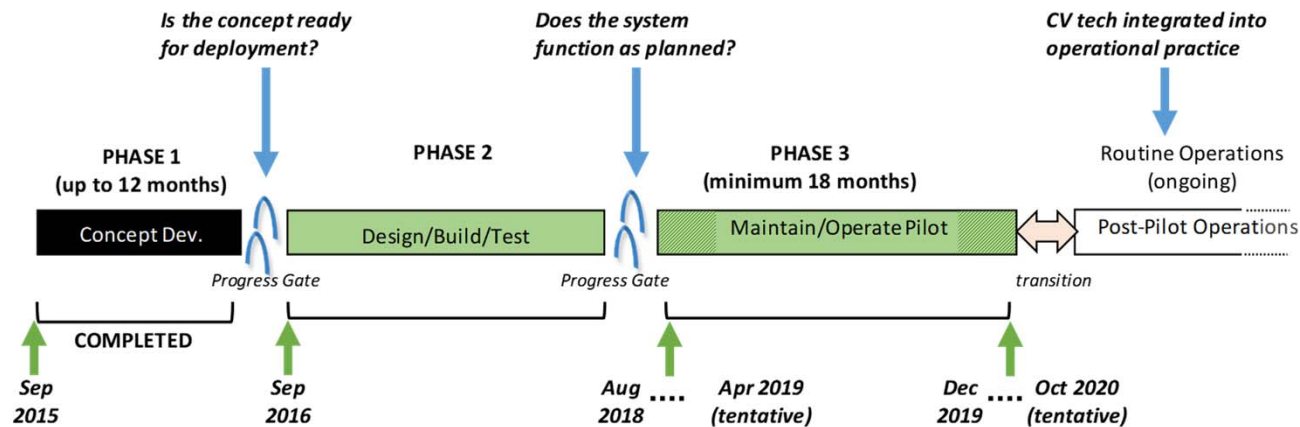
- Improve safety and mobility of travelers in New York City through CV technologies.
- Install V2V technology in up to 8,000 vehicles in Midtown Manhattan and V2I technology along high-accident rate arterials in Manhattan and Central Brooklyn.



- Alleviate congestion and improve safety during morning commuting hours.
- Deploy a variety of CV technologies on and in the vicinity of reversible express lanes and three major arterials in downtown Tampa to solve transportation challenges.



# CV Pilot Deployment Schedule



Source: FHWA  
Last updated: June 12, 2018

- **Phase 1: Concept Development (COMPLETE)**  
Creates the foundational plan to enable further design and deployment.
- **Phase 2: Design/Deploy/Test**  
Ensures deployment functions as intended (both technically and institutionally) after testing.
- **Phase 3: Maintain/Operate**  
Assesses the performance of the deployed system.
- **Postpilot Operations (CV tech integrated into operational practice).**

<https://www.its.dot.gov/pilots/>



# CV Pilots – Lessons Learned

- Prepare for concept evolution.
- Develop an approach to integrate CV pilot with existing TSMOs.
- Address commercial operators' priorities and concerns (privacy, liability, flexibility).
- Allow time for formalized agreements.
- Plan with postpilot operation in mind.
- Balance data needs (privacy/security versus performance measurement).



# Shyuan-Ren (Clayton) Chen, PhD

Roadway Team Leader

FHWA, Office of Safety R&D

[clayton.chen@dot.gov](mailto:clayton.chen@dot.gov)

# Thank you!

