Source: FHWA.

Source: FHWA.

Source: FHWA.

Source: FHWA.

Driving Innovation

Creating a Concept of Operations (ConOps) for Cooperative Driving Automation (CDA) Freeway Applications

U.S. Department of Transportation
Federal Highway Administration

SAXTON LABORATORY

Agenda

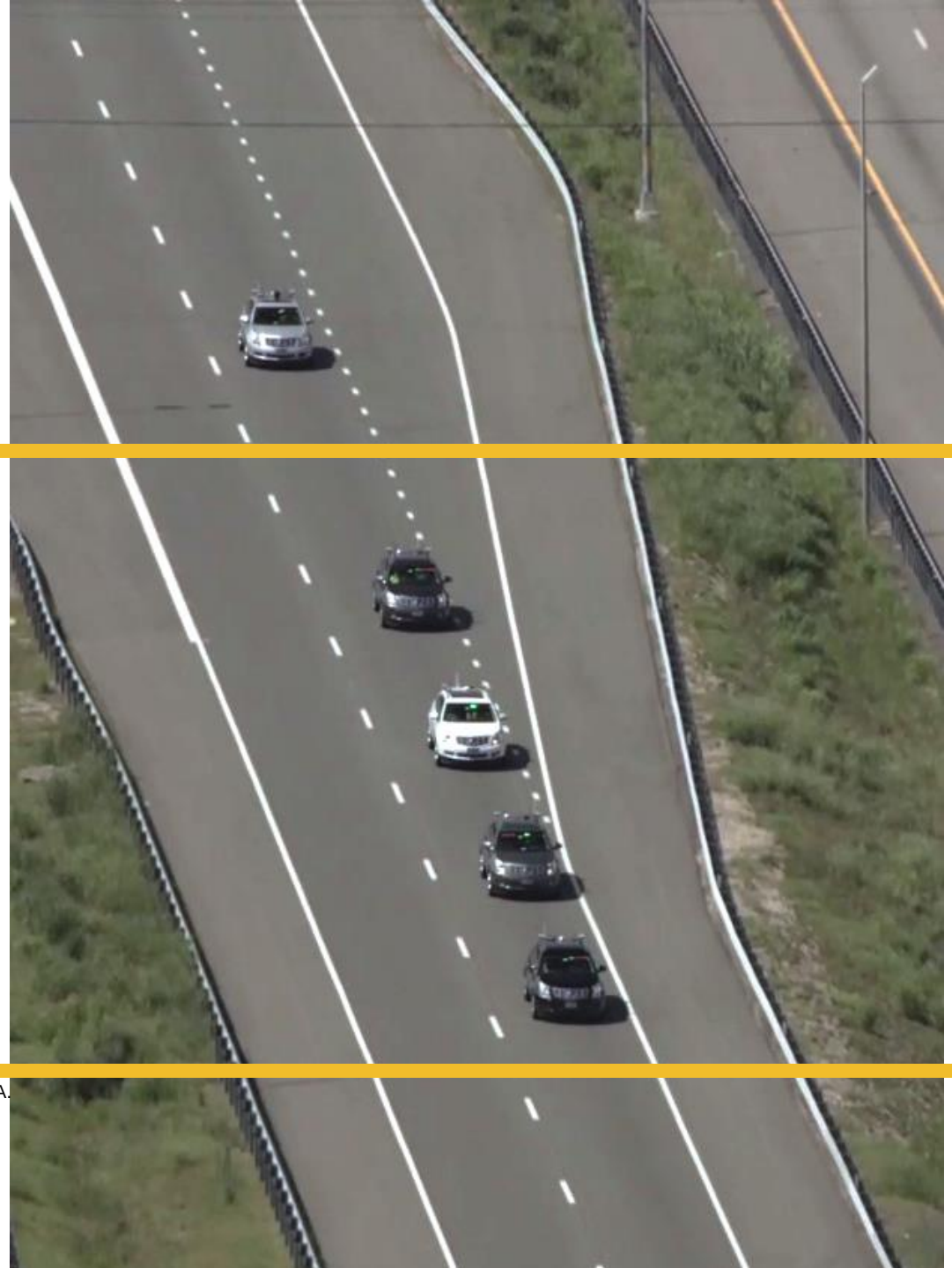
Introduction:

- CARMA^{SM} Program.
- Project Overview.

CDA Freeways (Integrated Highway Prototype II or IHP2) ConOps Overview:

- ConOps Outline.
- ConOps Key Areas.

Discussion and Q&A.



CARMA[SM] PROGRAM

Source: FHWA.

U.S. Department of Transportation
Federal Highway Administration

What is CARMA℠?

The U.S. Department of Transportation's (USDOT) **open source** platform for the research and development (R&D) of CDA.

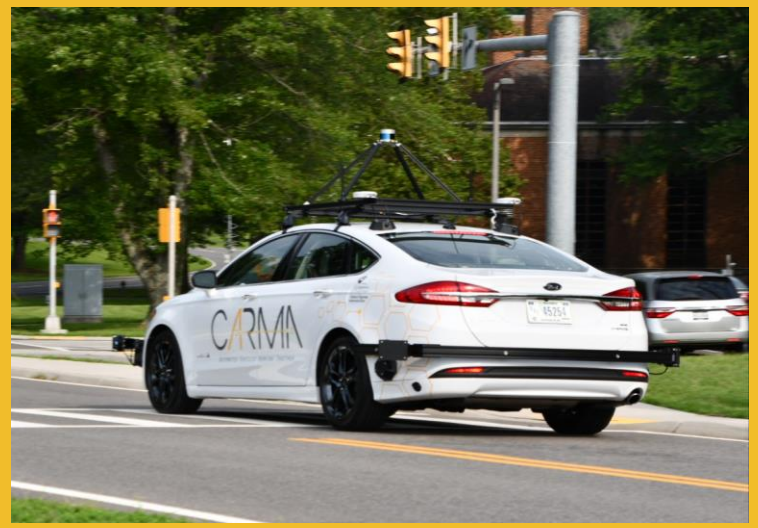
CDA enables automated vehicles (AVs) to work together and with infrastructure to increase mobility and safety.

Source: FHWA.

Cooperative Automation

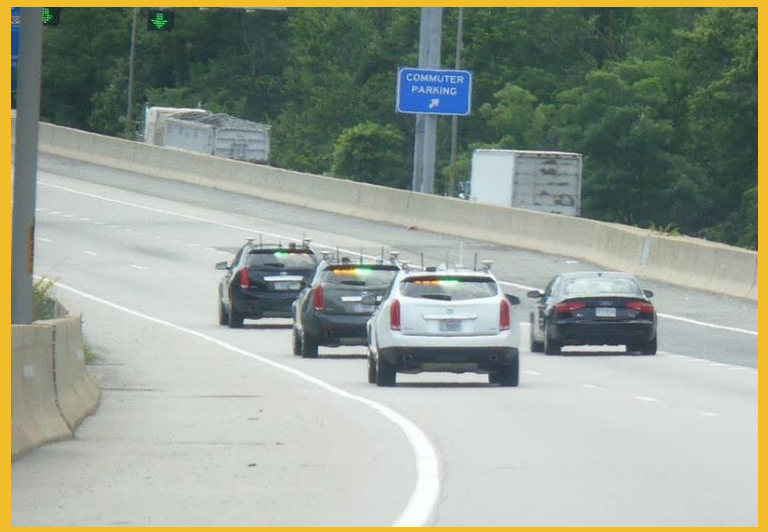
Research Program

Research focuses on **AVs working together and with roadway infrastructure** to increase safety and improve operational efficiency.



Source: FHWA.

Reduce fuel consumption at intersections by 20 percent.



Source: FHWA.

Double capacity of existing lanes.

Source: FHWA.

Provide fuel savings of 10 percent.

CARMA 1

COOPERATIVE ADAPTIVE CRUISE CONTROL (CACC)

Objectives:

- Develop AV Testing Capability.
- Develop an Algorithm for Proof of Concept CACC Vehicle Platooning.
- Demonstrate CACC Enabled on Five SAE Level 1 AVs.

SAE = Society of Automotive Engineers

Source: FHWA.

Source: FHWA.
Icon source: FHWA.

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INTEGRATED HIGHWAY PROTOTYPE (IHP)

Objectives:

- Build a new CARMA2 research platform *(open source).*
- Develop an algorithm *(open source)* for:
  - Speed Harmonization.
  - Vehicle Platooning.
  - Cooperative Lane Change.
  - Cooperative Ramp Merge.
  - Signalized Intersection Approach and Departure.

5
Cooperative Driving Features

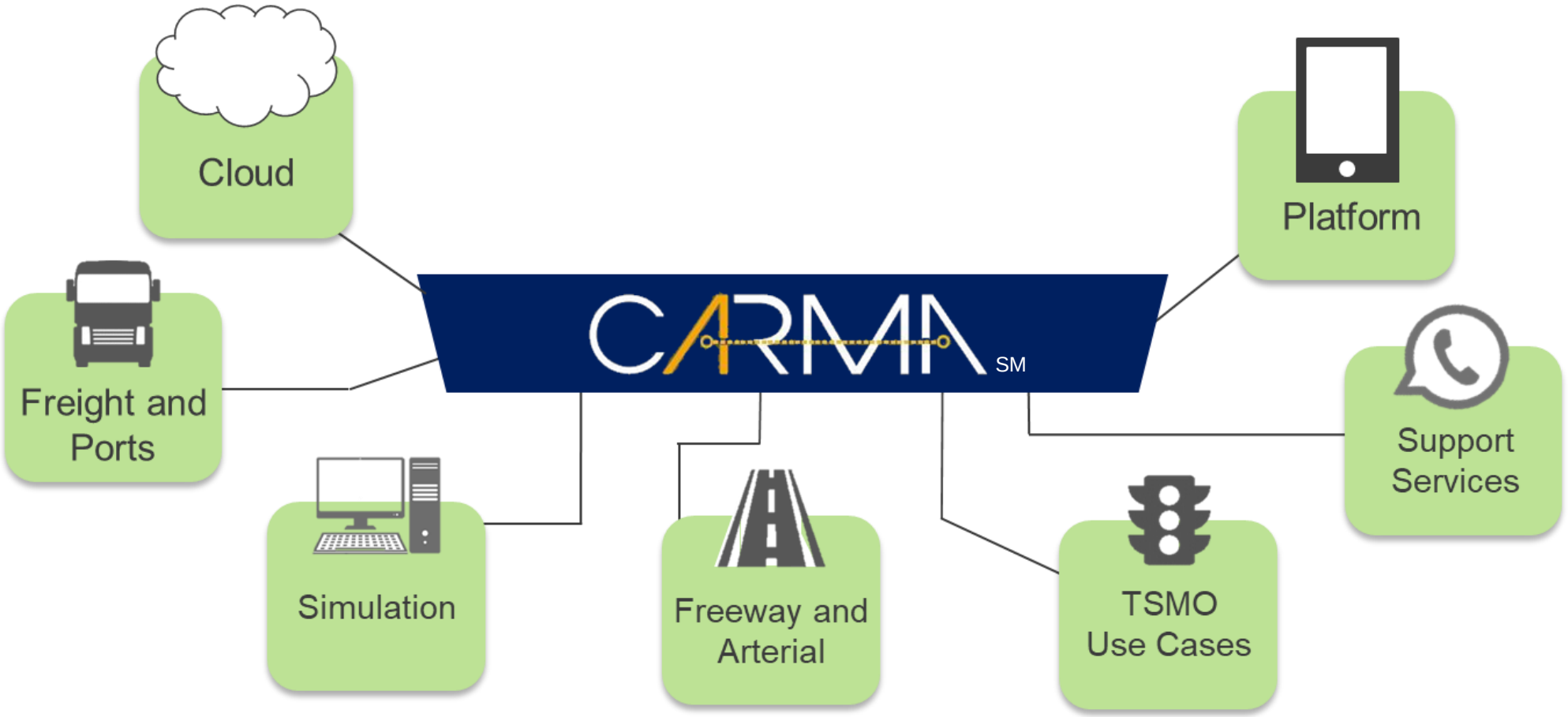
24
Days at Aberdeen Test Center (ATC)

22,000
Miles of Closed Track Testing

42,000
Lines of Code

Source: FHWA.

CARMA Project Structure



Source: FHWA.

TSMO = Transportation Systems Management and Operations

Federal Highway Administration (FHWA) Automated Research Vehicles

- Use industry's AV technology.
- Based on existing AV open source software.
- Equipped with CARMA Platform and Messenger.

CARMA Platform

- Adds vehicle-to-everything (V2X) communications.
- Enables AVs to cooperate.
- Facilitates participation and collaboration.

AVs

Coming Soon

First Responder Vehicle

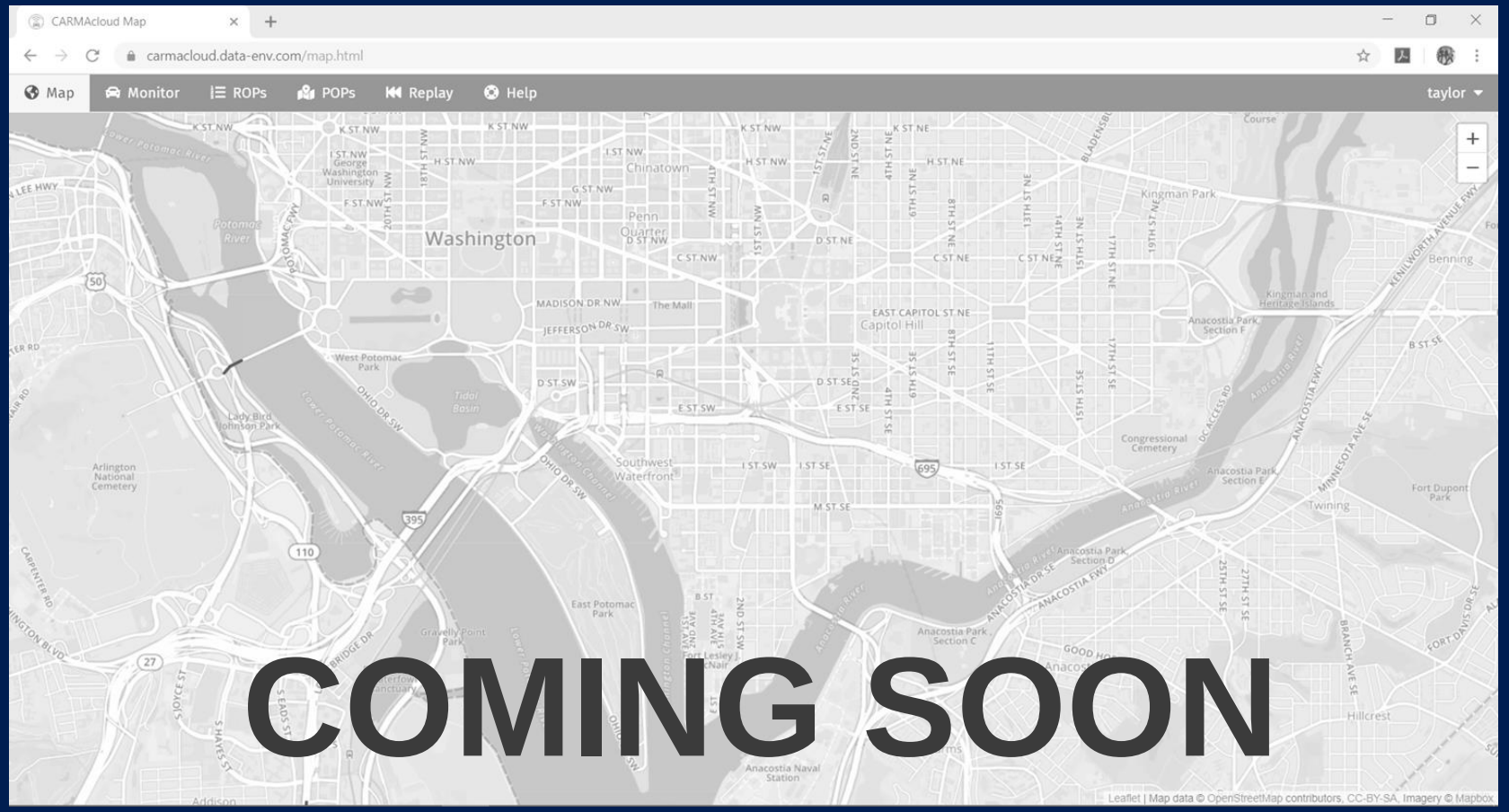
Automated Trucks

1tenth Model Vehicles

Source: FHWA.

CARMA Cloud℠

- Provides interaction between the roadway operators and AVs.
- Enables management of AVs to improve traffic.
- Builds understanding of how to manage traffic of the future.



Map Data: © OpenStreetMap contributors, CC-BY-SA. Imagery © Mapbox.

Where is CARMA℠ Going?

CARMA is growing across modes, applications, and the country.

- USDOT multimodal partners.
- Transportation Systems Management and Operations (TSMO) use cases.
- CARMA Collaborative℠: Nationwide network of CDA researchers.
- CARMA Support Services: Technical support for CARMA software.

USDOT Multimodal Partners:

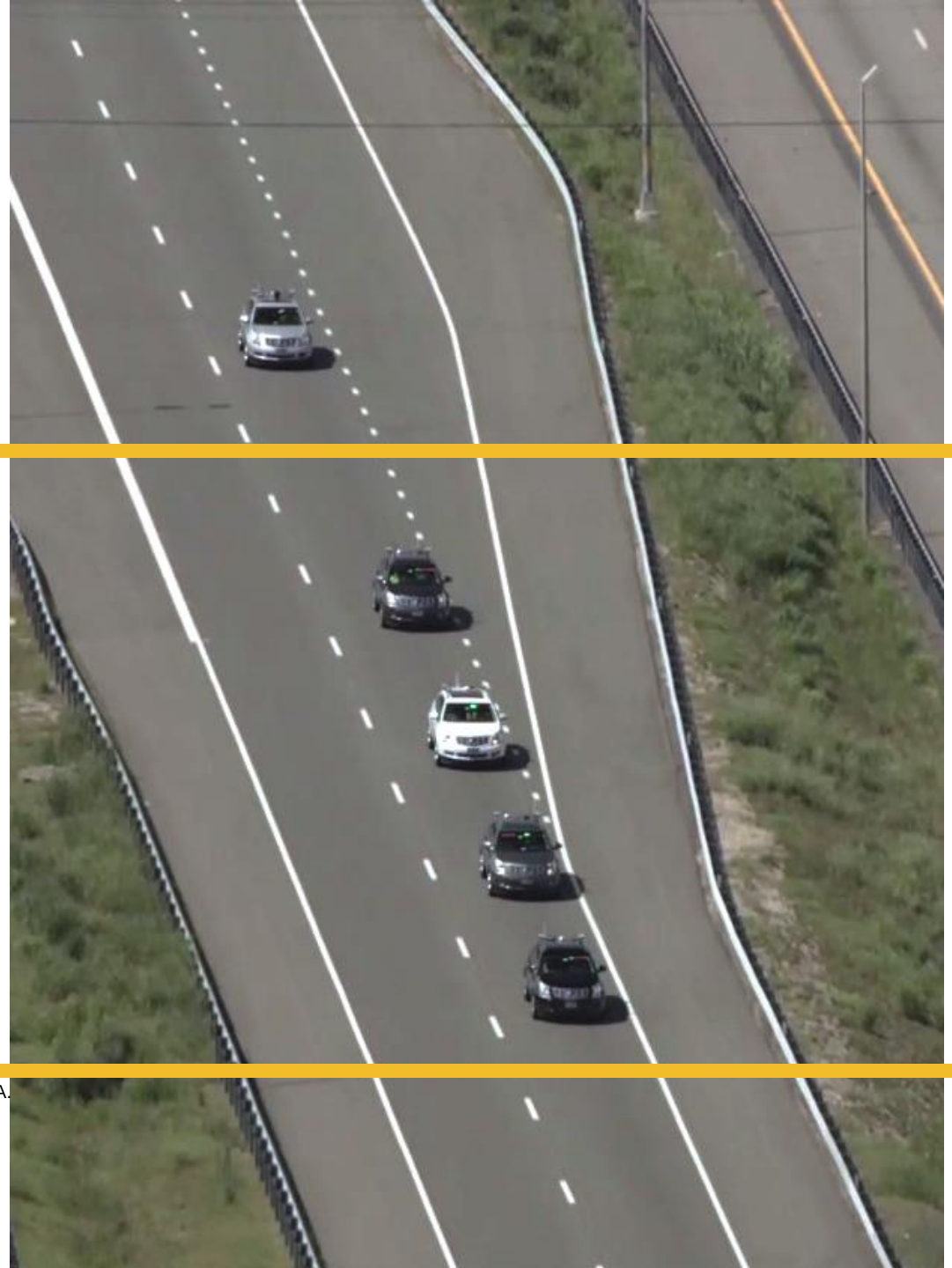
- FHWA.
- Federal Motor Carrier Safety Administration.
- Maritime Administration.
- Intelligent Transportation Systems Joint Program Office.
- Volpe National Transportation Systems Center.

To Learn More about CARMA, Visit:

- **FHWA Site** – https://highways.dot.gov/research/research-programs/operations/CARMA
- **GitHub Site –** https://github.com/usdot-fhwa-stol
- **Confluence Site –** https://usdot-carma.atlassian.net/wiki/spaces/CAR/overview
- **Jira Site –** https://usdot-carma.atlassian.net/secure/Dashboard.jspa
- **CARMA Collaborative** – CARMA@dot.gov
- **CARMA Support Services** – CARMAsupport@dot.gov

Icon source: FHWA.

Questions?



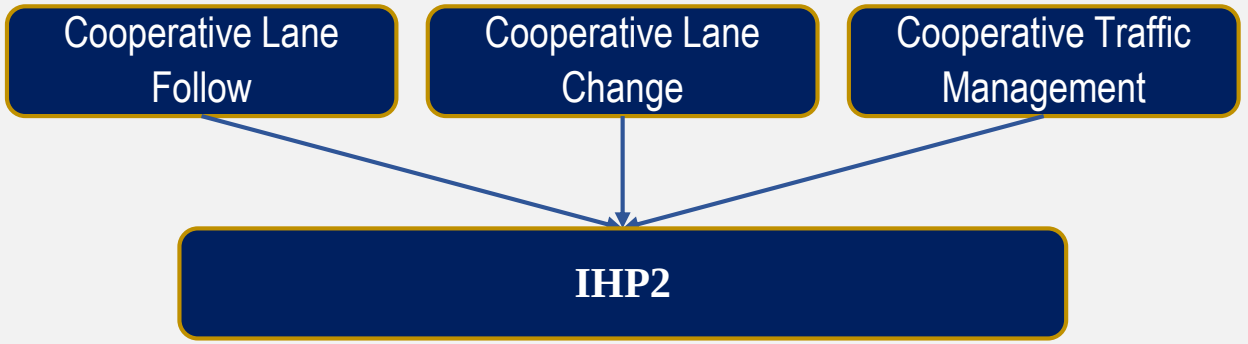
PROJECT OVERVIEW

Source: FHWA.

U.S. Department of Transportation
Federal Highway Administration

Project Overview: CDA Freeway Applications

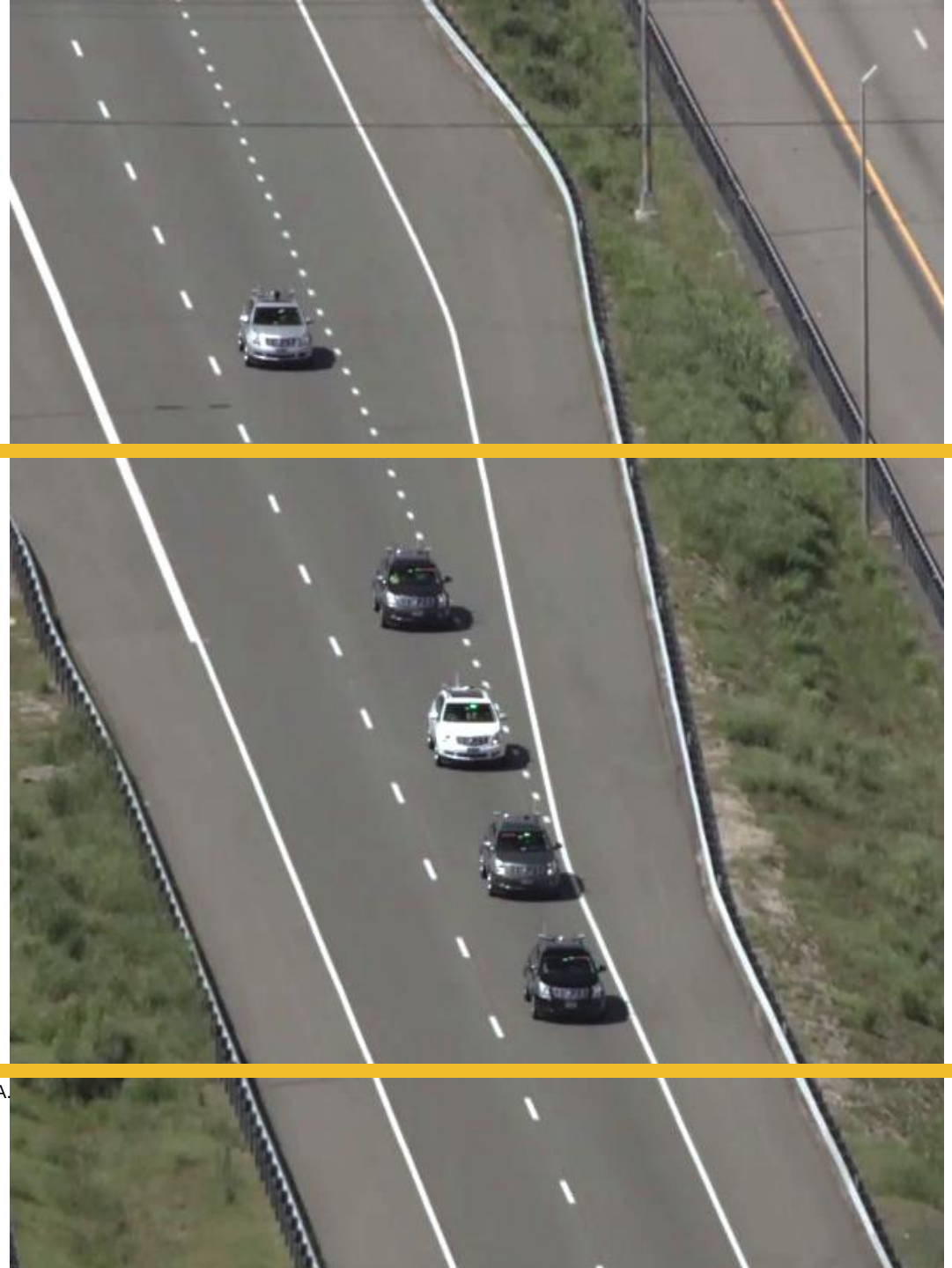
- This project builds off a prior FHWA project that advanced CDA freeway features using SAE Level 1 automated driving technology.
  "Integrated Highway Prototype I" (IHP1).
- This project integrates CDA freeway features into a single solution with the goal of mitigating recurring congestion with SAE automated driving systems (ADS) Level 3+ technology.
  "Integrated Highway Prototype II" (IHP2).



Source: FHWA.

Today's Objective

- Introduce cooperative automation program.
- Review IHP1.
- Present draft ConOps for CDA IHP2.
- Solicit feedback.



CONOPS OVERVIEW

Source: FHWA.

U.S. Department of Transportation
Federal Highway Administration

ConOps Outline

Chapter 1. Scope and Summary.

- **Chapter 2.** Existing Conditions and Opportunities for Change.

  Existing CDA Freeway Applications: IHP1.

- **Chapter 3.** Operational Concept for Next Generation of CDA Freeway Applications.

  This Project: IHP2.

- **Chapter 4.** Operational Scenarios.

Chapter 5. Analysis of the Proposed System.

IHP

Platooning

Lane Change/Merge

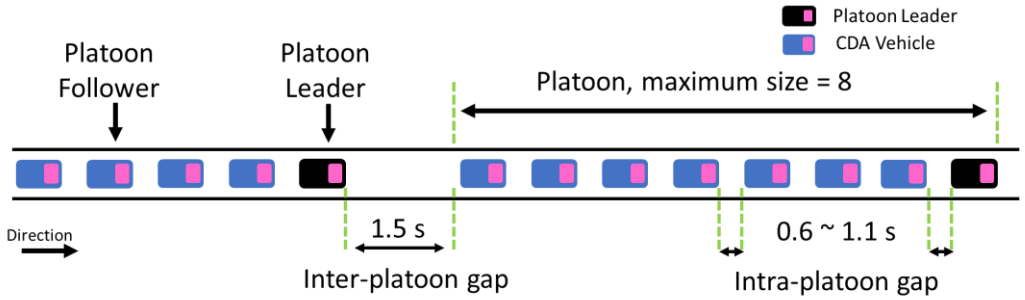
Speed Harmonization

IHP

Source: FHWA.

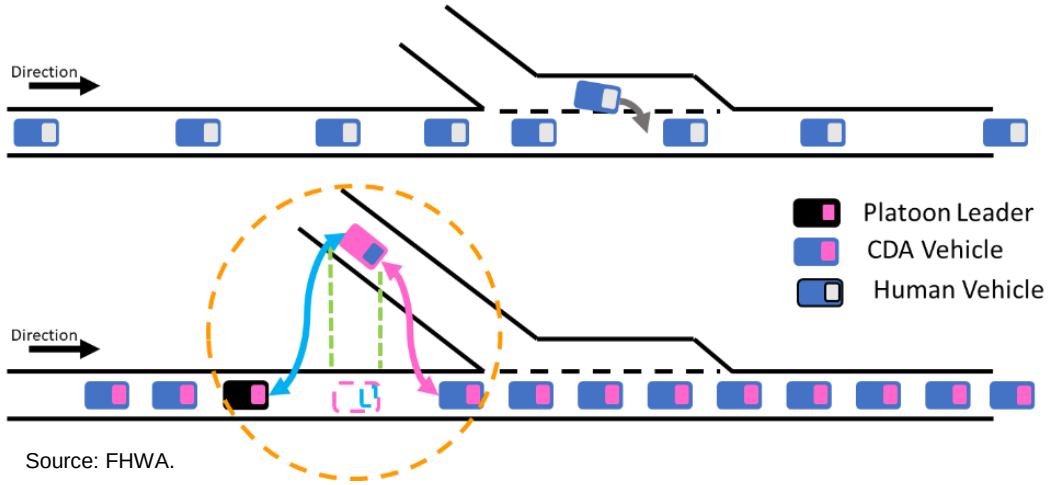
IHP1

CACC Platooning (limited capability of cooperation)



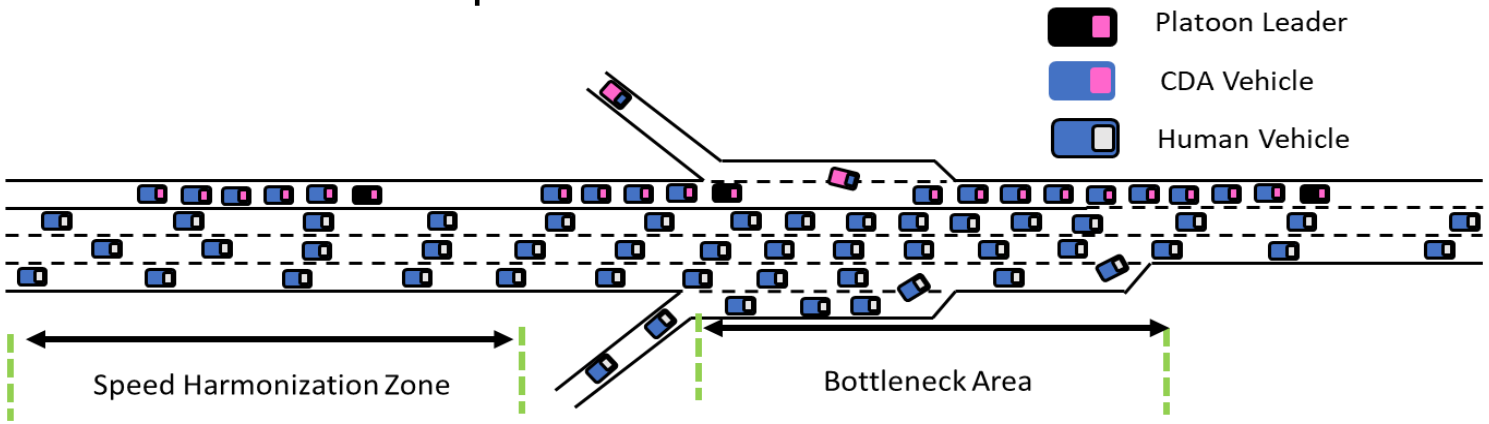
Source: FHWA.

Cooperative Merge



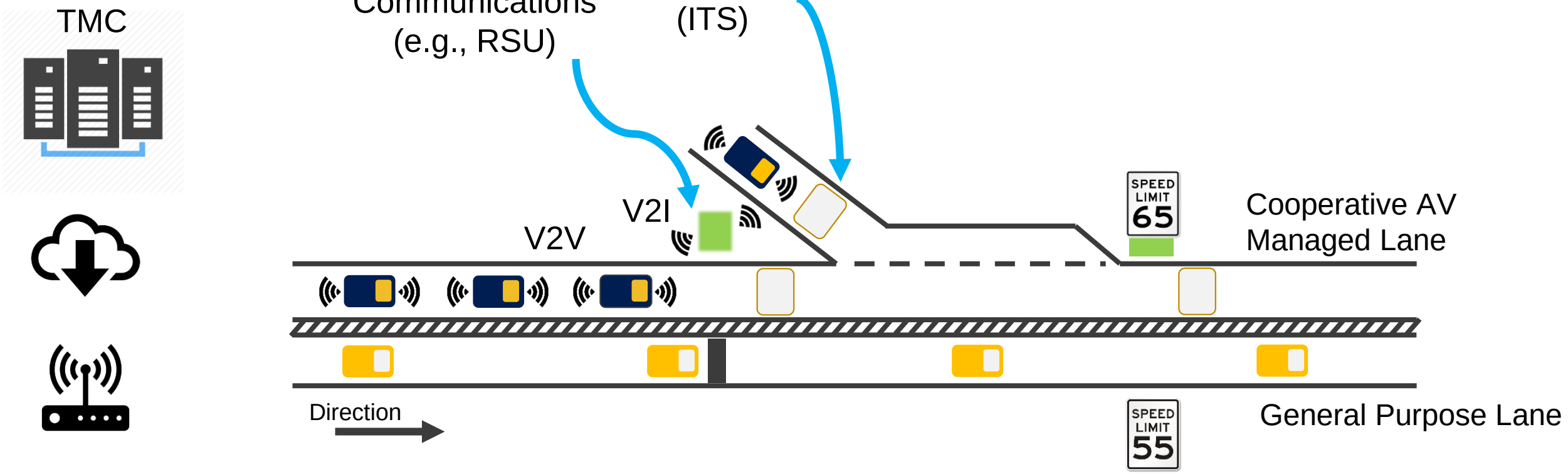
Source: FHWA.

Speed Harmonization



Source: FHWA.

IHP1



Source: FHWA.

TMC: Traffic Management Center.
V2I: Vehicle-to-Infrastructure.
V2V: Vehicle-to-Vehicle.
RSU: Roadside Units.
ITS: Intelligent Transportation System.
AV: Automated Vehicle.

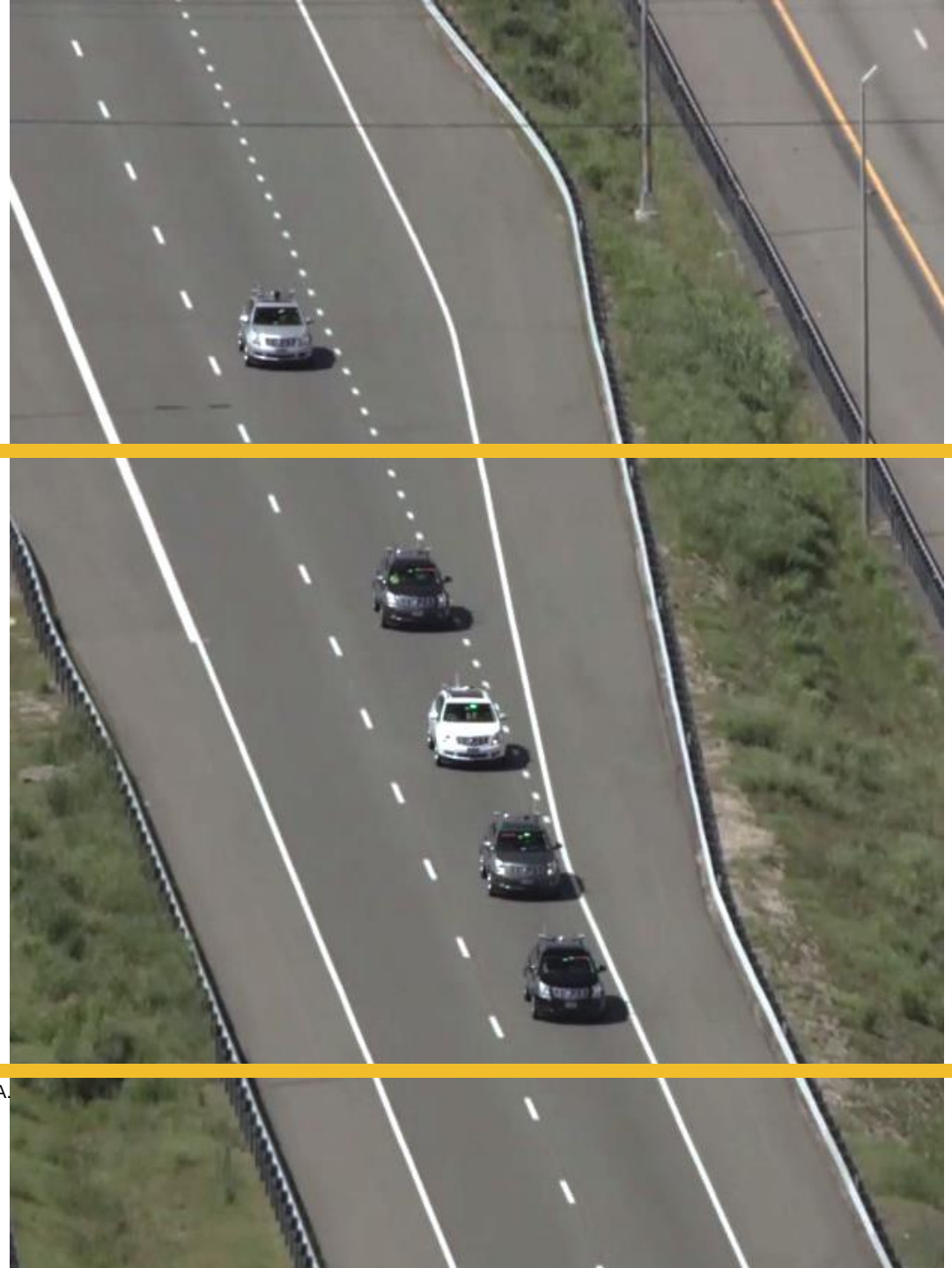
IHP2 Stakeholders

- Road Users:
  - Regular Human Drivers.
  - Connected Human Drivers.
  - Isolated ADS Vehicle Owners/Operators.
  - CDA Vehicle Owners/Operators (various levels of automation and classes of cooperation).
- Infrastructure Owner and Operators (IOO).

Justification for and Nature of Changes

- With more advanced sensing and computing capabilities on an ADS, how do we figure out how the data from these systems can be shared to help road users?
  - What if an ADS shares its perception information to improve situational awareness?
  - What if an ADS shares its plan for the future 5 sec, 20 sec, 1 min?
  - What if an ADS negotiates maneuvers with other ADS?
- What is the role of infrastructure (e.g., cloud) in supporting automation?
  - How does dynamic digital infrastructure work around changes in the infrastructure ahead (such as work zones, weather, or everyday congestion…)?
  - How do we manage congestion better with infrastructure and this upcoming ADS technology?

Questions?



NEW CARMA FEATURES

Source: FHWA.

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CARMA Cooperative Classes

CARMA	SAE Driving Automation Levels					
	No Driving Automation *Driver does all the driving*	**Advanced Driver Assistance Systems** *Driver monitors driving environment*		**ADS** *ADS monitor driving environment*		
	Level 0 *No Driving Automation*	**Level 1** *Driver Assistance*	**Level 2** *Partial Driving Automation*	**Level 3** *Conditional Driving Automation*	**Level 4** *High Driving Automation*	**Level 5** *Full Driving Automation*
Cooperative Classes						
No Cooperative Automation						
Class A: Status-Sharing *Here I am and this is what I see*						
Class B: Intent-Sharing *This is what I plan to do*						
Class C: Agreement-Seeking *Lets do this together*						
Class D: Prescriptive *I will do as directed*						

Being developed by SAE as the new J3216 currently under ballot.

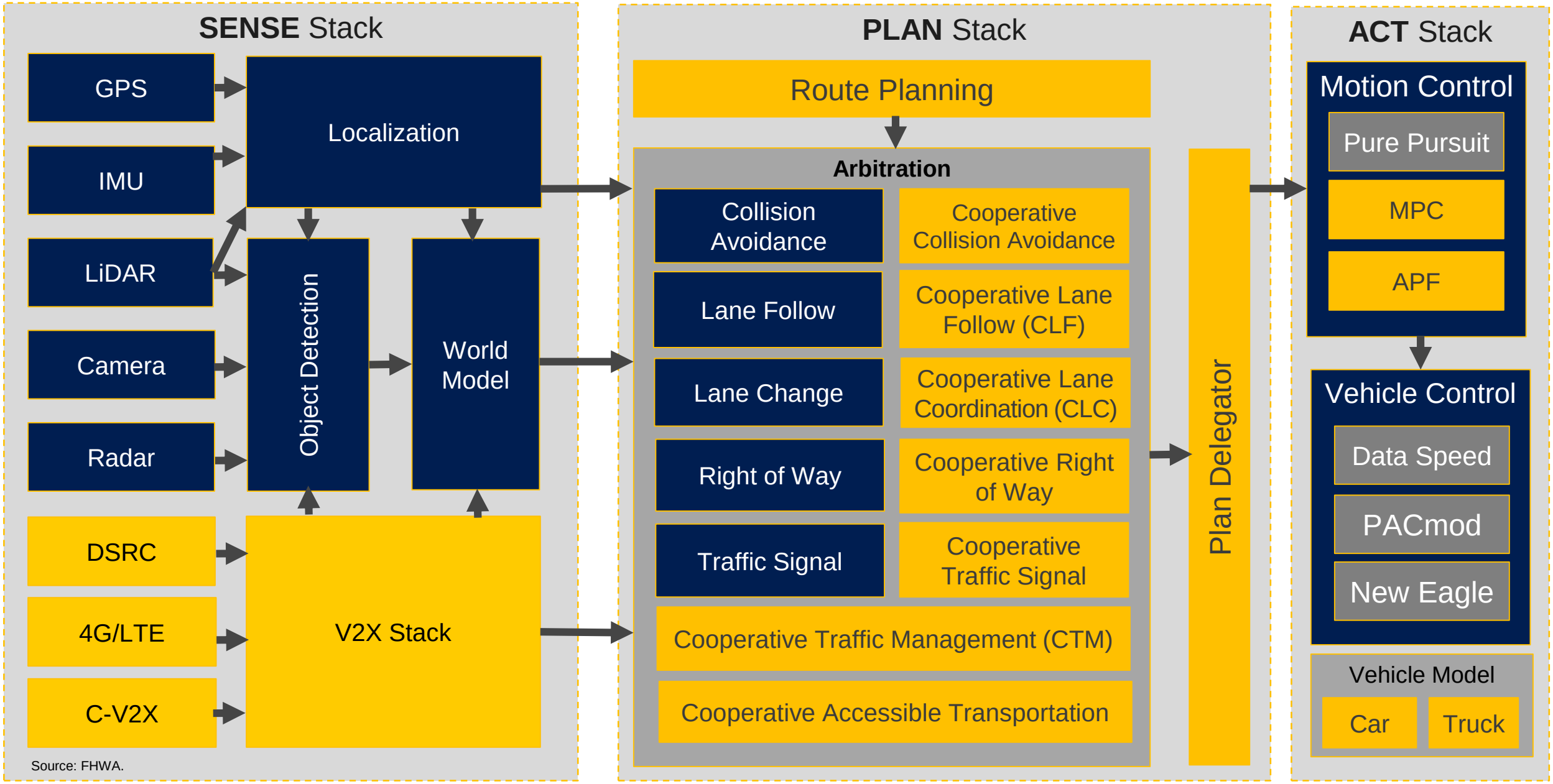
U.S. Department of Transportation
Federal Highway Administration

Source: FHWA.

CARMA Platform℠

IMU = Inertial Measurement Unit
LiDAR = Light Detection and Ranging
DSRC = Dedicated Short-Range Communications
C-V2X = Cellular-V2X

MPC = Model Predictive Control
APF = All Predecessor Following



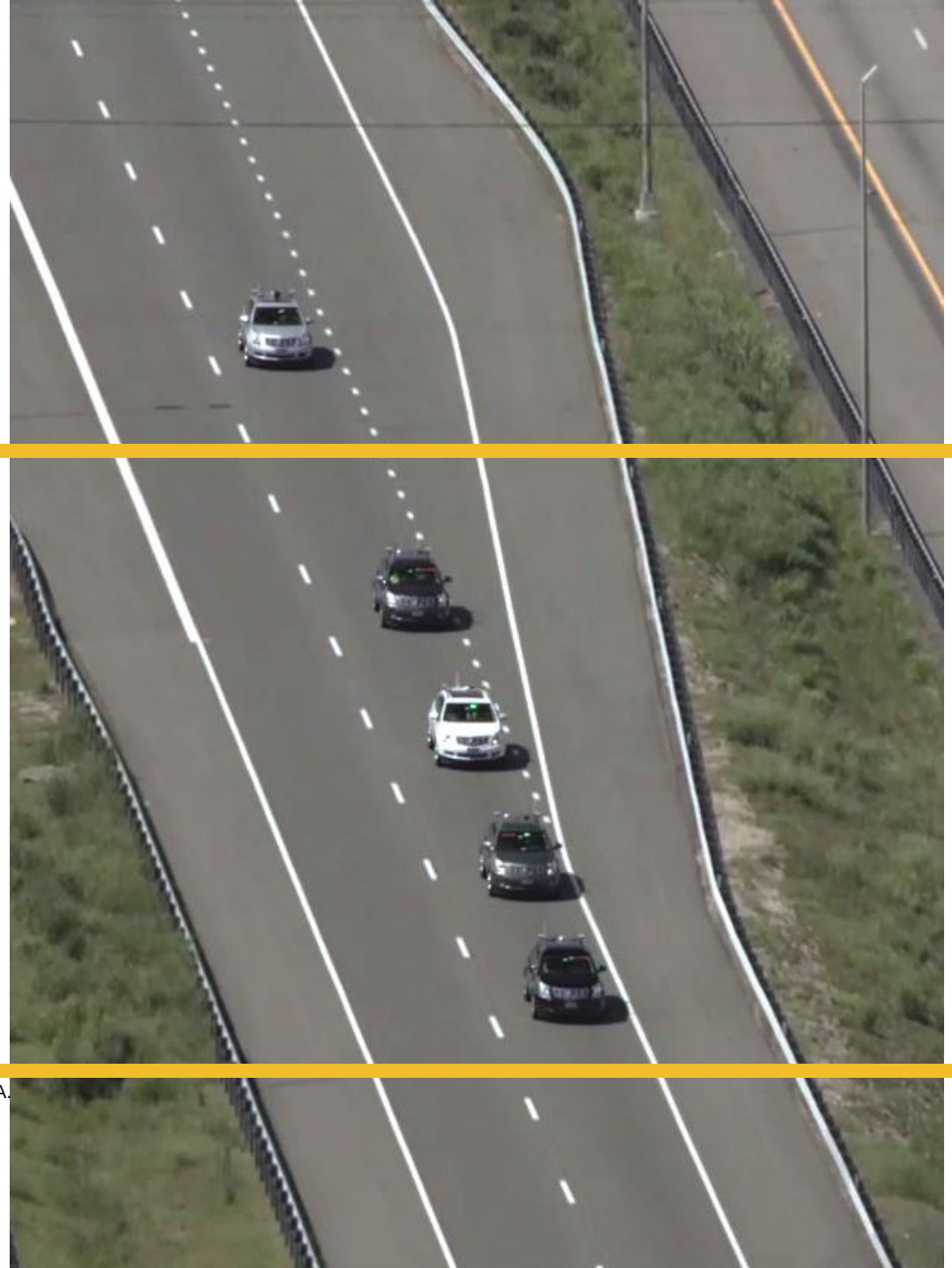
Source: FHWA.

Features of IHP2

This ConOps addresses the application of the IHP concept to freeways, including CTM strategies, CLF, and CLC.

IHP2 Feature	
CLF	CACC (Strings)
	Platooning (Groups)
CLC	Cooperative Lane Change
	Cooperative Merge
	Cooperative Weave
CTM	Speed Control
	Gap Control
	Lane Assignment
	Queue Management

Questions?



TECHNOLOGICAL FRAMEWORK AND NEEDS FOR IHP2

Source: FHWA.

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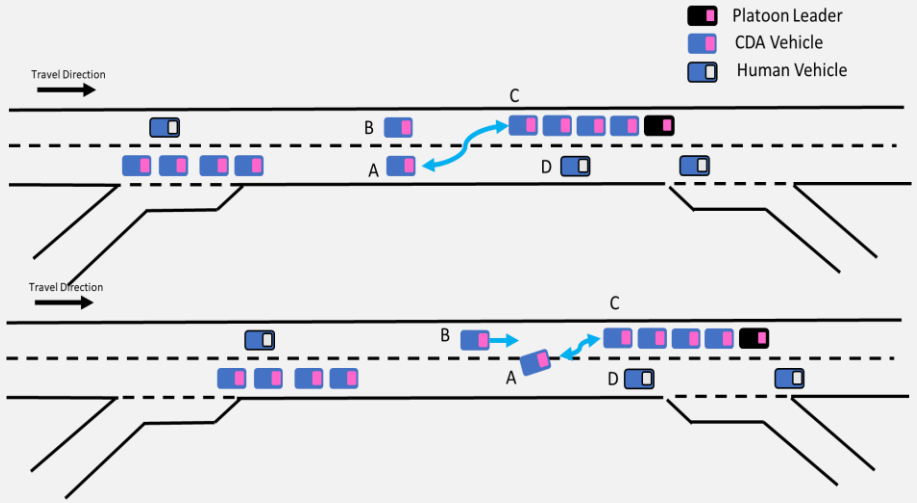
CLF

Allows two or more vehicles to closely travel together as platoons or CACC strings.

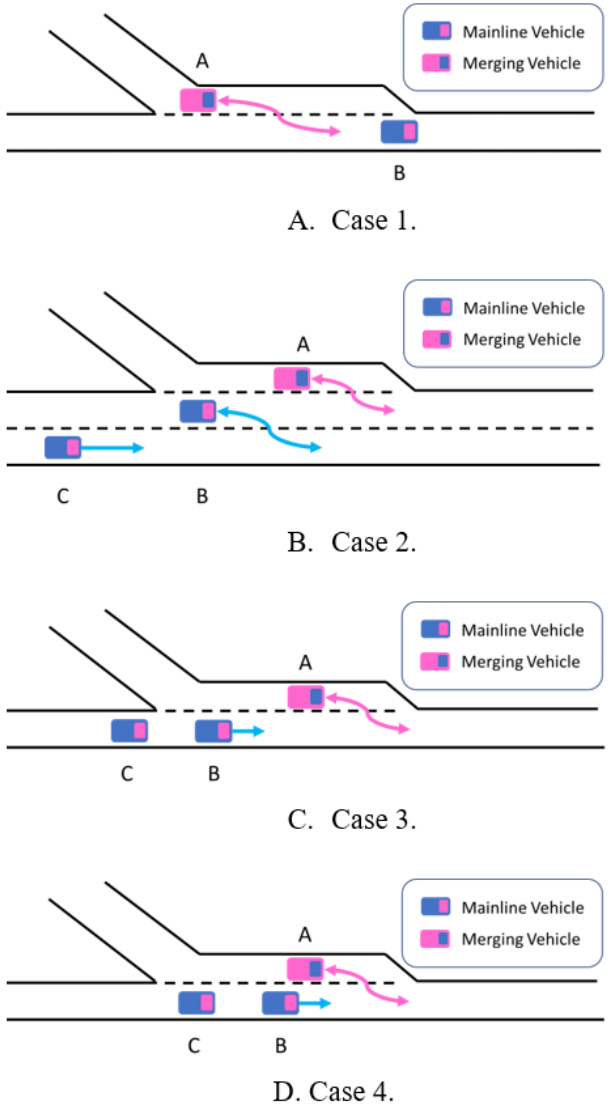


Source: FHWA.

Category	Platooning	CACC
Control Hierarchy	Hierarchical control with special responsibilities for platoon leader	Decentralized control with no special responsibilities for the string leader
Membership	Coordinated platoon/group membership	Ad hoc string membership and vehicle behave independently
Spatial Scope	Operations in a single or multiple lanes for platoon lane change, search for partners, etc.	Operations in a single lane with small following gaps

CLC

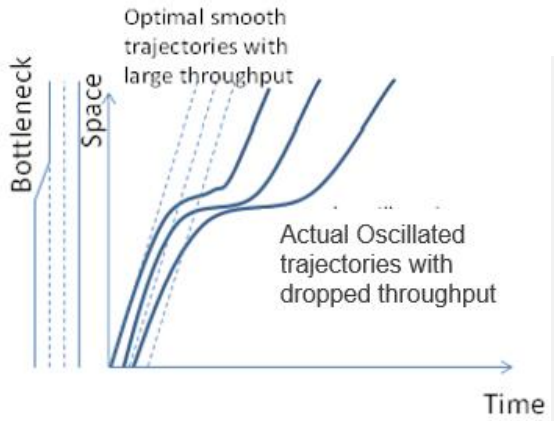
Cooperative Lane Change	Plans a smooth lateral motion from the current lane into an adjacent lane by first checking for collision risk with neighbor vehicles in the target lane and initiating cooperative agreement(s) with one or more of them, as necessary, to plan a safe lane change within the physical constraints of the situation.
Cooperative Merge	Plans a smooth lateral motion from the current lane, which is either ending or being combined with another (e.g., when two highways merge), into the lane that the current lane merges into.
Cooperative Weave	Allows two (or more) CDA vehicles to plan simultaneous, or near-simultaneous, lane changes where each vehicle will be changing lanes into the lane of the other vehicle.



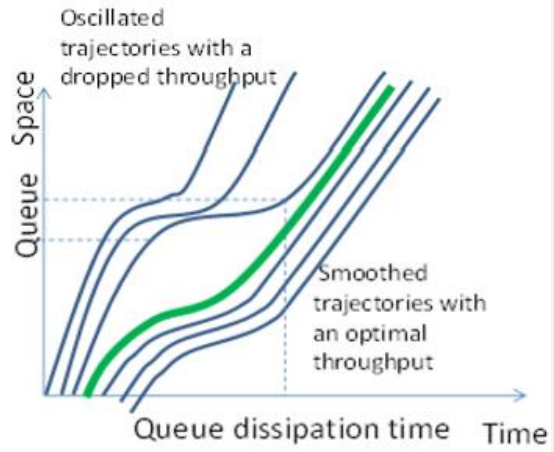
Source: FHWA.

CTM

Speed Control	Allows a vehicle to adjust its speed based on communication/rules from other vehicles, the cloud, or another entity (e.g. pedestrian).
Gap Control	Allows a vehicle to adjust its gap to its preceding vehicle, whether part of a string, group, or neither, based on the communication/rules provided from other vehicles or the cloud.
Lane Assignment	Accepts a request from the cloud regarding which lane the vehicle should plan to be in, and if necessary, when appropriate, calls for the lane change and/or merge features to be executed.



(a) Benchmark without trajectory smoothing.



(b) Illustration of harmonized trajectory.

Source: FHWA.

Infrastructure – Cloud (CARMA Cloud)

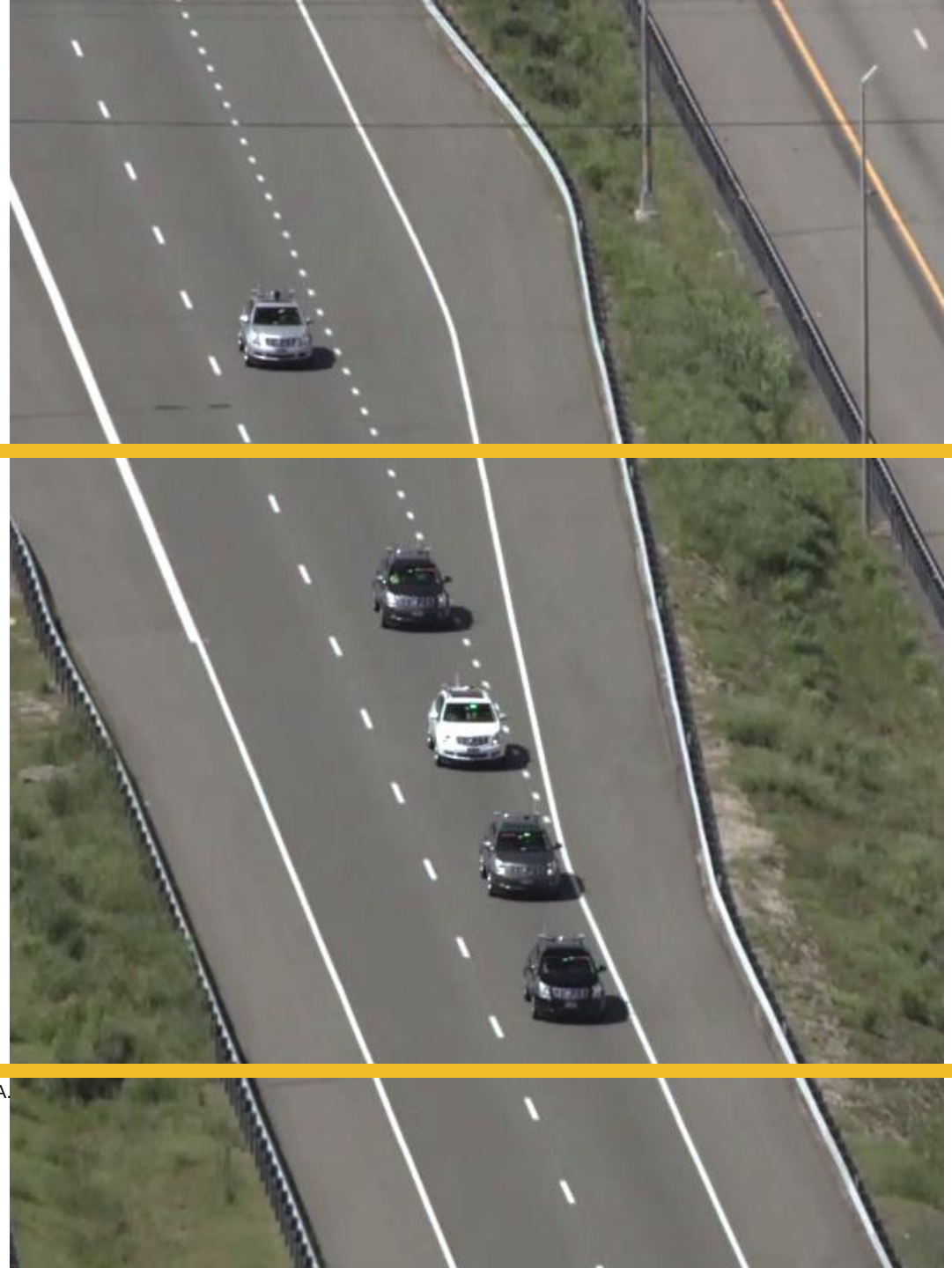
Explanation of CARMA Cloud and the role of IOOs in developing the rule strategies for addressing congestion.

Cloud-to-vehicle	Mapping Rules.	• Updates to lane configuration. • Updates to dynamic world models.
	Planning Rules.	• Speed rules. • Speed harmonization. • Min gap rules. • Platooning statues (allowed or not). • Platooning limitations (2 car, 3 car, 4 car, etc.).
Vehicle-to-cloud	Cooperative Perception.	• Vehicle current status, intent, etc. • Local world information sensed by each CDA vehicle.

Performance Metrics

- Vehicle Behavior:
  - Separation Distances/Gaps, Disengagements, Travel Speeds, Speed Changes.
  - Data-Exchanges During Negotiation (Cooperation Class 3).
- Traffic Performance:
  - Safety.
  - Stability.
  - Throughput.
  - Flow Breakdown and Reliability.
  - Sustainability.

Questions?



OPERATIONAL SCENARIOS

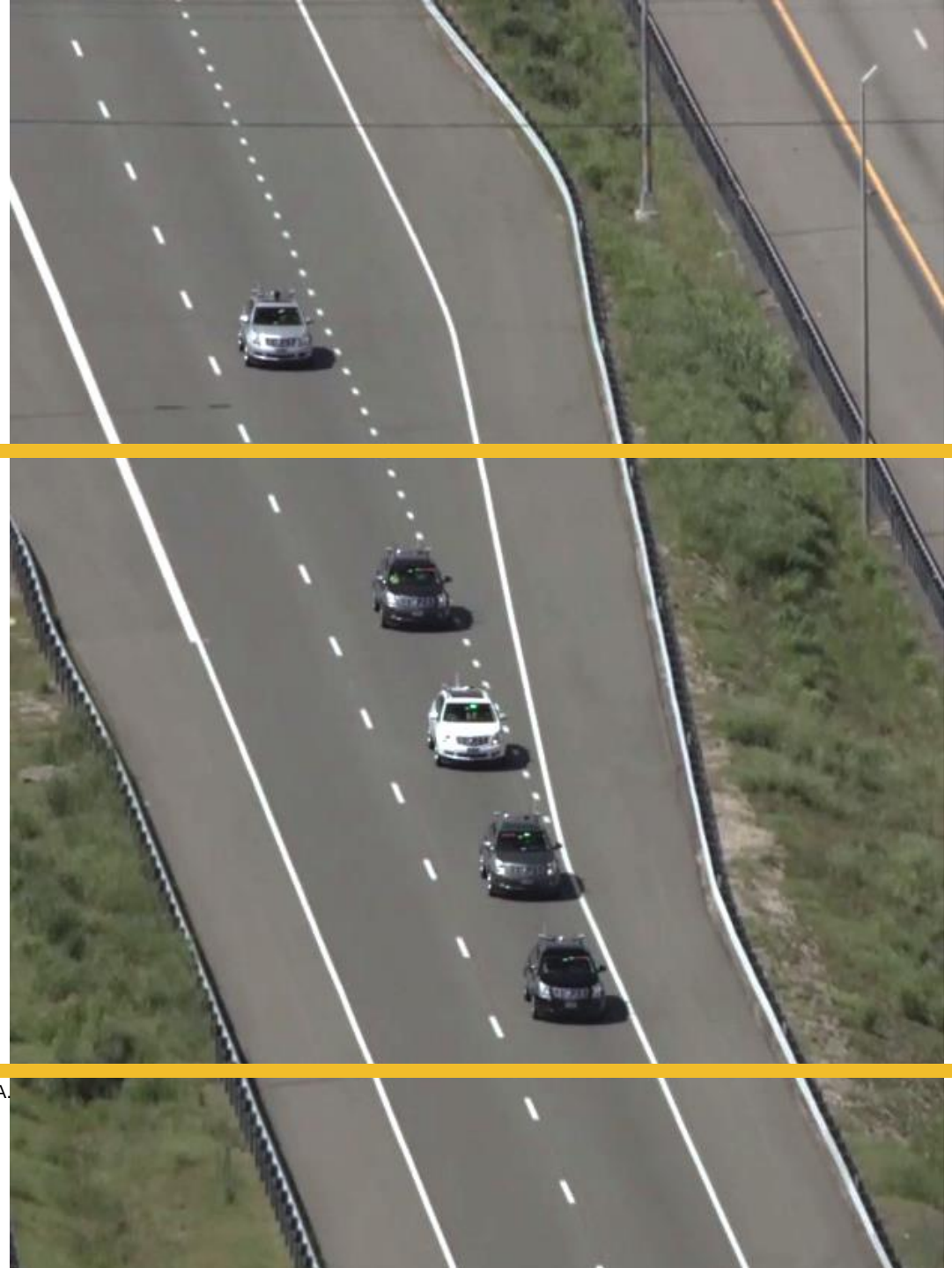
Source: FHWA.

Three Selected Operational Scenarios

- End-to-End CDA Operations from Entering to Exiting a Freeway.
- CTM with Lane Assignment and Speed Control.
- Dedicated Facility Operations for Early Deployment.

High-Level Testing Plan

- Simulation Testing:
  - ADS simulators.
  - Traffic simulators.
- Closed-Track Testing: End-to-end CDA operational scenarios.
- Public Road Testing: Managed-lane facility with light live traffic.



DISCUSSION AND Q&A

Source: FHWA.

NEXT STEPS

- ConOps will be generated using input from stakeholders.
  Now through April 2020.

- Algorithms will be developed, simulated, and refined.
  April through October 2020.

- The applications will be deployed on CARMA-enabled vehicles and demonstrated in light traffic.
  October 2020 through July 2021.

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This research is supported in part by the U.S. Department of Transportation Federal Highway Administration.

Contact us!

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Source: FHWA.

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