



All photos source: FHWA.



CARMASM

Automated Vehicles **Working Together**

Using Open-Source Software to Transform the Transportation Network

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U.S. Department of Transportation
Federal Highway Administration

SAXTON
LABORATORY



U.S. Department of Transportation (USDOT) Partners:

- FHWA
- Office of Research and Development for Safety and Operations (HRDSO)
- Office of Transportation Management (HOTM)
- Office of Transportation Operations (HOTO)
- Office of Freight Management and Operations (HOFM)
- Resource Center (RC)
- Intelligent Transportation Systems Joint Program Office (ITS JPO)
- Federal Transit Administration (FTA)
- Federal Motor Carrier Safety Administration (FMCSA)
- Maritime Administration (MARAD)



Agenda

- Cooperative driving automation (CDA) defined.
- CARMA program overview.
- CARMA evolution and testing.
- Next in the CARMA program.





SAE International J3216¹

CDA: Automation that uses machine-to-machine (M2M) communication to enable cooperation among two or more entities with capable communications technology and is intended to facilitate the safer, more efficient movement of road users, including enhancing performance of the dynamic driving task (DDT) for a vehicle with driving automation feature(s) engaged.

Publicly released May 2020.





RELATIONSHIP BETWEEN CLASSES OF COOPERATIVE DRIVING AUTOMATION (CDA) J3216 AND LEVELS OF AUTOMATION J3016¹

SAE Standard CDA J3216

		PARTIAL AUTOMATION OF DDT			COMPLETE AUTOMATION OF DDT		
		SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
		No Driving Automation (human does all driving)	Driver Assistance (longitudinal OR lateral vehicle motion control)	Partial Driving Automation (longitudinal AND lateral vehicle motion control)	Conditional Driving Automation	High Driving Automation	Full Driving Automation
NO COOPERATIVE AUTOMATION		e.g., Signage, TCD	Relies on driver to complete the DDT and to supervise feature performance in real time		Relies on ADS to perform complete DDT under defined conditions (fallback condition performance varies between levels)		
CDA CLASSES	SAE CLASS A STATUS SHARING Here I am and what I see	e.g., Brake Lights, Traffic Signal	Potential for improved object and event detection ¹		Potential for improved object and event detection ²		
	SAE CLASS B INTENT SHARING This is what I plan to do	e.g., Turn Signal, Merge	Potential for improved object and event prediction ¹		Potential for improved object and event prediction ²		
	SAE CLASS C AGREEMENT SEEKING Let's do this together	e.g., Hand Signals, Merge	N/A		C-ADS designed to attain mutual goals through coordinated actions		
	SAE CLASS D PRESCRIPTIVE I will do as directed	e.g., Hand Signals, Lane Assignment by Officials			C-ADS designed to accept and adhere to a command		

¹ Improved object and event detection and prediction through CDA Class A and B status and intent sharing may not always be realized, given that Level 1 and 2 driving automation features may be overridden by the driver at any time, and otherwise have limited sensing capabilities compared to Level 3, 4 and 5 ADS-operated vehicles.

² Class A and B communications are one of many inputs to an ADS's object and event detection and prediction capability, which may not be improved by the CDA message.

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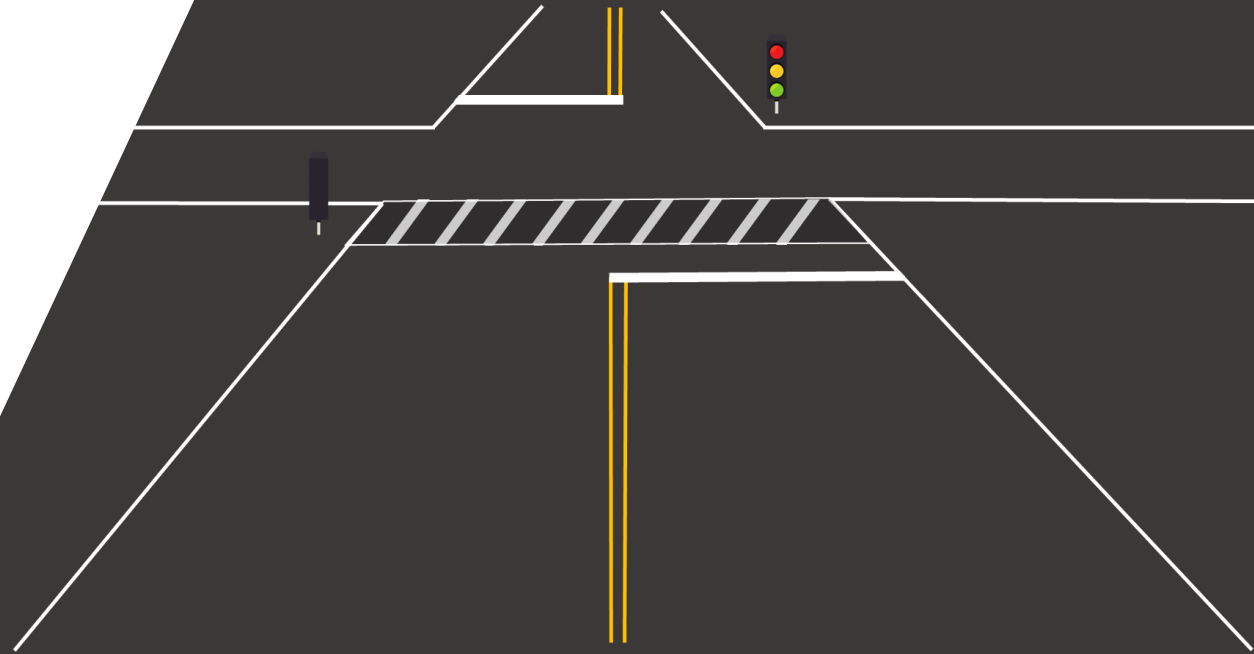
How can CDA help?

Leverages information from infrastructure and all connected roadway users to improve safety and mobility.

For example:

- Enhanced sensing.
- Intersection optimization.
- Congestion mitigation:
 - Work zones.
 - Traffic incidents.
 - Weather.

An AV sees this...





How can CDA help?

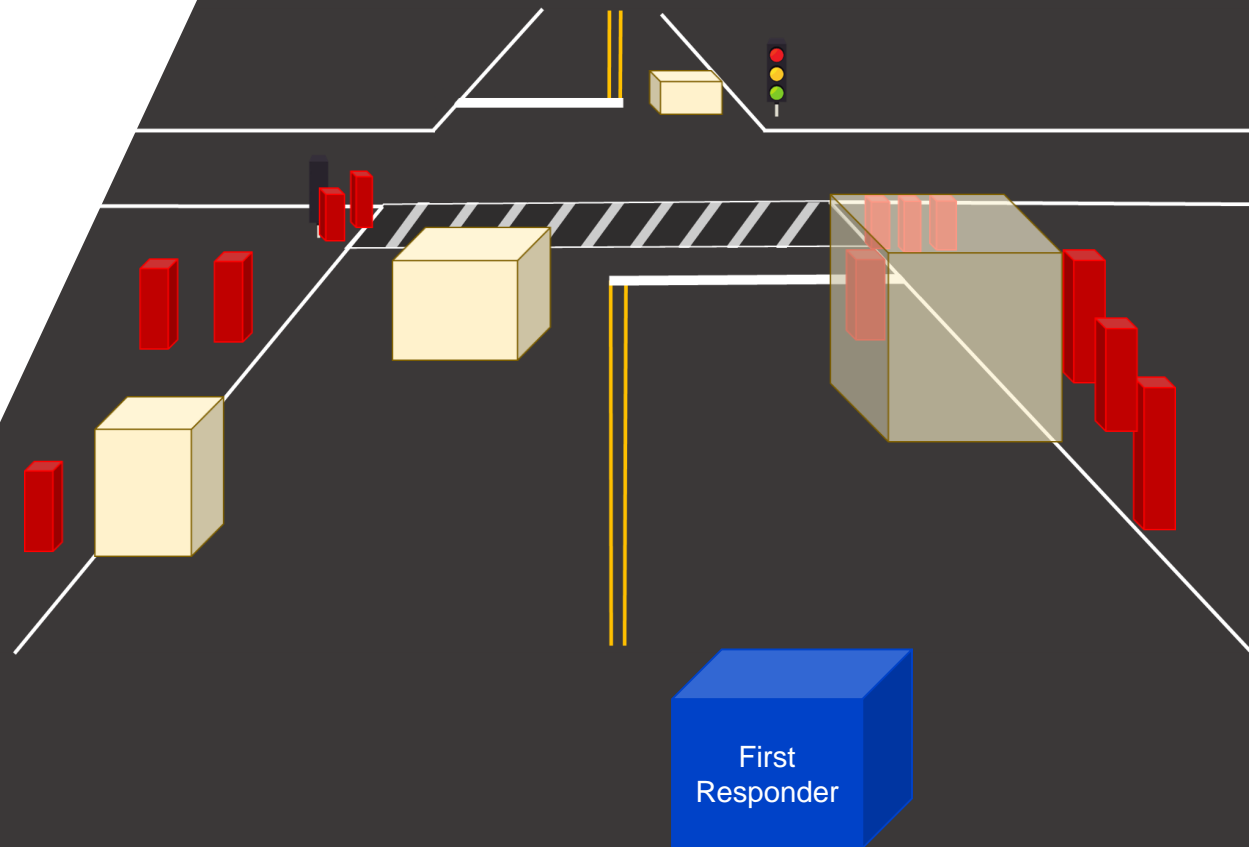
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How do you **detect** the objects you can't see?





How can CDA help?

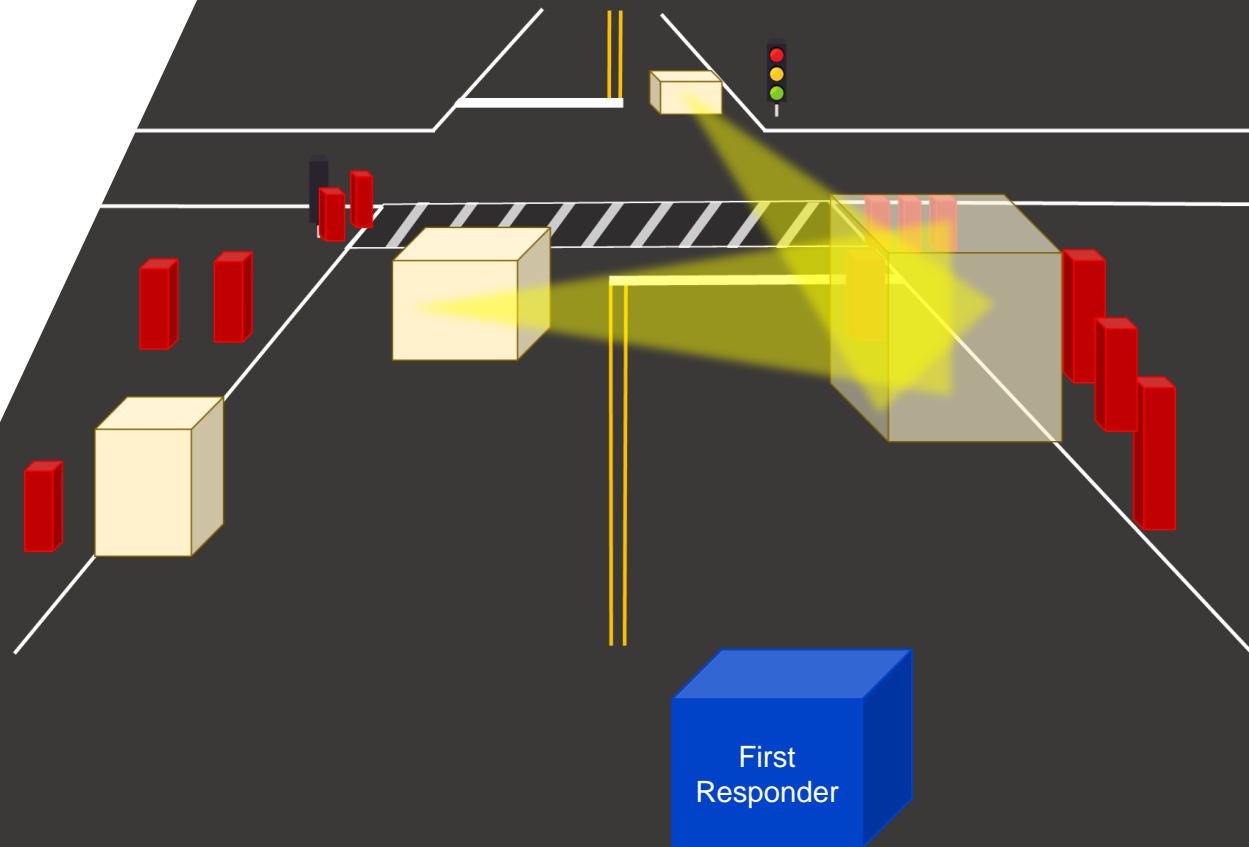
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Can you use sensor data from **other** vehicles?





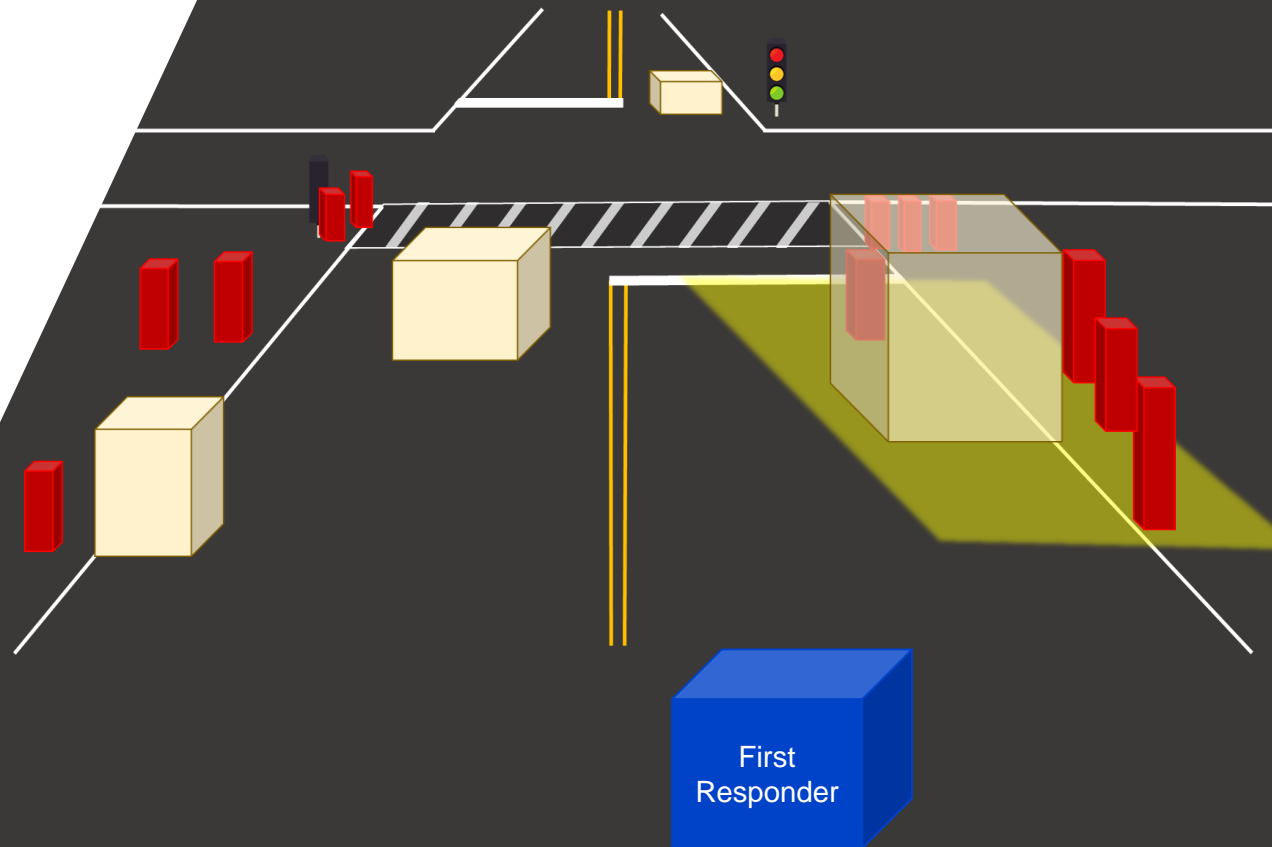
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Public transit vehicles could also participate in CDA through **shared perception**.





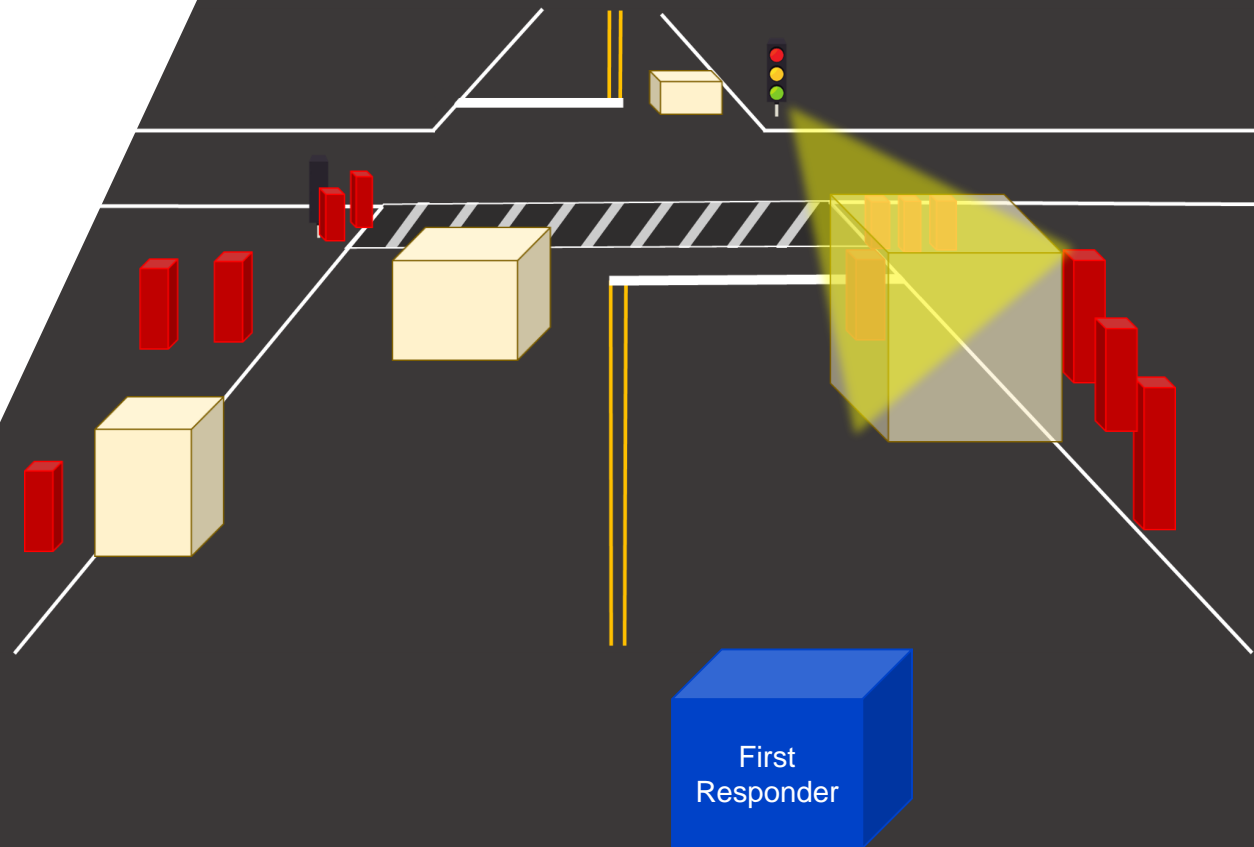
What about **infrastructure**?

How can CDA help?

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What Is the CARMA Program?



FHWA's initiative focused on improving the transportation system by leveraging emerging automated driving technology and vehicle-to-everything (V2X) technology to enable increased safety and operational performance in moving people and goods.



CARMA Ecosystem

A network of open source software (OSS) and support services focusing on how infrastructure can move traffic more efficiently by advancing transportation systems management and operations (TSMO) strategies.

PRODUCTS

- A** **CLOUD**
Cloud-based management of transportation systems
- B** **PLATFORM**
Vehicle automation platform for advancing CDA
- C** **MESSENGER**
Connectivity added to nonautomated vehicles
- D** **STREETS**
Vehicle-to-infrastructure roadside platform

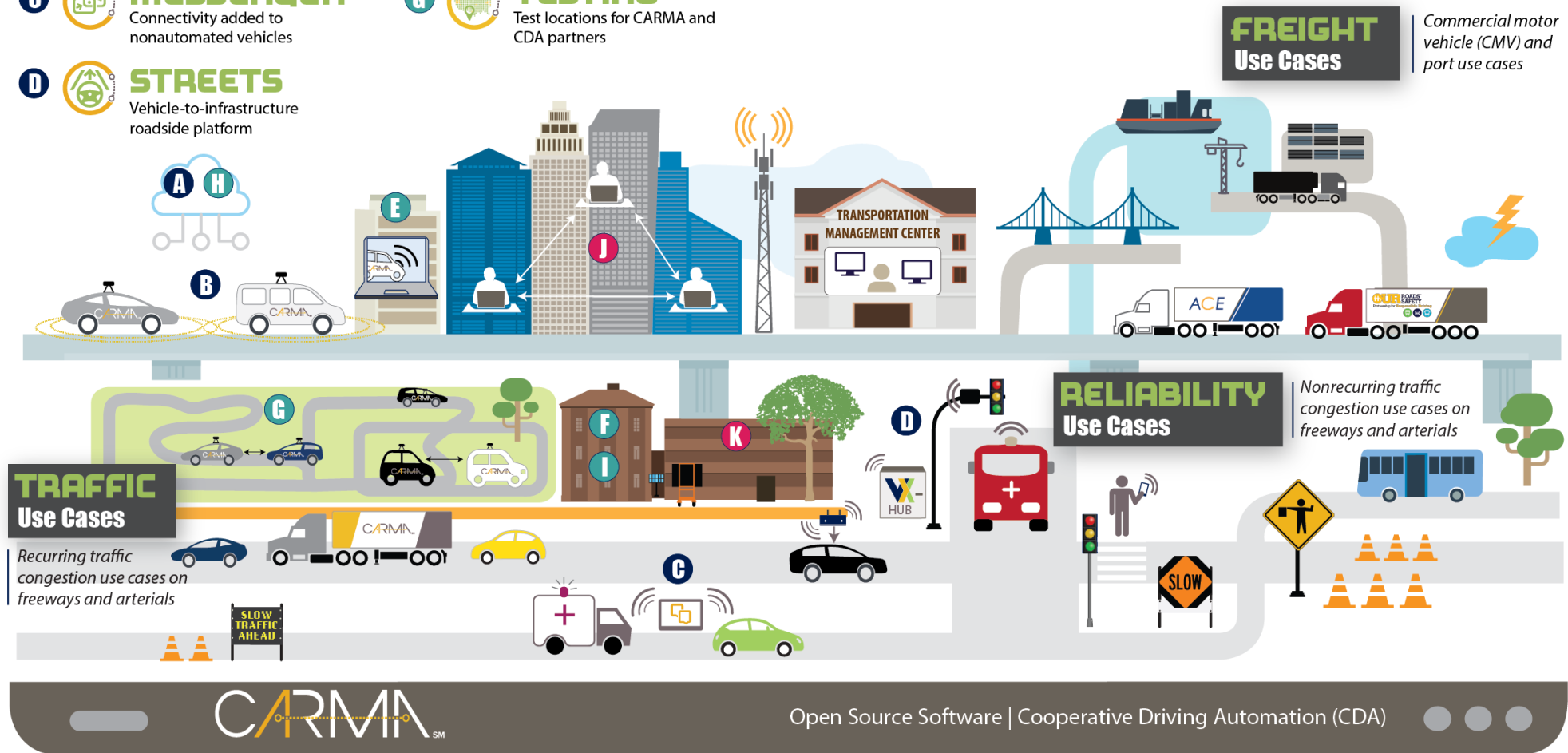
EVALUATION

- E** **SIMULATION**
CDA simulation and modeling
- F** **SAFETY**
Human factors testing on field, simulator, and driver-in-the-loop (DIL)
- G** **TESTING**
Test locations for CARMA and CDA partners

- H** **ANALYTICS**
Data management, analysis, machine learning, and artificial intelligence
- I** **1 TENTH**
Scaled down test vehicles

ENGAGEMENT

- J** **COLLABORATIVE**
Active community of users advancing CDA
- K** **SUPPORT**
Support and knowledge sharing for implementers of the CARMA product suite



CARMA Ecosystem: Use Cases



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Recurring traffic congestion use cases on freeways and arterials.

- Congestion
- Transit
- Traffic Signals

USDOT Partners:

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ITS JPO | FTA | FMCSA**



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Nonrecurring traffic congestion use cases on freeways and arterials.

- Work Zones
- Weather
- Traffic Incident Management (TIM)

USDOT Partners:

**FHWA | HRDSO | HOTO | RC
ITS JPO | FMCSA**



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Commercial motor vehicle (CMV) and port use cases.

- Port Drayage
- CMV
- Truck Platooning

USDOT Partners:

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ITS JPO | FMCSA | MARAD**



CARMA 1

Objectives:

- Develop AV testing capability.
- Algorithm development: proof of concept cooperative adaptive cruise control (CACC).
- Demonstrate CACC enabled on five SAE Level 1 AVs.



Source: FHWA.



Source: FHWA.



CARMA 2



Source: FHWA.

Objectives:

- **New CARMA2 Research Platform (*Open Source*).**
- **Algorithm Development (*Open Source*):**
 - Speed harmonization.
 - Vehicle platooning.
 - Cooperative lane change.
 - Cooperative ramp merge.
 - Signalized intersection approach and departure.



Source: FHWA.

5
Plugins

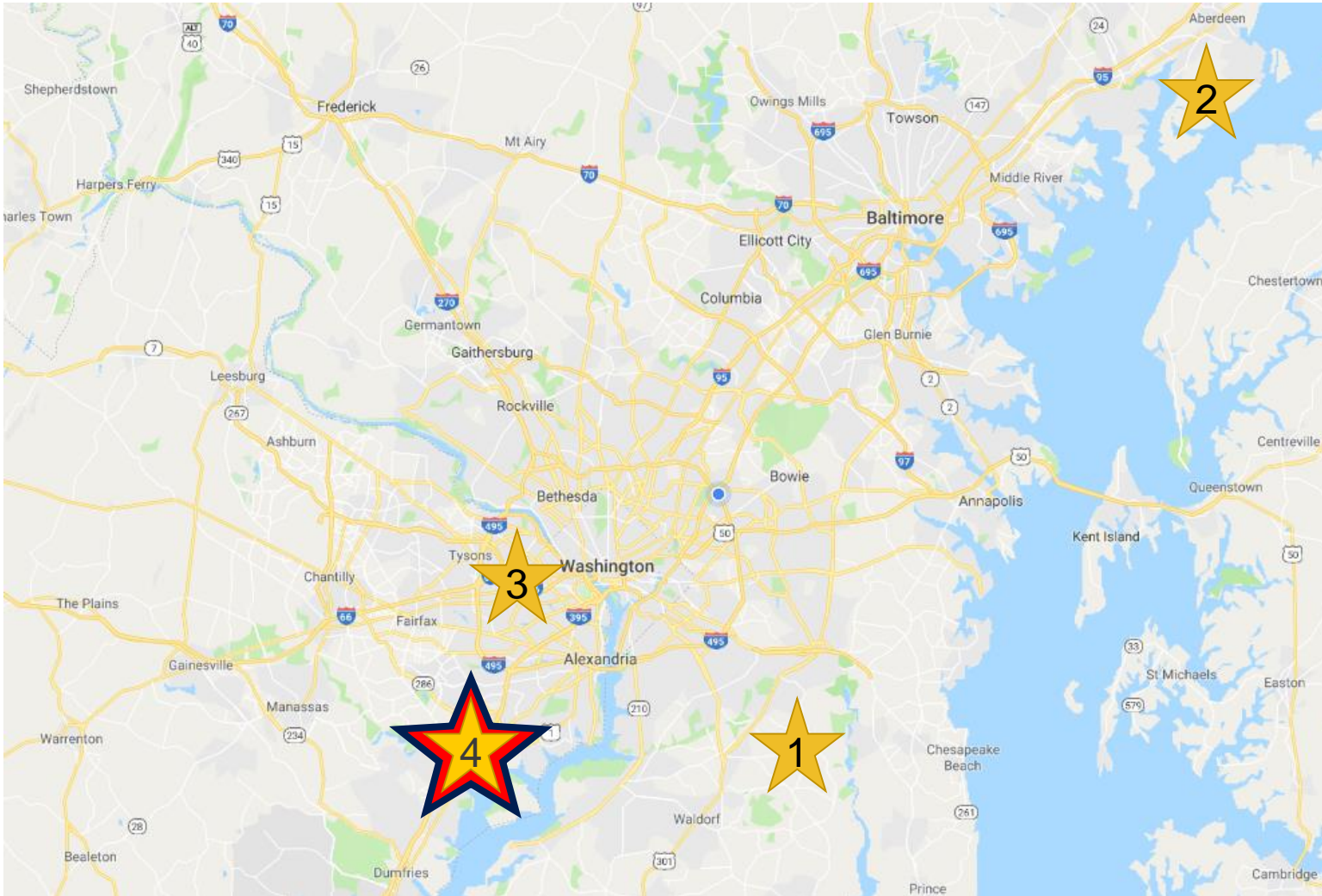
24
Days at Aberdeen
Test Center (ATC)

22,000
Miles of closed track
testing

42,000
Lines of code



TEST FACILITIES



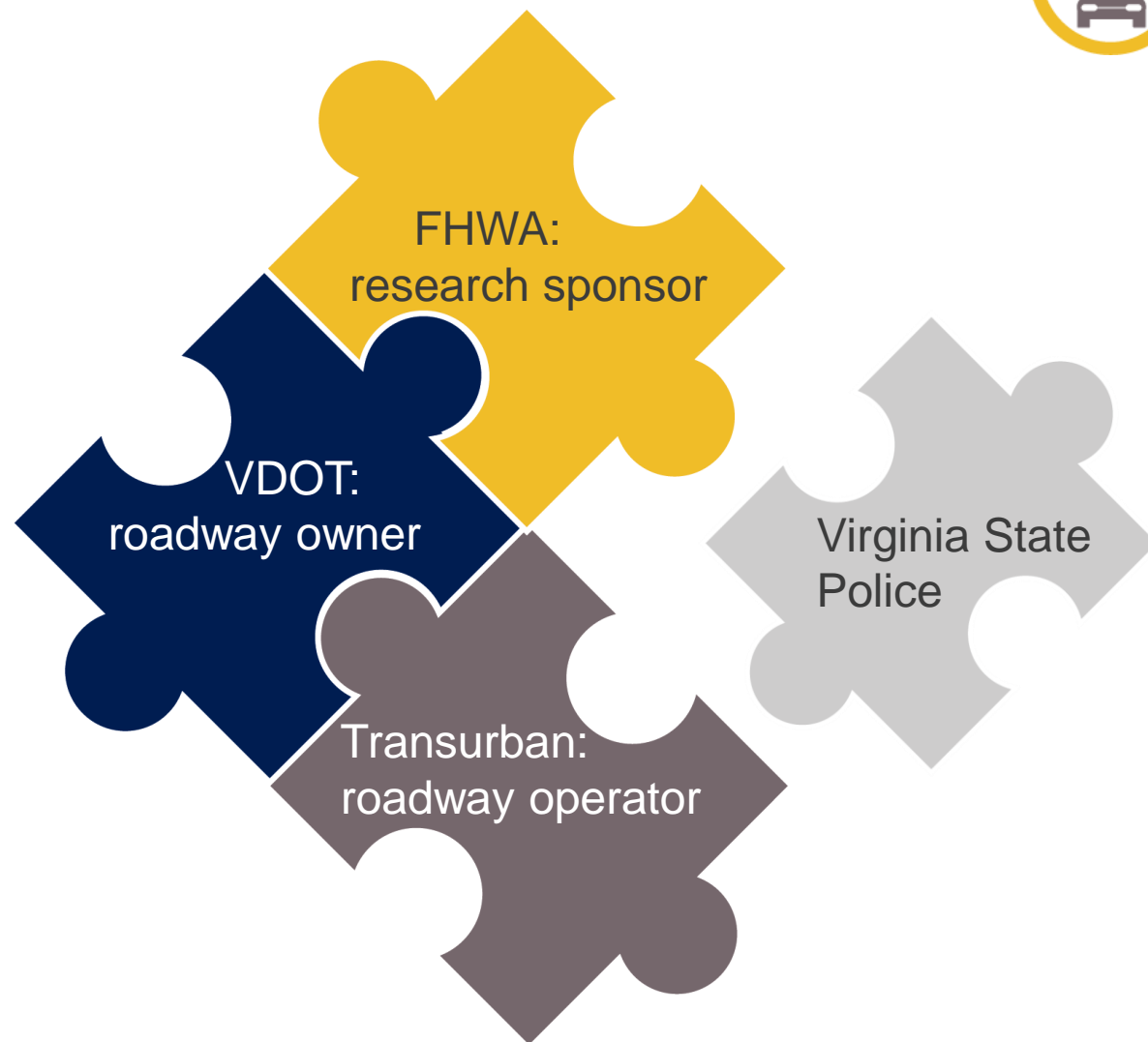
- Initial testing was done on closed testbeds:
 - Federal Law Enforcement Training Center (1).
 - Aberdeen Proving Ground (2).
 - Turner-Fairbank Highway Research Center (TFHRC) (3).
- Further testing was done on public roads (4).



Original Map: © 2018 Google. Map Data: © 2018 Google. Modifications: FHWA.

STAKEHOLDERS

- Public road testing was made possible by a memorandum of understanding (MOU) between FHWA, Virginia Department of Transportation (VDOT), and Transurban.
- Close coordination between the three primary stakeholders, and with Virginia State Police, was essential to success.



Source: FHWA.





SITE REQUIREMENTS

Requirement	Reason
Dedicated entrance to high-occupancy toll lanes (exclusive use if possible).	Minimize disruption from regular traffic.
Minimum 150 meter acceleration lane.	Provide time for the merging vehicle to accelerate to highway speed.
Minimum 150 meter merge lane.	Provide time for the vehicles to negotiate lane change.
Safe waiting area for a vehicle on the ramp (e.g., shoulder).	Minimize disruption to regular traffic.
Area to deploy mobile roadside unit trailer within 100 meters of merge area.	Provide infrastructure communication component.
Minimum 2 miles of mainline road upstream of merge area.	Allow time for platoon to form and stabilize.
Minimum 3 miles of mainline road downstream of merge area.	Allow time for merging vehicle to enter platoon and stabilize.
Northbound and southbound entrance close by (desirable).	Maximize test time by running in both directions.
Close proximity to TFHRC (desirable).	Increase efficiency by minimizing travel time.
Staging area nearby (e.g., parking lot).	Provide an area for the team to prepare and regroup.
Smooth pavement surface.	Minimize disturbances to drivers and sensors.
No construction on the on-ramp or on the test portion of the facility April–June.	Minimize disruption from other activities.
Helicopters allowed to fly overhead.	Provide the ability to film the field experiment from the air.



PREPARATION



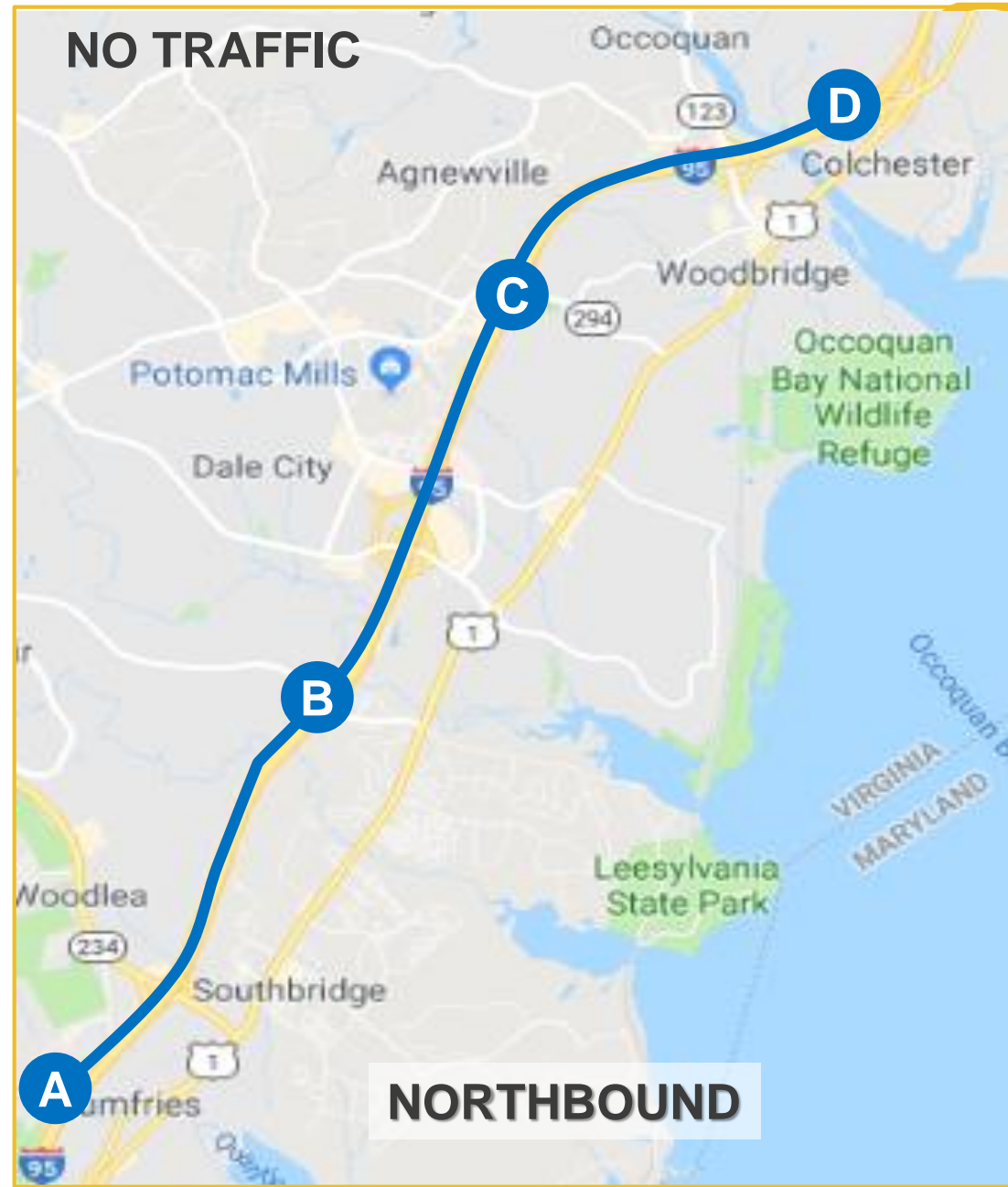
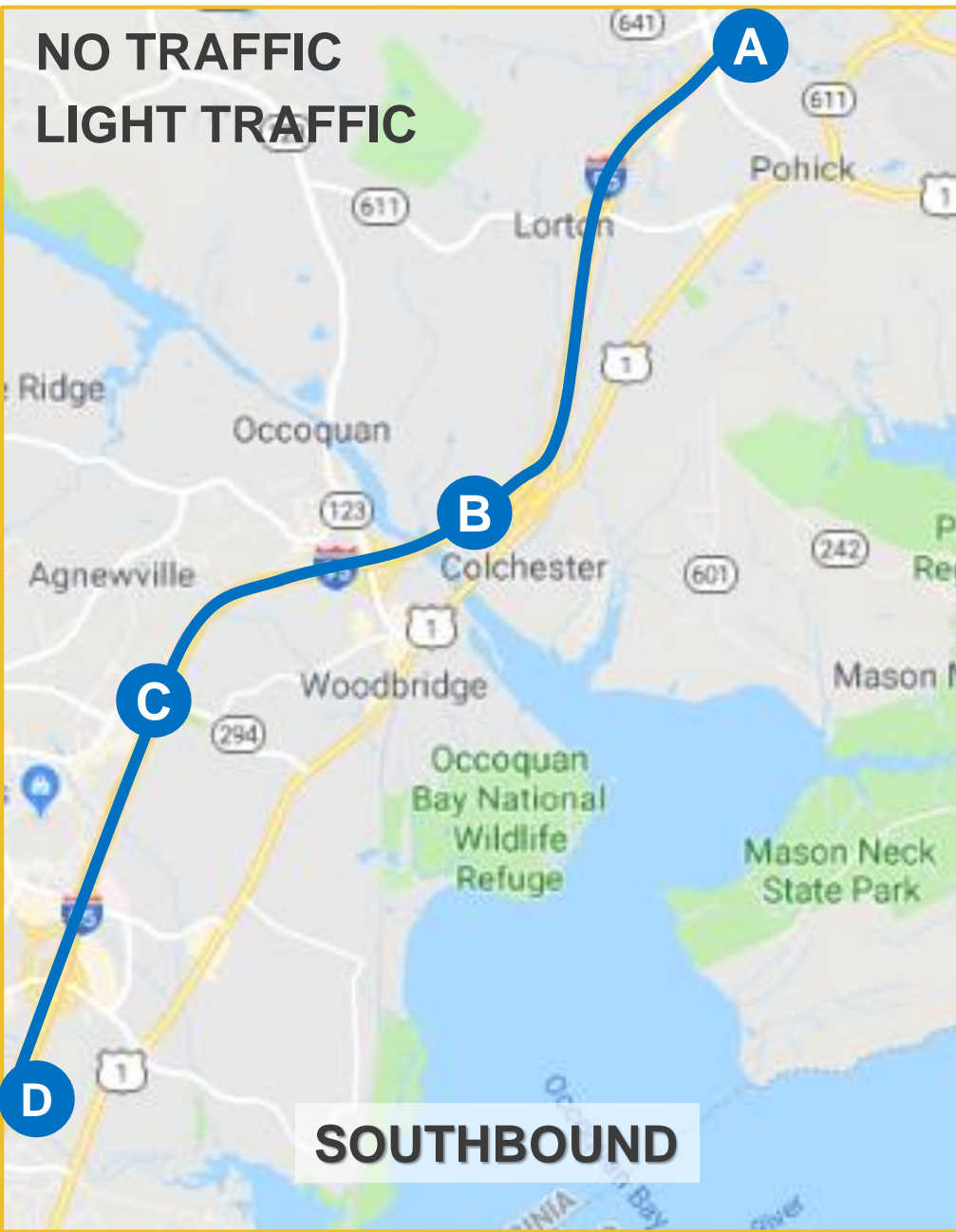
- ✓ Preliminary testing on closed courses.
- ✓ Work with stakeholders to identify test locations on public roads.
- ✓ Verify and install the necessary infrastructure.
- ✓ Plan, plan, plan.

Source: FHWA.





TEST ROUTES

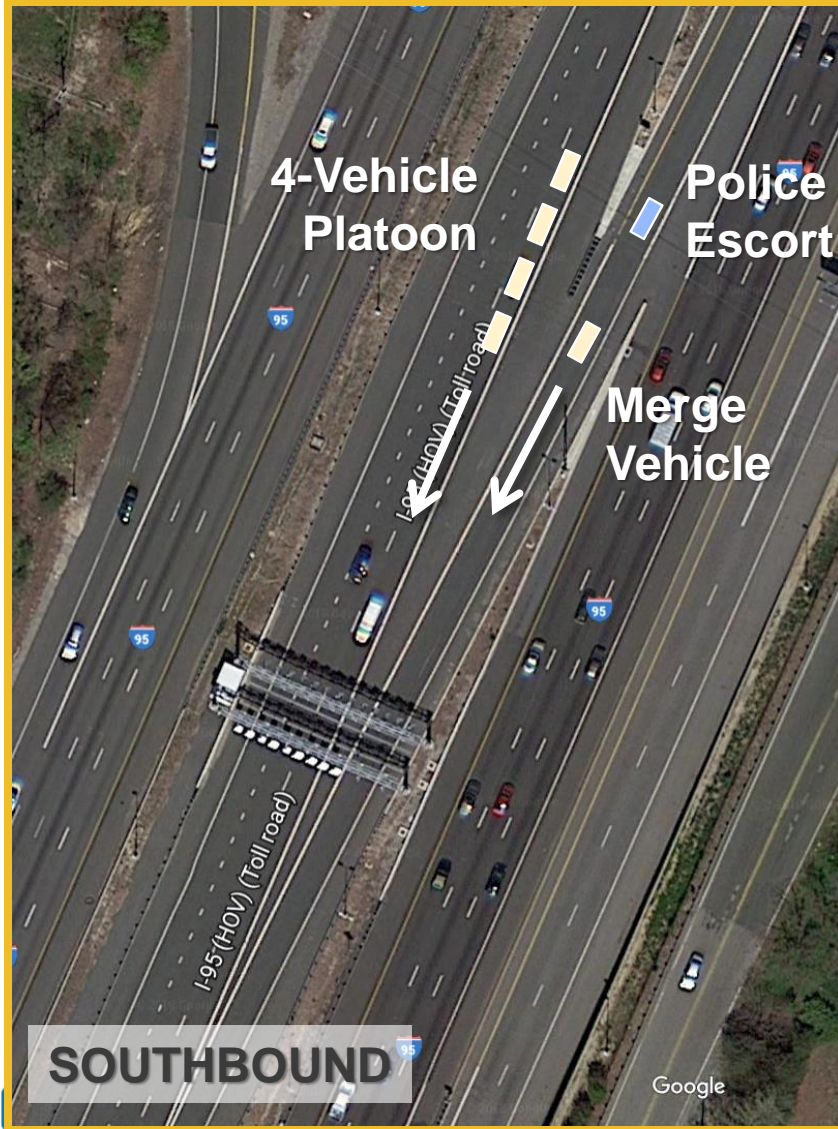


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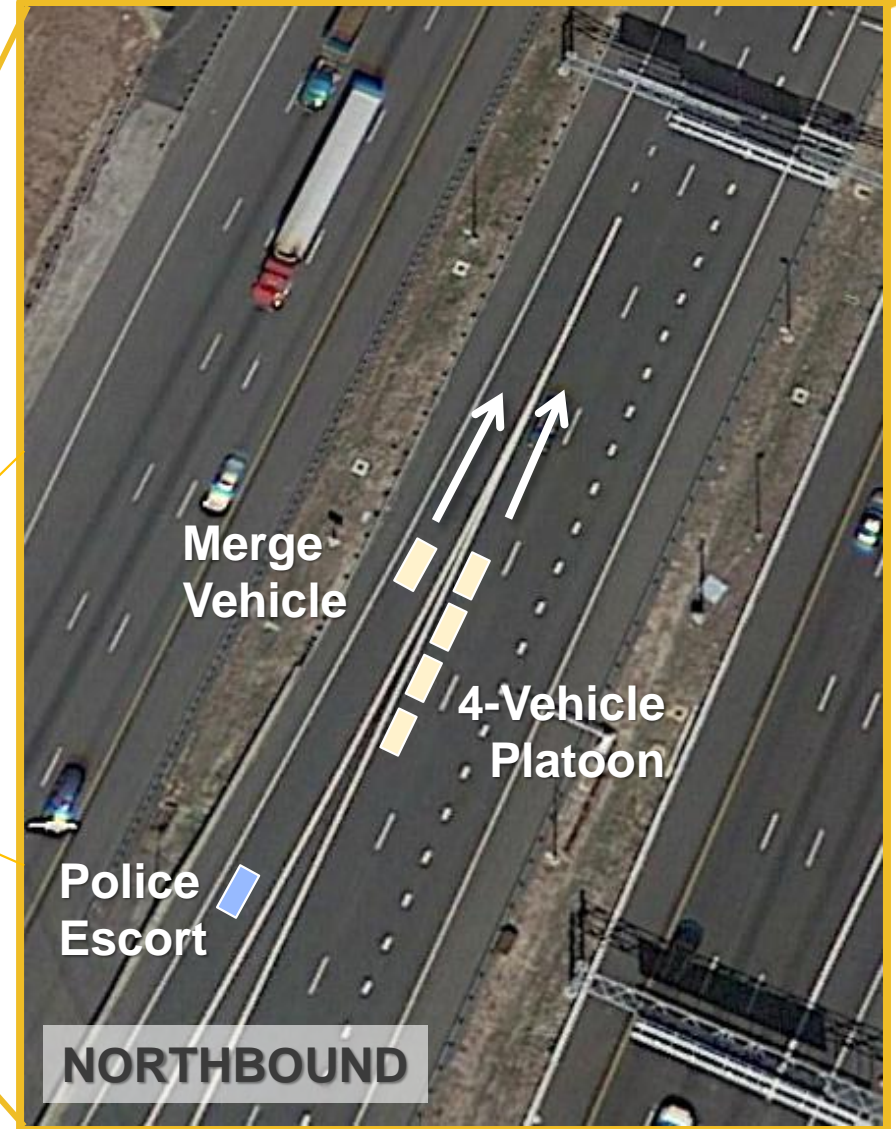
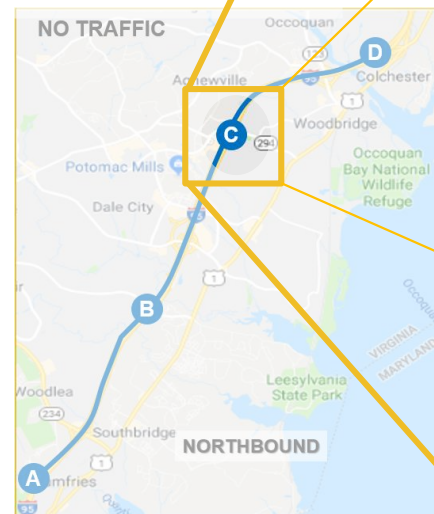
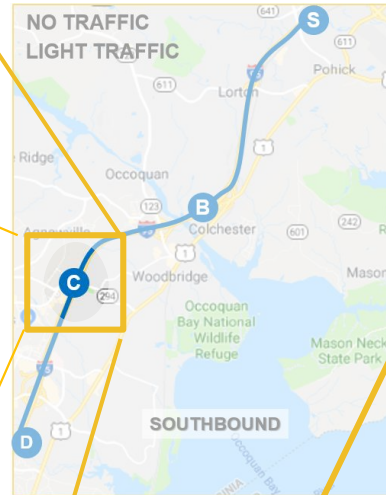
MERGE AREAS



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LESSONS LEARNED

 Operations and Research teams have different mindsets:

 Research team needs to plan more than usual.

 Operations team needs to be more flexible than usual.

 Cellular connection is not guaranteed.

 Virginia State Police can provide a wealth of practical knowledge.

 Communication is key before, during, and after.



WORKING WITH IOOs

Infrastructure owner-operators (IOOs) are focused on serving road users through:

- Detailed planning.
- Minimal disruption.
- Coordinating with other users.

Researchers are focused on generating knowledge of:

- New applications.
- Data collection.



CARMA 1Tenth



Ask how you can work with us to develop CARMA 1tenth.

- Scaled-down automated driving system (ADS) cars with hardware for autonomous driving, built by a community of ADS developers.
- Cost-efficient ADS research with a customized platform to aid CDA development.
- Capability to engage a larger research community and enable faster learning of CDA research.



Source: FHWA.



CARMA Collaborative and CARMA Support Services



A collaborative environment where the program works with academic institutions to conduct research and testing while providing an active community of users advancing CDA.


Contact Us

 CARMA@dot.gov



Questions about implementing CARMA into your research?

Contact Us

 Open 8 a.m.–5 p.m. ET
Monday–Friday
(excluding any holidays)

 CARMAsupport@dot.gov

Academic Collaborators



Source: FHWA.



Source: FHWA.



To Learn More About CARMA, Visit:



FHWA Site¹ – <https://highways.dot.gov/research/research-programs/operations/CARMA>



GitHub[®] Site² – <https://github.com/usdot-fhwa-stol>



Confluence Site³ – <https://usdot-carma.atlassian.net/wiki/spaces/CAR/overview>



ROS Discourse⁴ – <https://discourse.ros.org/c/carma/59>



CARMA Collaborative Contribution Form⁵ – https://docs.google.com/forms/d/1eKWV7MupHmjHBL3VFp8WXoxtty7SYG2P2Xm-NMIOU_w/edit

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4. ROS Discourse. (2020). "CARMA." (website) Available online: <https://discourse.ros.org/c/carma/59>.
5. Google Forms. "CARMA Collaborative Contribution Form." (website) Available online: https://docs.google.com/forms/d/1eKWV7MupHmjHBL3VFp8WXoxtty7SYG2P2Xm-NMIOU_w/viewform?edit_requested=true.





Contact us!



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