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OFFICE OF RESEARCH,  
DEVELOPMENT,  
AND TECHNOLOGY

# CARMA<sup>SM</sup> DEVELOPMENT UPDATE

## CAT Coalition - Resources Work Group Webinar

November 10, 2021

Pavle Bujanović  
Technical Manager, FHWA



# AGENDA

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- Connected and automated vehicle (CAV) overview.
- CARMA Program overview.
- Work zone use case and testing.
- Questions and answers.

# CAVs

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# SAE

## SAE J3016™ LEVELS OF DRIVING AUTOMATION



	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You are <b>not</b> driving when these automated driving features are engaged – even if you are seated in “the driver’s seat”		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
What do these features do?	These are driver support features			These are automated driving features		
	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/acceleration support to the driver	These features provide steering AND brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met	This feature can drive the vehicle under all conditions	
Example Features	<ul style="list-style-type: none"> <li>• automatic emergency braking</li> <li>• blind spot warning</li> <li>• lane departure warning</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering OR</li> <li>• adaptive cruise control</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering AND</li> <li>• adaptive cruise control at the same time</li> </ul>	<ul style="list-style-type: none"> <li>• traffic jam chauffeur</li> </ul>	<ul style="list-style-type: none"> <li>• local driverless taxi</li> <li>• pedals/steering wheel may or may not be installed</li> </ul>	<ul style="list-style-type: none"> <li>• same as level 4, but feature can drive everywhere in all conditions</li> </ul>

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SAE International. 2020. *SAE Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles J3016\_202005*, 2020-05-07 revision, United States. Last accessed 2020-10-06: [https://www.sae.org/standards/content/j3216\\_202005/](https://www.sae.org/standards/content/j3216_202005/).

# COOPERATIVE DRIVING AUTOMATION



Source: FHWA.

SAE  
International  
J3216

**Cooperative driving automation (CDA):** Automation that uses machine-to-machine 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 DDT for a vehicle with driving automation feature(s) engaged.

*Publicly released May 2020.*

DDT = dynamic driving task.

SAE International. 2020. *Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles*. SAE J3216\_202005. Warrendale, PA: SAE International. [https://www.sae.org/standards/content/j3216\\_202005/](https://www.sae.org/standards/content/j3216_202005/), last accessed October 19, 2020.



## RELATIONSHIP BETWEEN CLASSES OF COOPERATIVE DRIVING AUTOMATION (CDA) J3216 AND LEVELS OF AUTOMATION J3016



		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
<b>NO COOPERATIVE AUTOMATION</b>		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)		
<b>CDA CLASSES</b>	<b>SAE CLASS A STATUS SHARING</b>	Here I am and what I see	e.g., Brake Lights, Traffic Signal	Potential for improved object and event detection <sup>1</sup>	Potential for improved object and event detection <sup>2</sup>		
	<b>SAE CLASS B INTENT SHARING</b>	This is what I plan to do	e.g., Turn Signal, Merge	Potential for improved object and event prediction <sup>1</sup>	Potential for improved object and event prediction <sup>2</sup>		
	<b>SAE CLASS C AGREEMENT SEEKING</b>	Let's do this together	e.g., Hand Signals, Merge	N/A	C-ADS designed to attain mutual goals through coordinated actions		
	<b>SAE CLASS D PRESCRIPTIVE</b>	I will do as directed	e.g., Hand Signals, Lane Assignment by Officials		C-ADS designed to accept and adhere to a command		

TCD = traffic control device; ADS = automated driving systems; C-ADS = cooperative ADS; DDT = dynamic driving task; N/A = not applicable.

<sup>1</sup> 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.

<sup>2</sup> 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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# CARMA PROGRAM

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# WHAT IS THE CARMA PROGRAM?



FHWA's initiative focuses on improving the U.S. transportation system by leveraging emerging automated driving technology and vehicle-to-everything technology. Using these technologies, the CARMA Program aims to improve transit safety and operational performance.



Source: FHWA.



# CARMA PROGRAM ECOSYSTEM

The CARMA Program Ecosystem is a network of open-source software and support services focusing on how infrastructure can move traffic more efficiently by advancing transportation systems management and operations (TSMO) strategies.



Source: FHWA.

# CDA RESEARCH TRACKS AND USE CASES



Recurring traffic congestion use cases (freeways, arterials).

- Congestion.
- Transit.
- Traffic signals.

**USDOT Partners:**

FHWA | HRDSO | HOTM | RC  
ITS/JPO | FTA | FMCSA | OST-R | HASS COE



Nonrecurring traffic congestion use cases (freeways, arterials).

- Work zones.
- Weather.
- Traffic incident management (TIM).

**USDOT Partners:**

FHWA | HRDSO | HOTO | RC  
ITS/JPO | FMCSA | OST-R | HASS COE



Commercial motor vehicle (CMV) and port use cases.

- Port drayage.
- CMV.
- Truck platooning.

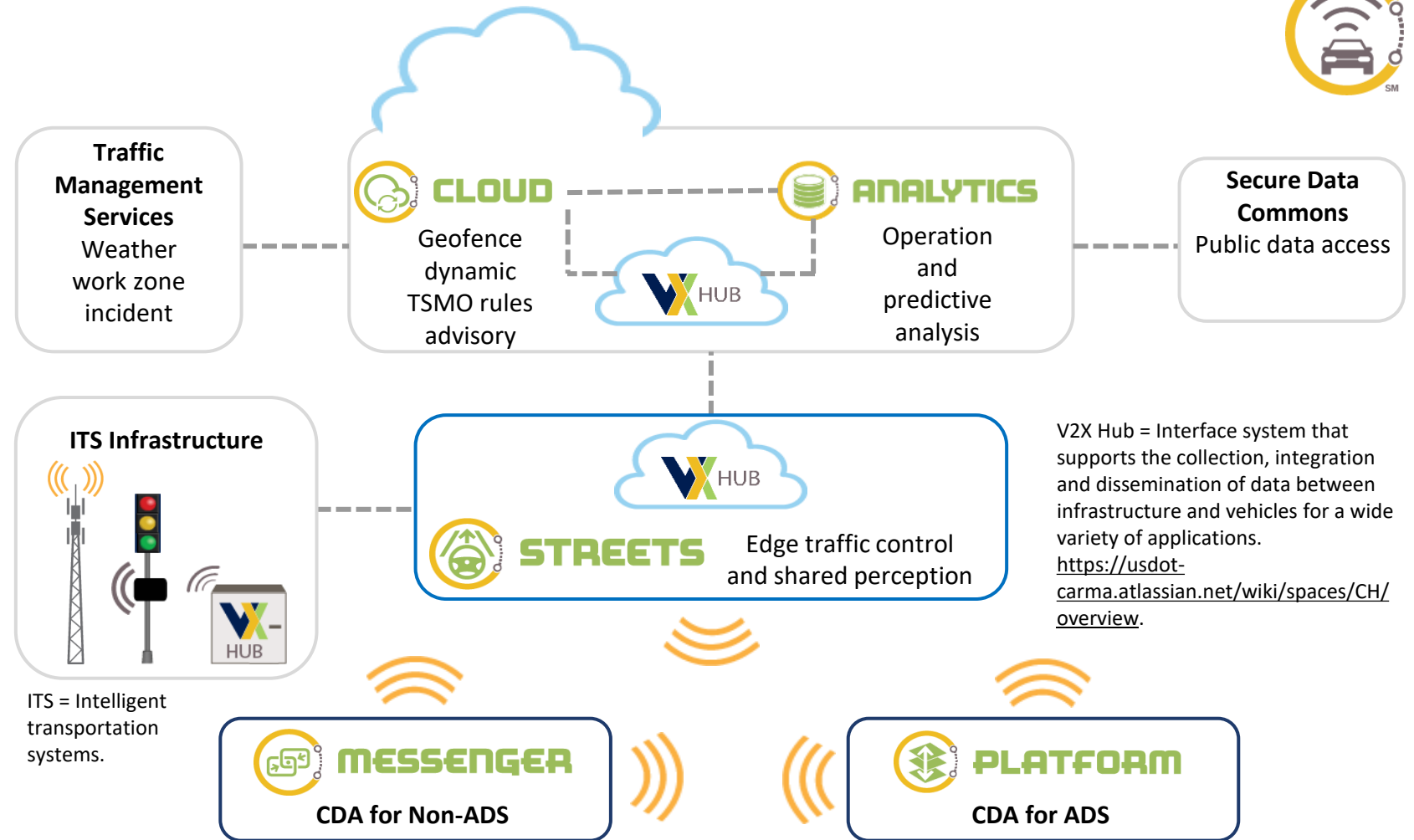
**USDOT Partners:**

FHWA | HRDSO | HOFM | RC | ITS/JPO  
FMCSA | MARAD | OST-R | HASS COE

See slide 30 for a full list of partners.

- **CARMA Cloud<sup>SM</sup>** source code is available on [GitHub](#).
- FHWA's **Work Zone Data Exchange (WZDx)** program will work alongside CARMA Cloud to share information about work zones with CARMA vehicles.
- Grants are being awarded to further CARMA Cloud and WZDx research.

ADS = automated driving system.



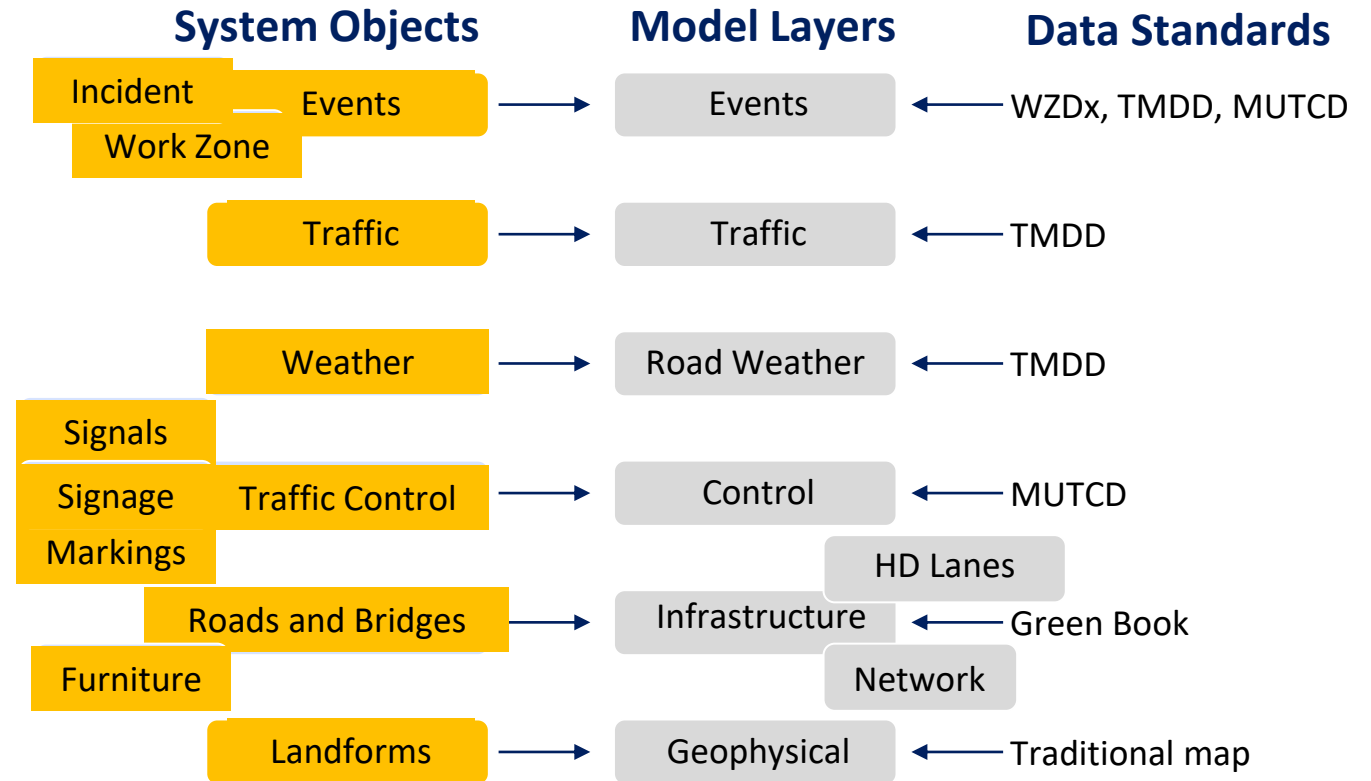
Source: FHWA.

# CARMA CLOUD



Rethinking maps and controls to provide actionable data in cooperative automation.

- System objects are common to human and automated drivers.
- Maps may try to overlay data about any of those objects as model layers.
- Data standards are common to human driving and automated contexts.
- Roadway control markings and signings are separated from the roadway models, enabling advanced use cases with dynamic controls.
- Incident and work zone use cases for CDA are deconstructed to dynamic lane controls that are bundled into an “incident” or a “work zone.”



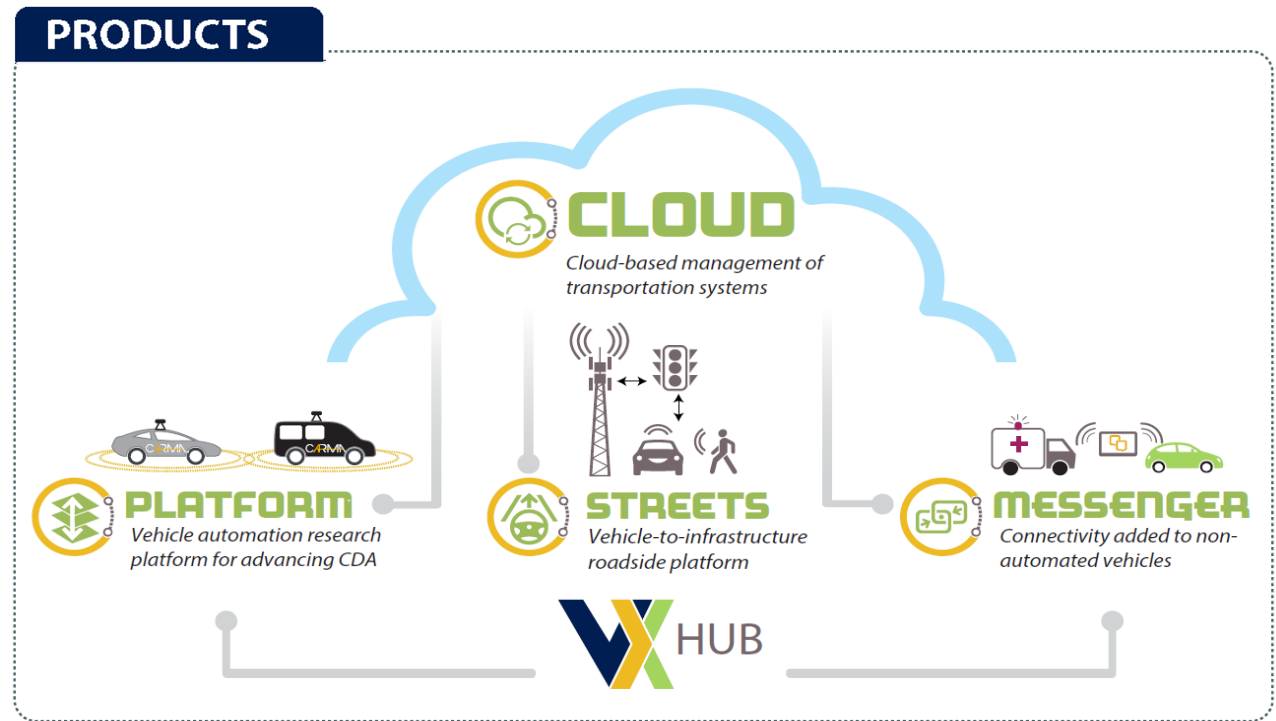
Source: FHWA.

TMDD = traffic management data dictionary; MUTCD = Manual on Uniform Traffic Control Devices; HD = high definition.



CARMA Streets<sup>SM</sup> is now available on [GitHub](#).

CARMA Streets is an infrastructure-based platform for automated vehicles (AVs) to share information and intent with other vehicles and infrastructure, enabling cooperative actions that improve transportation operations and safety.

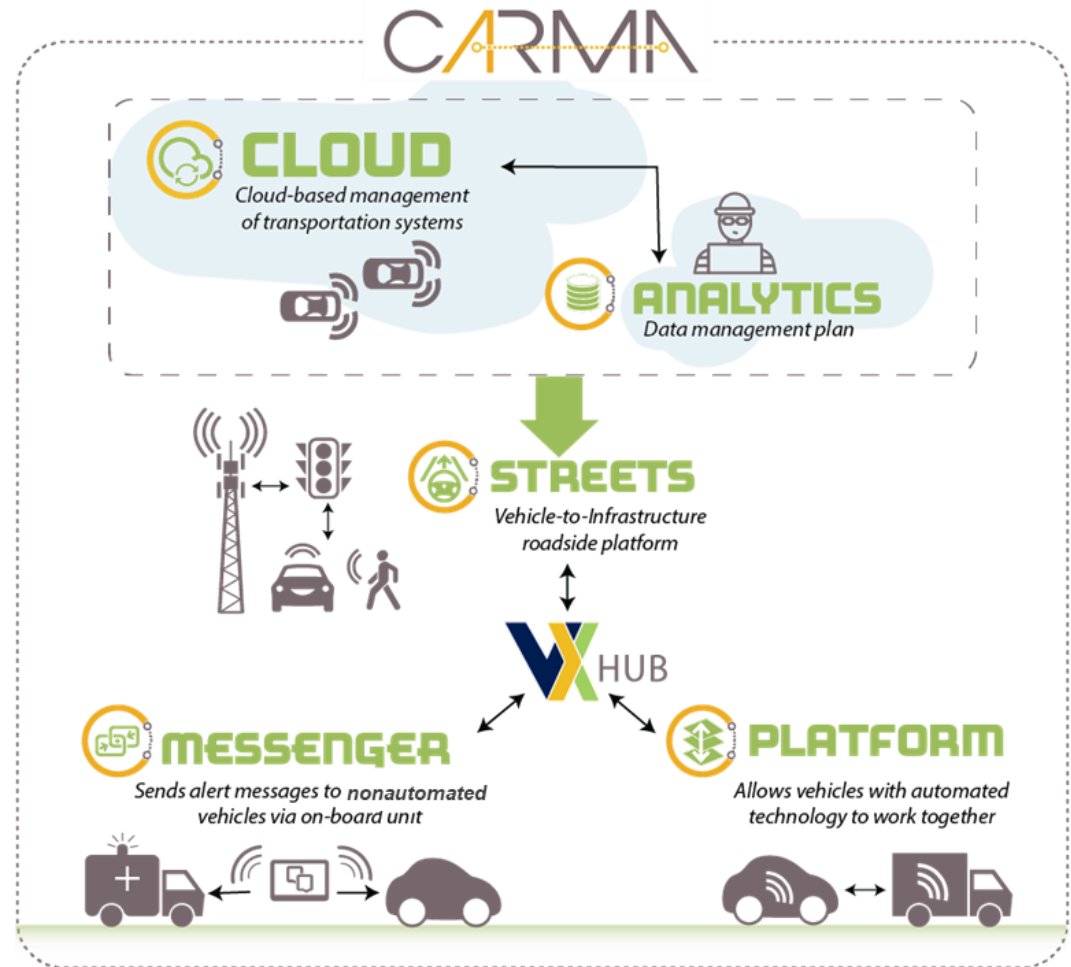


Source: FHWA.

# CARMA STREETS

CARMA Streets functions include the following:

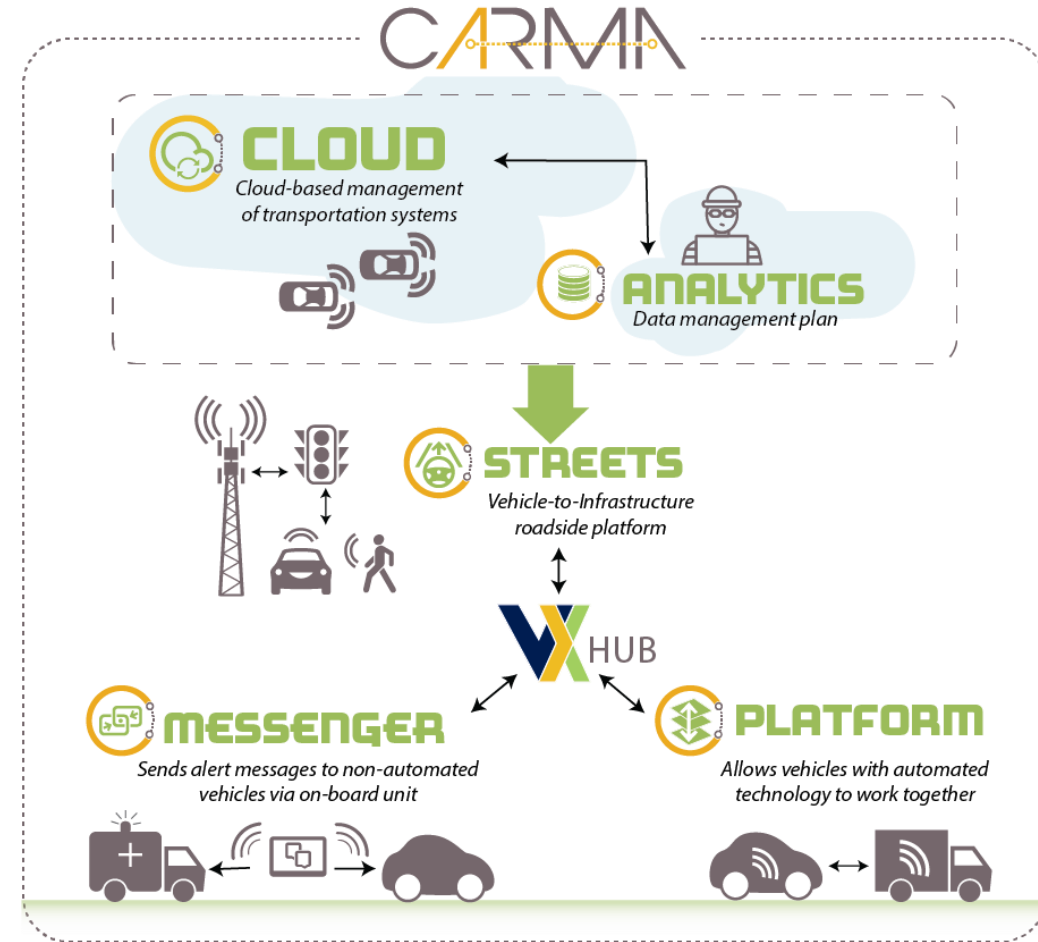
- Interfacing between management applications (CARMA Cloud) and roadside infrastructure.
- Communicating with roadside infrastructure systems and CDA vehicles.
- Using edge computing capabilities for process optimization.



Source: FHWA.

CARMA Platform<sup>SM</sup> is now available on [GitHub](#).

CARMA Platform is a vehicle-based platform for AVs to share information and intent with other vehicles and infrastructure, enabling cooperative actions that improve transportation operations and safety.

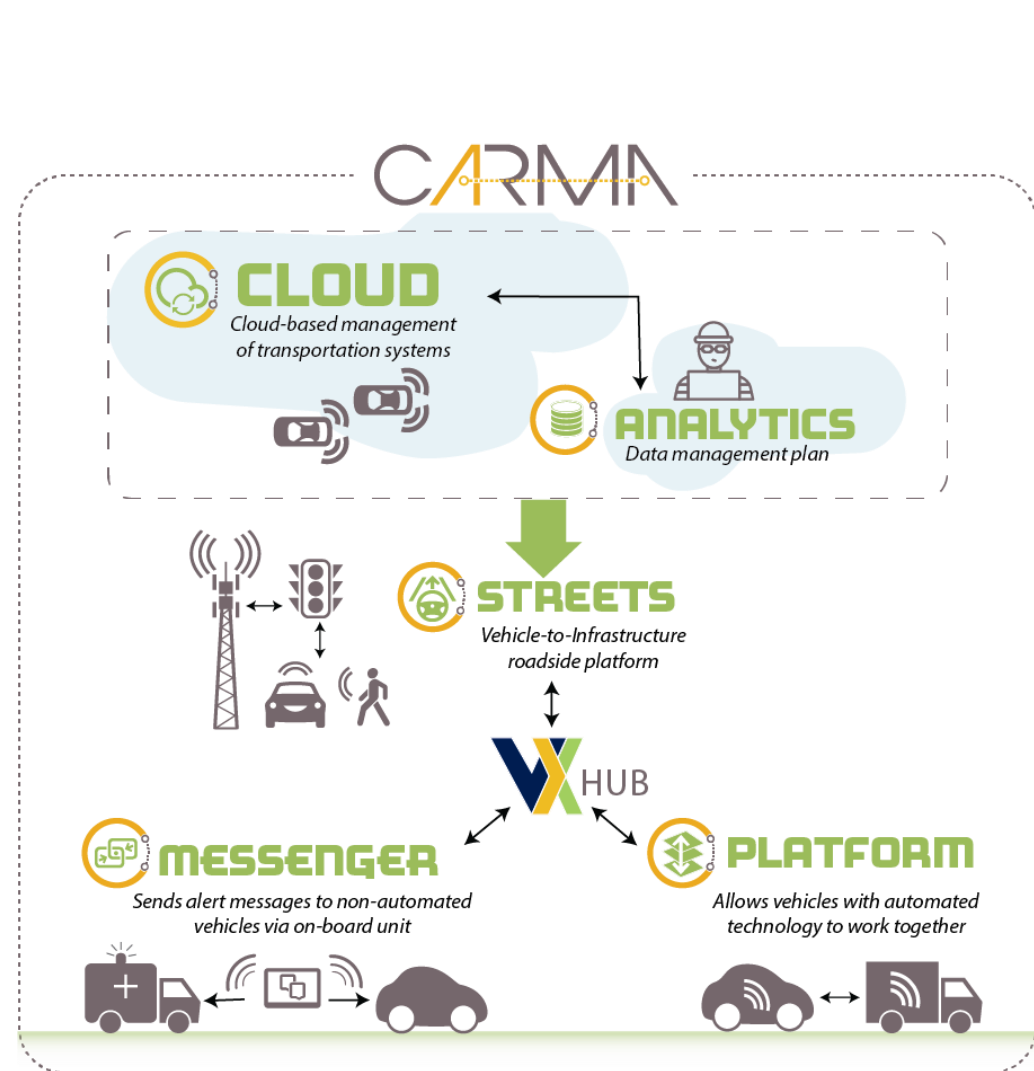


Source: FHWA.

# Messenger

CARMA Messenger<sup>SM</sup> will soon be available on [GitHub](#).

CARMA Messenger is a vehicle-based platform for manual vehicles that enables communication and cooperation with AVs.



Source: FHWA.





# CARMA3

## PROJECT OVERVIEW AND OBJECTIVES

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**Project Goal:** Advance understanding of cooperative ADS (C-ADS) developed on the CARMA Platform to test arbitration and negotiation strategies applied to enhance infrastructure efficiency and ultimately reduce traffic congestion.

### Objectives:

- Develop a working level 3-capable CARMA Platform.
- Develop a set of testable use cases that demonstrate how C-ADS capabilities will integrate with TSMO and freight mobility strategies.
- Gain acceptance from the CAV community, demonstrated by interactive contributions to the open-source CARMA Platform.

# CARMA3

## TESTING MILESTONES

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**Milestones:** TIM, basic travel, weather, and work zone **validation** testing.

Generally, testing activities occur in the following order (steps may be omitted in certain cases):

### 1. Unit:

- Confirms that individual software components work properly, which is usually done via “mock” inputs.
- Does not require field tests on a test track.

### 2. Integration:

- Confirms that individual software components have been integrated properly such that running them together does not produce errors.
- Used to ensure that the components can talk to each other.
- May or may not require field tests on a test track.

### 3. Verification:

- Ensures that the system was built correctly, according to system requirements.
- Usually requires field tests on a test track.

### 4. Validation:

- Conducted by an independent party to confirm that the system delivers the use cases according to user needs and requirements.
- Requires field tests on a test track.

**5. Demonstration:** Shows internal and external stakeholders that the use case has been successfully implemented.

# WORK ZONE USE CASE

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# WORK ZONE FRAMEWORK



TSMO-focused transportation management system (TMS) operations are activities that TMSs, and especially traffic management centers, typically perform **when work zones are active**.



Source: FHWA.



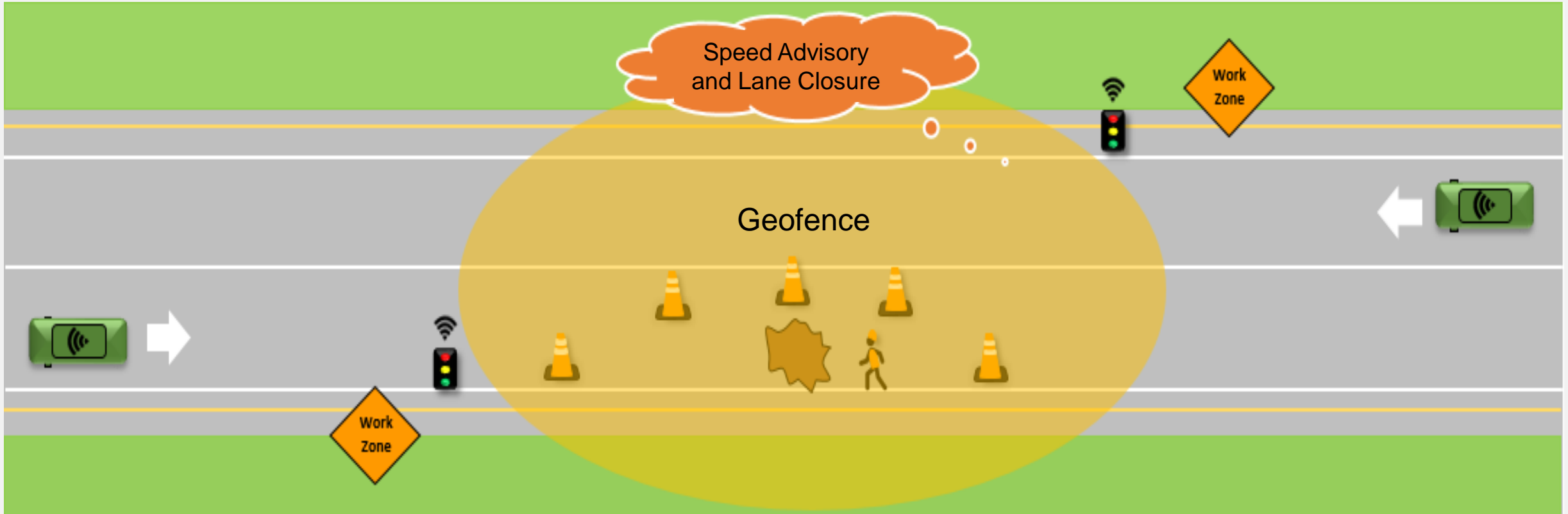
# WORK ZONE USE CASE

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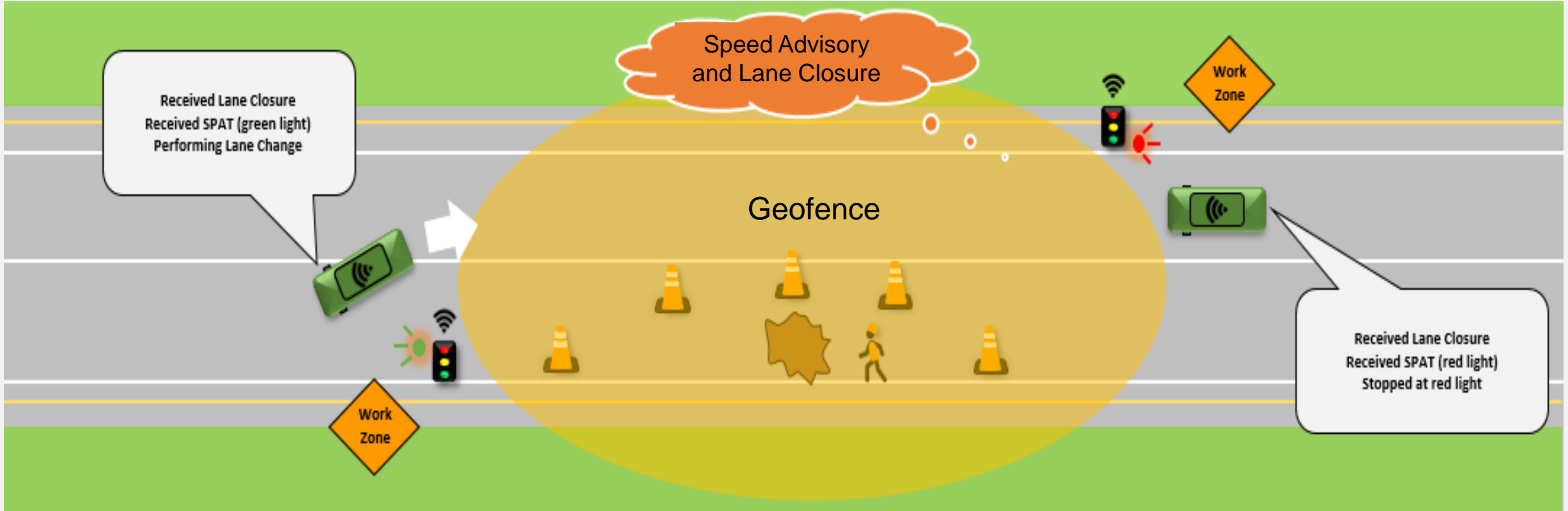
- **Products:** CARMA Platform and CARMA Cloud.
- **Features:**
  - ADS lane change—unobstructed lane change.
  - Cooperative traffic monitoring, such as Geofence speed advisory and gap control.
  - Cloud world model—lane closure.
  - Cooperative traffic signaling and fixed signal timing.

# WORK ZONE SCENARIO



Source: FHWA.

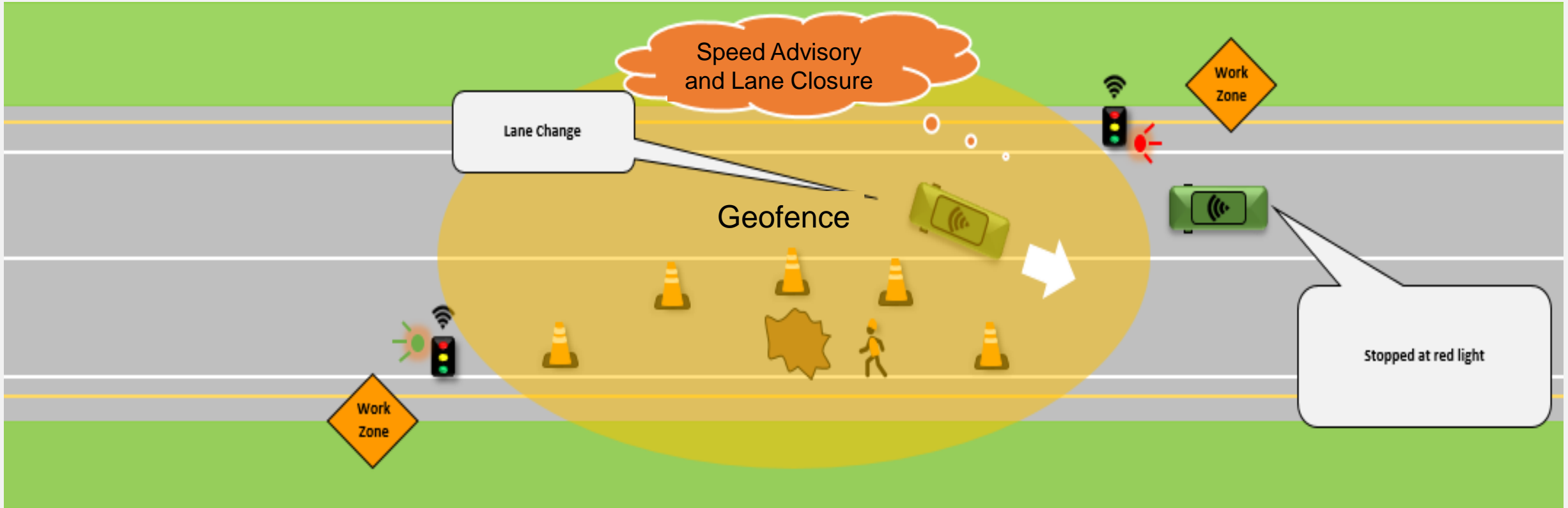
# WORK ZONE SCENARIO



Source: FHWA.

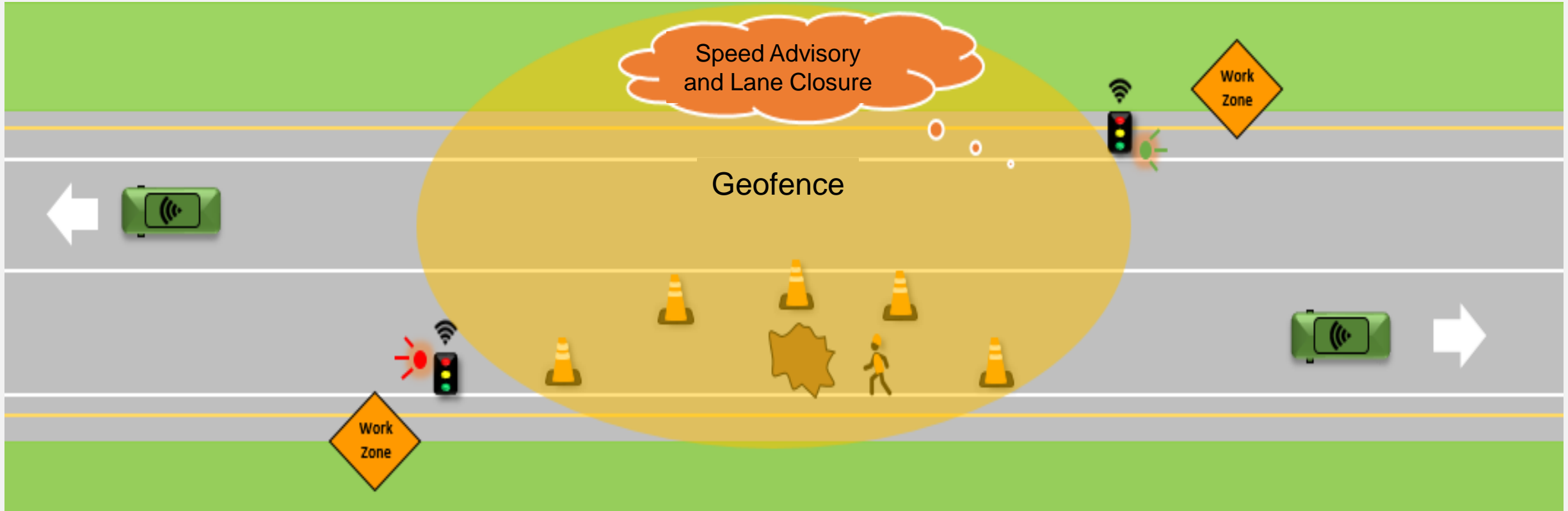
SPaT = signal phase and timing.

# WORK ZONE SCENARIO



Source: FHWA.

# WORK ZONE SCENARIO



Source: FHWA.

# CARMA COLLABORATIVE AND CARMA SUPPORT SERVICES



CARMA Collaborative is 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](mailto:CARMA@dot.gov)



Questions about implementing CARMA into your research?

## Contact Us

 Open 8 a.m.–5 p.m. ET  
Monday–Friday

 [CARMAsupport@dot.gov](mailto:CARMAsupport@dot.gov)  
[WZDxSupport@dot.gov](mailto:WZDxSupport@dot.gov)

## Academic Collaborators



Source: FHWA.





# TO LEARN MORE ABOUT CARMA AND WORK ZONES, 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/CRMECO/overview?mode=global>.



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



**OSS4ITS** – <https://usdot-oss4its.atlassian.net/wiki/spaces/OSSFITS/overview?homepageId=163901>.

# QUESTIONS AND ANSWERS

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# USDOT PARTNERS

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- 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).
- FHWA Resource Center (RC).
- Intelligent Transportation Systems Joint Program Office (ITS/JPO).
- Federal Transit Administration (FTA).
- Federal Motor Carrier Safety Administration (FMCSA).
- Maritime Administration (MARAD).
- Office of the Assistant Secretary for Research and Technology (OST-R).
- Highly Automated Systems Center of Excellence (HASS COE).

# CONTACT

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