Source: FHWA

Source: FHWA

Source: FHWA

Source: FHWA

CARMA Webinar Series

CARMA Cloud℠ and CARMA Streets

November 10, 2020

Taylor Lochrane, FHWA
Wade Goforth, Leidos
Kyle Garrett, Synesis Partners

U.S. Department of Transportation
Federal Highway Administration

SAXTON LABORATORY

Housekeeping

- Please dial-in to the conference via phone to ask questions and participate in the questions and discussion portion:
  - Dial-in: (800)-832-0736
  - Room #990-1296
  - Unmute yourself: *#
- The chat pod is also available for you to ask questions. A moderator will announce your question.

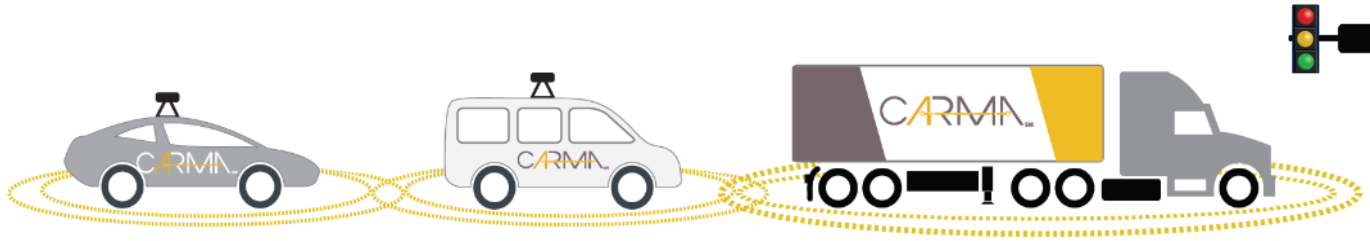
CARMA[SM]
Webinar Series

CARMA Cloud
and
CARMA Streets

Agenda

- Cooperative driving automation (CDA) and CARMA review.
- CARMA Cloud within the program ecosystem.
- CARMA Streets within the program ecosystem.
- Next in the CARMA program.
- Questions and answers.

CDA



Source: FHWA.

SAE International J3216

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 [1]

1. SAE International. SAE J3216_202005™, Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles, United States. Last accessed 2020-10-19: https://www.sae.org/standards/content/j3216_202005/.

SAE Standard

CDA J3216

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

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/

			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.

P20542738

U.S. Department of Transportation
Federal Highway Administration

What Is the CARMA Program?

U.S. Department of Transportation
Federal Highway Administration

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.

Source: FHWA.

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℠ Open Source Software | Cooperative Driving Automation (CDA)

U.S. Department of Transportation
Federal Highway Administration

CARMA Ecosystem: Use Cases

©Bim, 1167082302, iStock Editorial/Getty Images Plus

TRAFFIC

Recurring traffic congestion use cases on freeways and arterials.

- Congestion
- Transit
- Traffic Signals

USDOT Partners:
FHWA | HRDSO | HOTM | RC
ITSJPO | **FTA** | **FMCSA**

© buzbuzzer, 172651046, iStock Editorial/Getty Images Plus

RELIABILITY

Nonrecurring traffic congestion use cases on freeways and arterials.

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

USDOT Partners:
FHWA | HRDSO | HOTO | RC
ITSJPO | **FMCSA**

© shaunl, 170006076, iStock Editorial/Getty Images Plus

FREIGHT

CMV and port use cases.

- Port Drayage
- CMV
- Truck Platooning

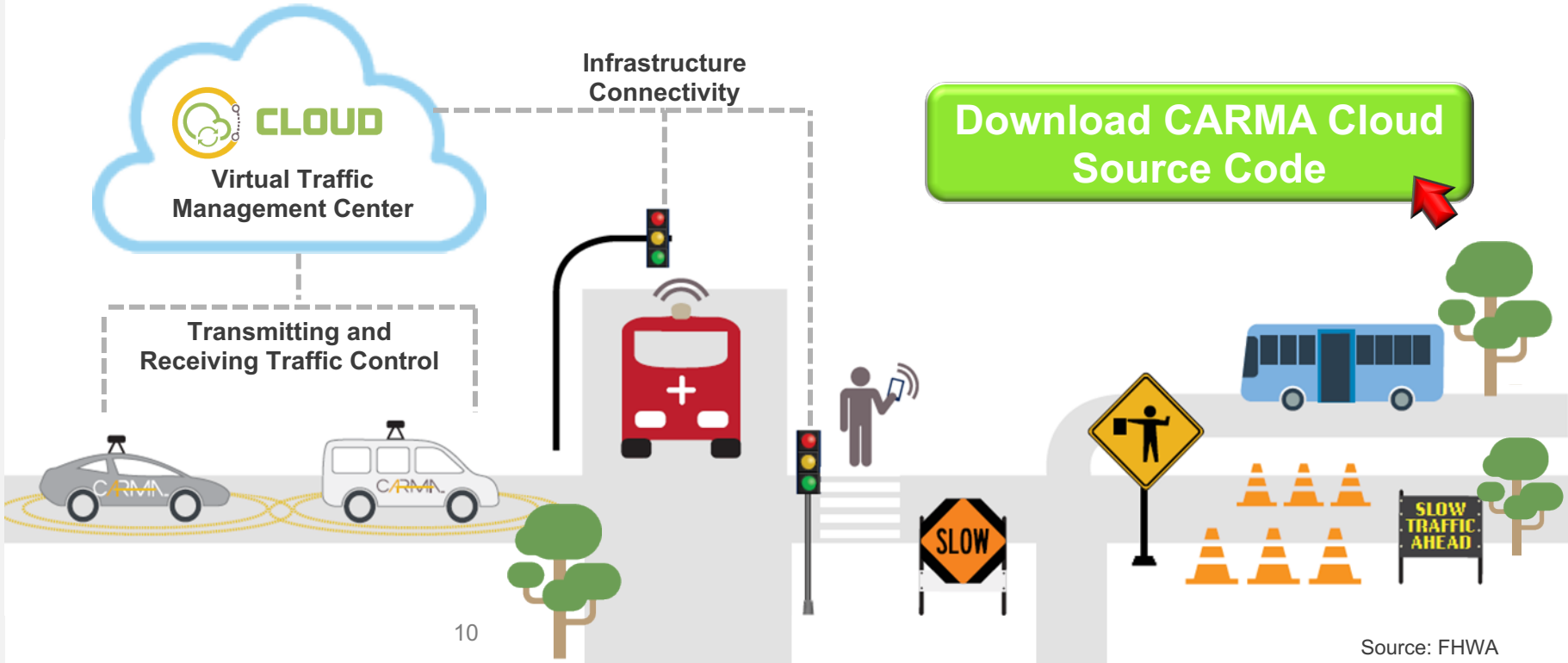
USDOT Partners:
FHWA | HRDSO | HOFM | RC
ITSJPO | **FMCSA** | **MARAD**

CARMA Cloud[SM] source code available on GitHub.

- Provides downloadable, cloud-based OSS service.
- Enables communication with cloud services and vehicles, road users, and infrastructure devices capable of communication.
- Identifies geofence lane segments to apply TSMO strategies.
- Applies TSMO automated driving system (ADS) rules of practice.

Dynamic traffic control messages (TCM) used to support TSMO use case strategies:

- **Speed:** Sending speed limits and reductions in speed.
- **Headway:** Managing single vehicle headways and platoon gaps.
- **Platoon size:** Setting platoon size limit.
- **Lane closures:** Providing precise lane closure locations for work zones and incidents.
- **Lane restrictions:** Restricting access to lanes by vehicle class or occupancy, by time of day.
- **Other variables to be defined**.



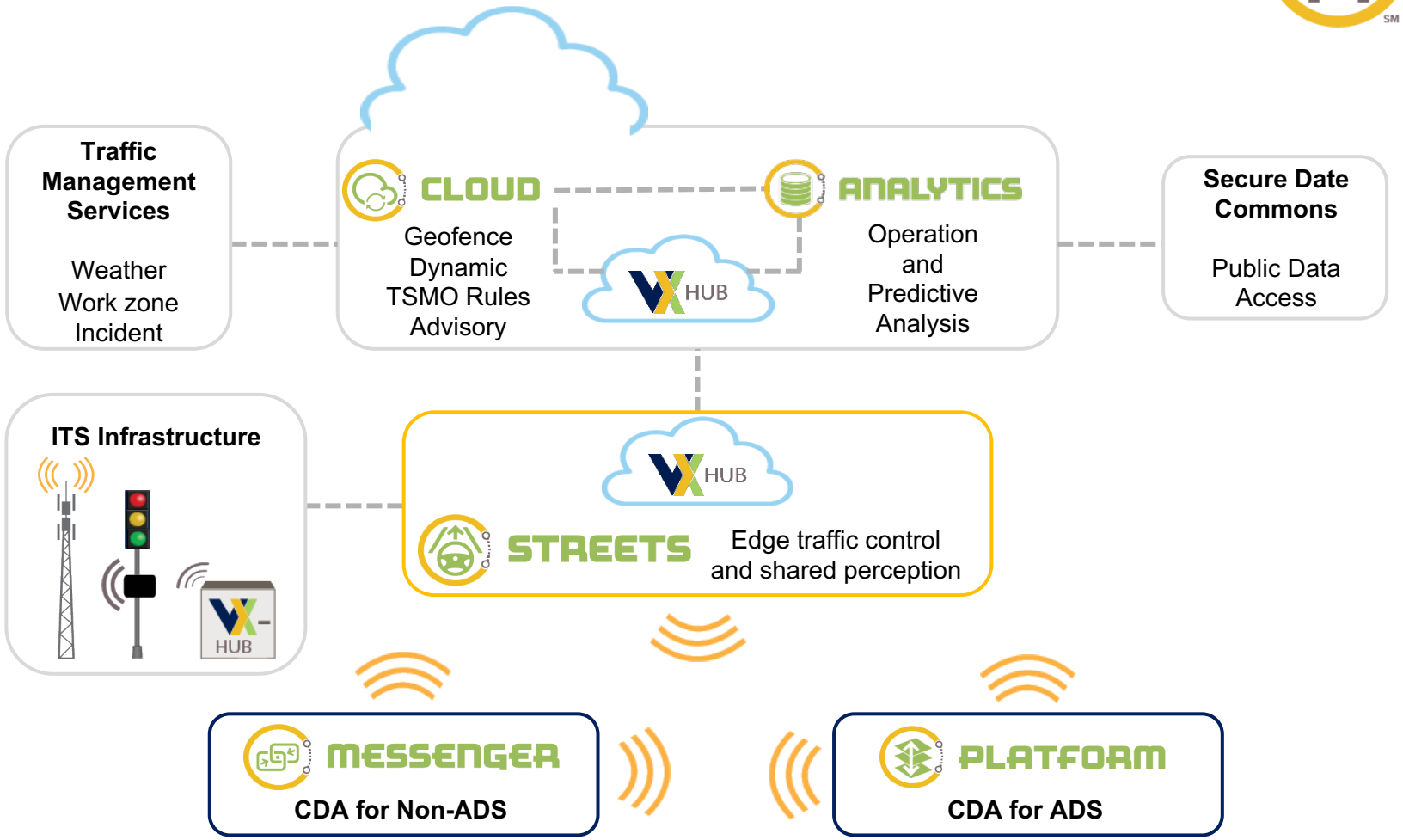
Source: FHWA

U.S. Department of Transportation
Federal Highway Administration

CARMA Cloud℠ source code 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.



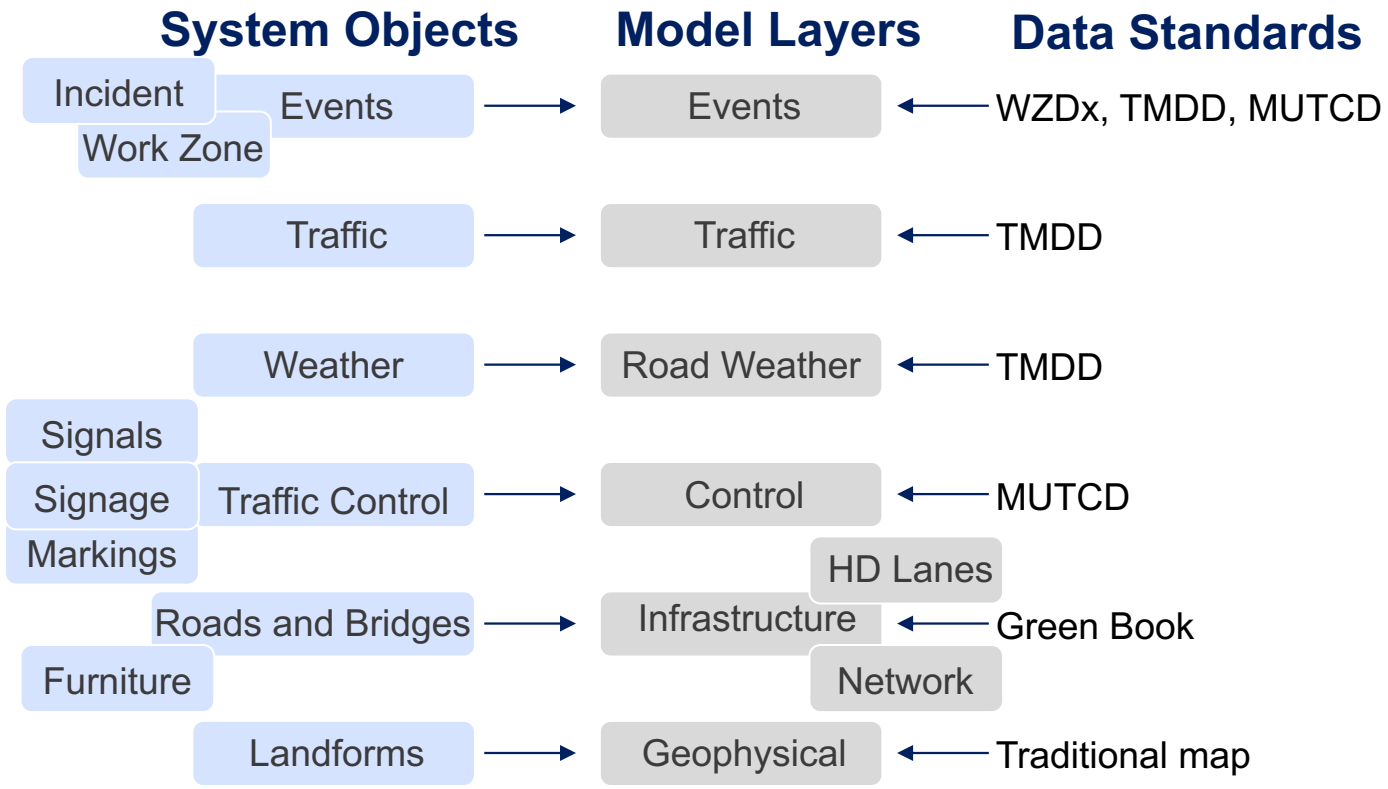
Intelligent Transportation Systems (ITS)
Source: FHWA

CARMA Cloud

Source code available on GitHub.

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 signage are separated from the roadway models which enables 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.”



Traffic Management Data Dictionary (TMDD), Manual on Uniform Traffic Control Devices (MUTCD)

CARMA Cloud

Source code available on GitHub.

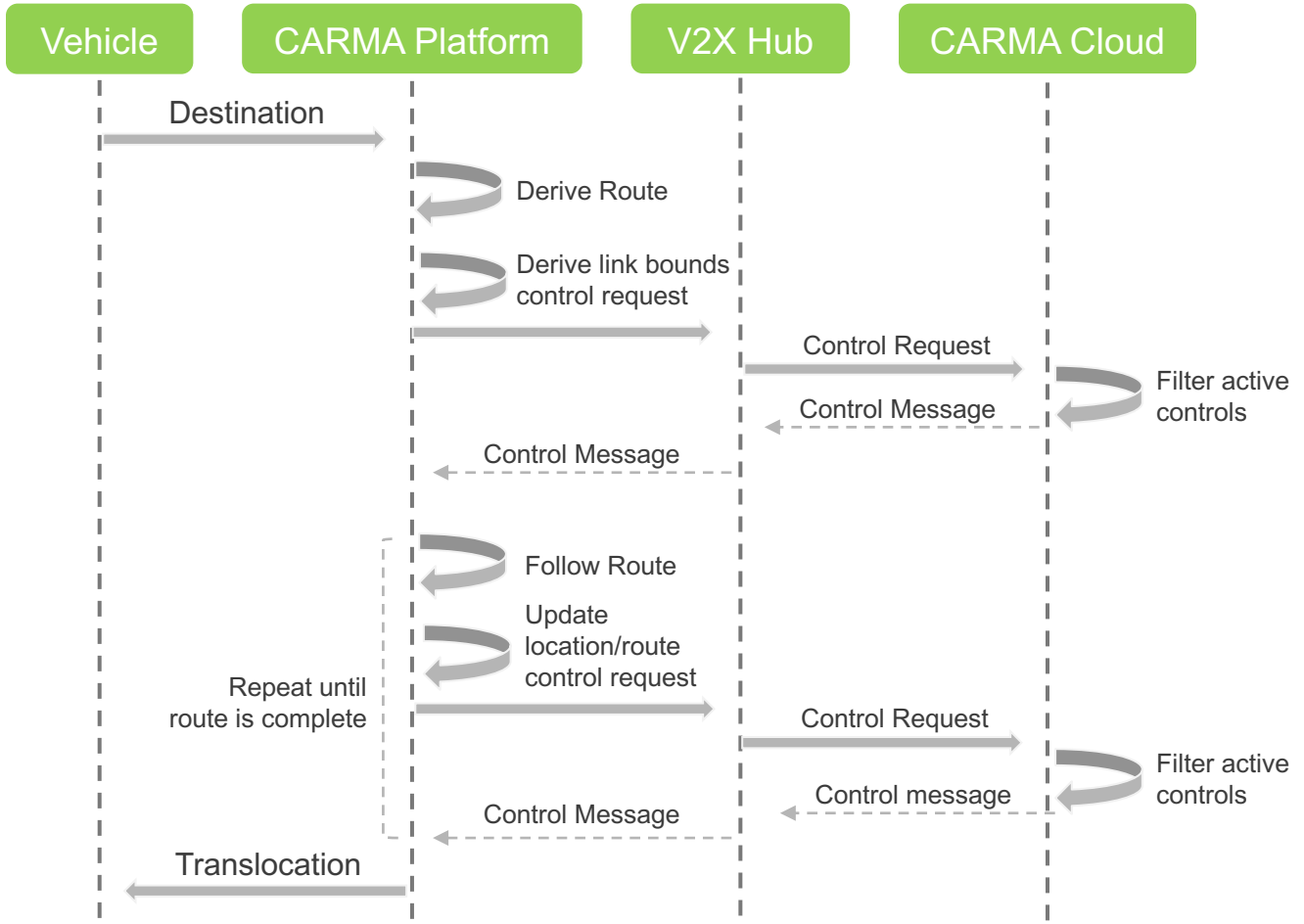
Example: Work zones might consist of a closed lane segment, overlaid scheduled lanes (for signaling reversal of travel direction), and stop lines at the approaches.

CARMA Cloud

Source code available on GitHub.

CARMA Cloud sends TCMs relevant to planned routes through the V2X Hub to CARMA Platform

- TCMs are requested at initial route planning and for route updates.
- Traffic control requests are sets of link boundaries for the route.
- Boundaries can be tightly drawn to reduce the message size or broader to reduce potential new requests in transit.
- Communication is asynchronous, and messages track their completion progress.



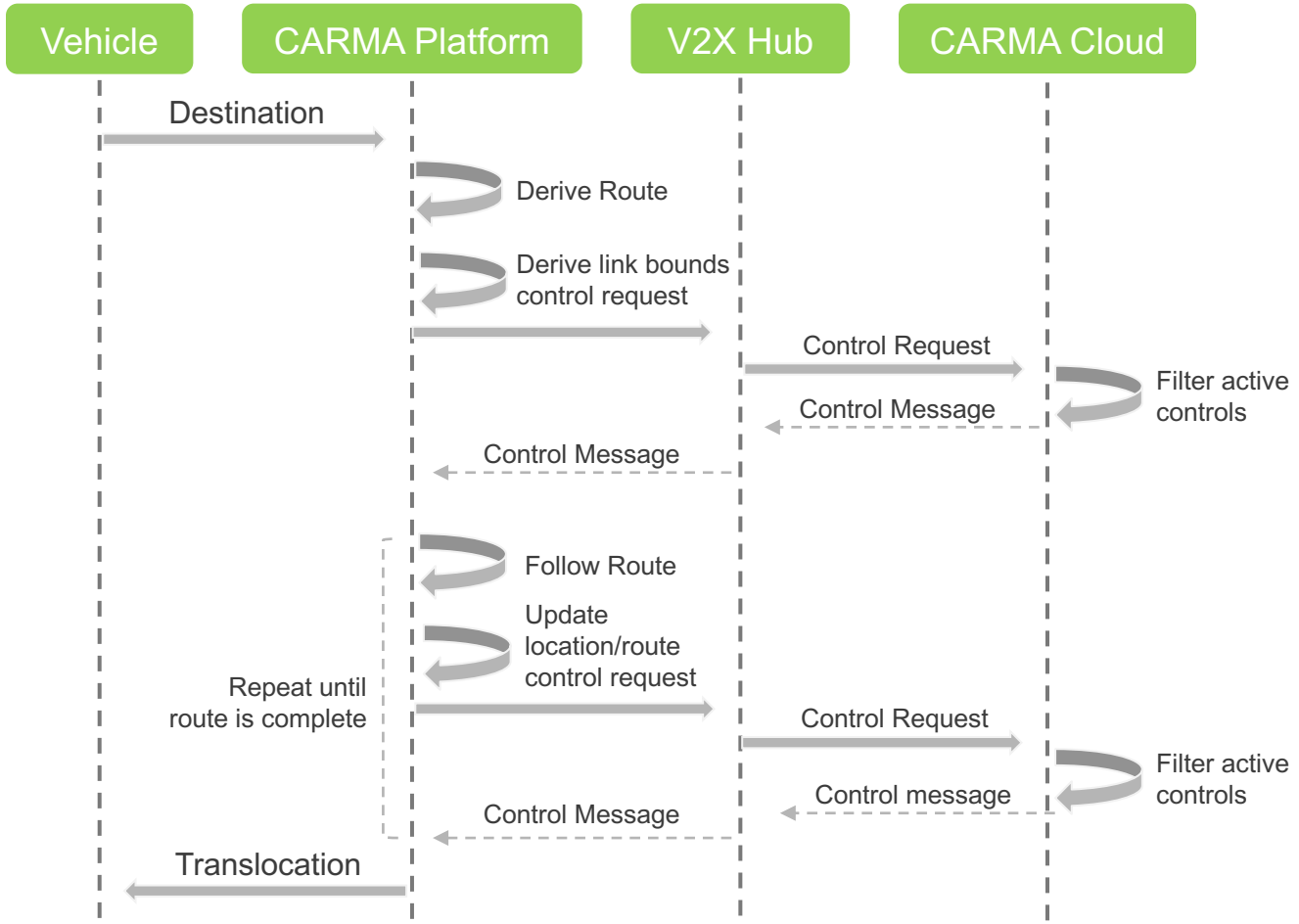
Source: FHWA

CARMA Cloud

Source code available on GitHub.

TCMs each describe specific traffic controls to be applied to paths along which vehicles are traveling.

- One TCM is sent per unique traffic control type/vehicle type set, e.g., restricted lanes for tractor/trailers or passenger vehicles.
- TCMs contain:
  - Traffic control type.
  - Vehicle types to which the control applies.
  - Schedules for the traffic control.
  - Path geometry definition.
- Path geometry definition includes projection information, 3D lane center point, width, and angle.

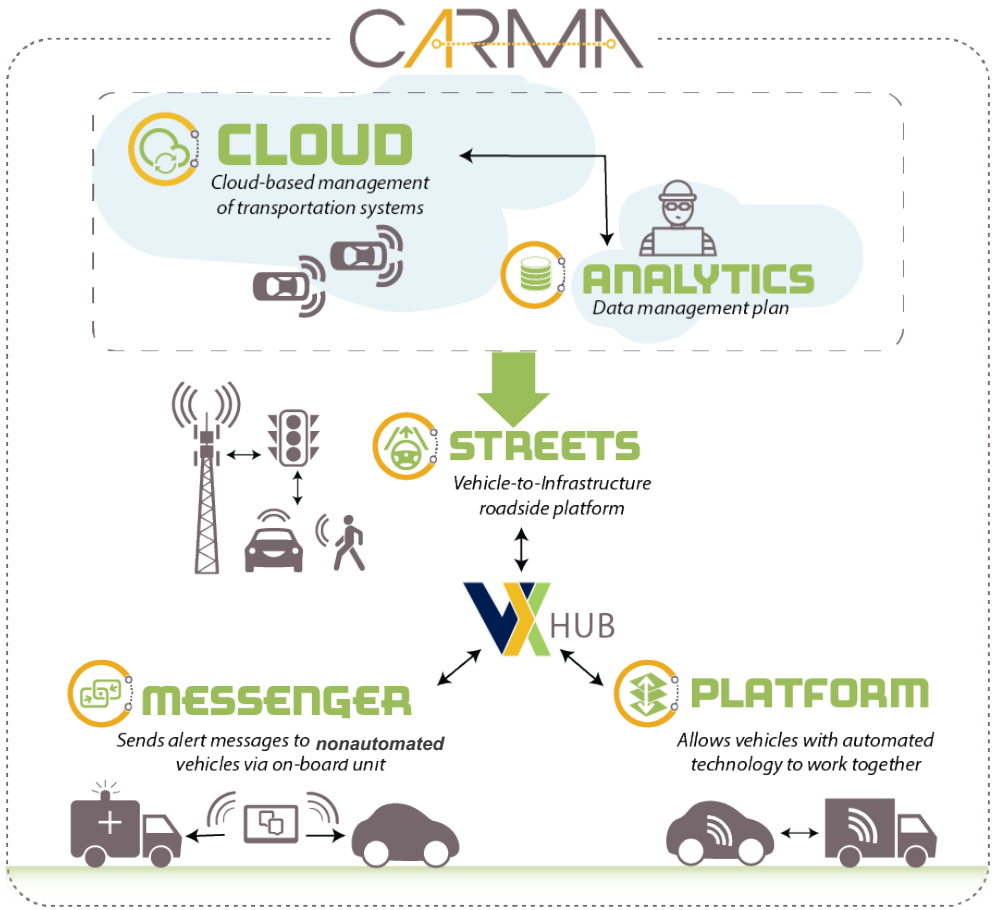


Source: FHWA

CARMA Streets

CARMA Streets provides:

- Local interface between management applications (CARMA Cloud) and roadside infrastructure.
- Ability for roadside infrastructure systems to communicate with CDA vehicles and each other.
- Edge computing capabilities for process optimization.

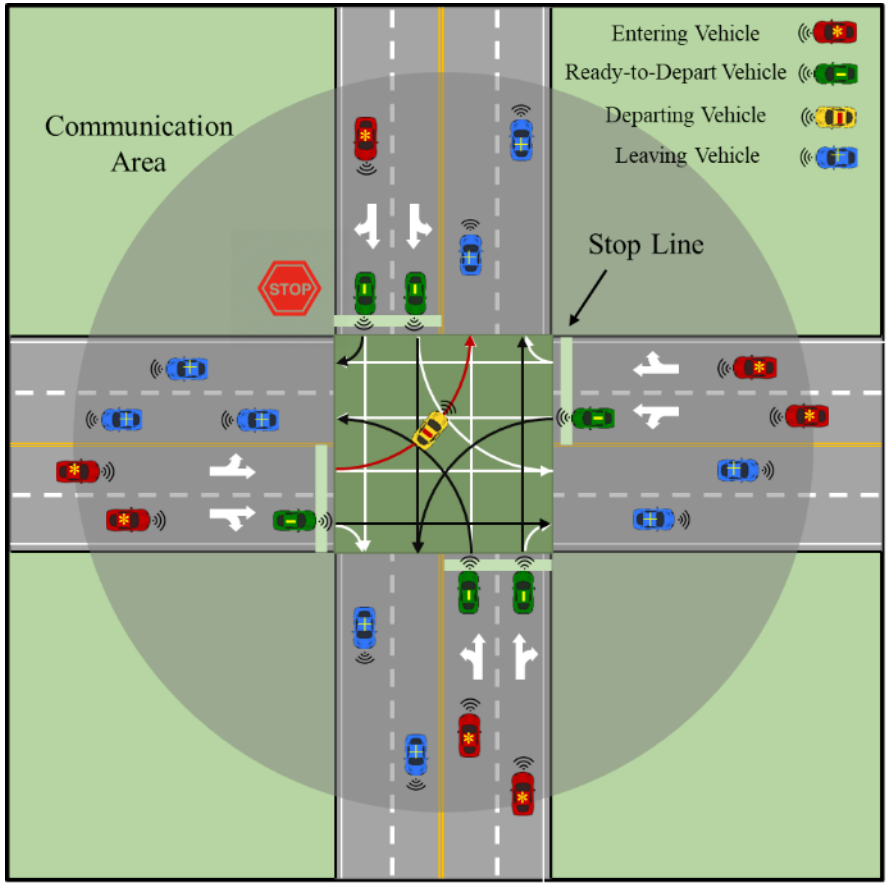


Source: FHWA

CARMA Streets

TSMO Objectives:

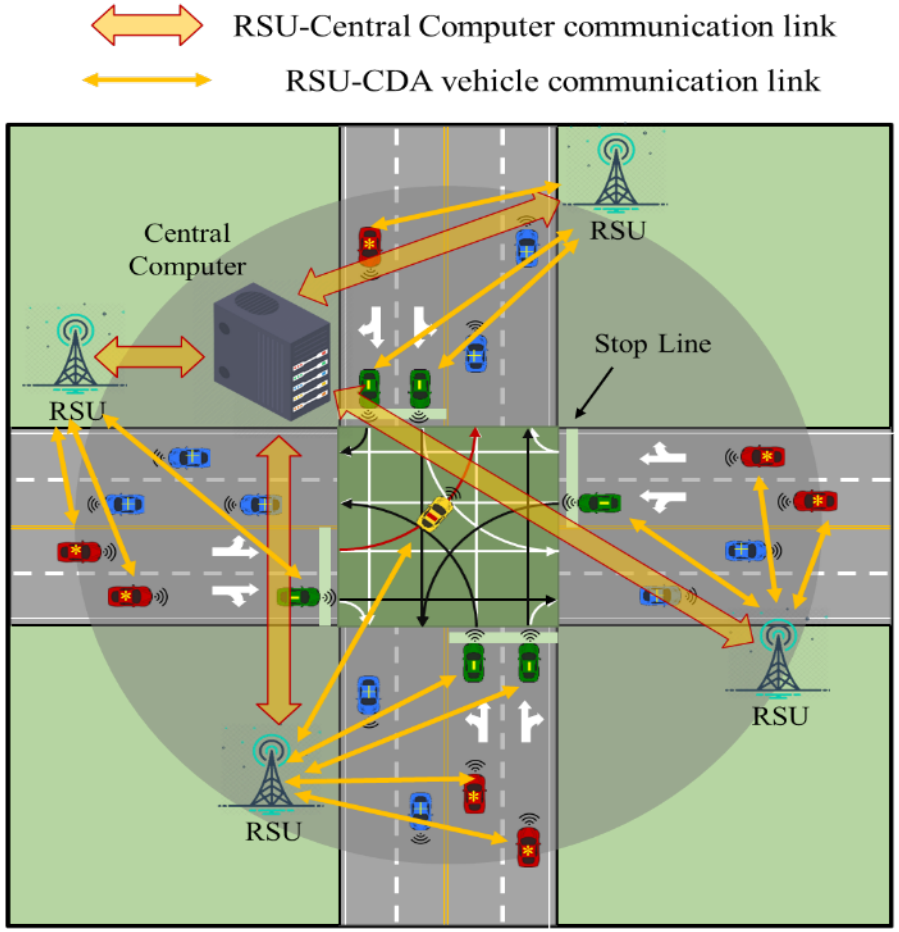
- Maintain Safety
- Reduce Traffic Congestion
- Improve Energy Efficiency



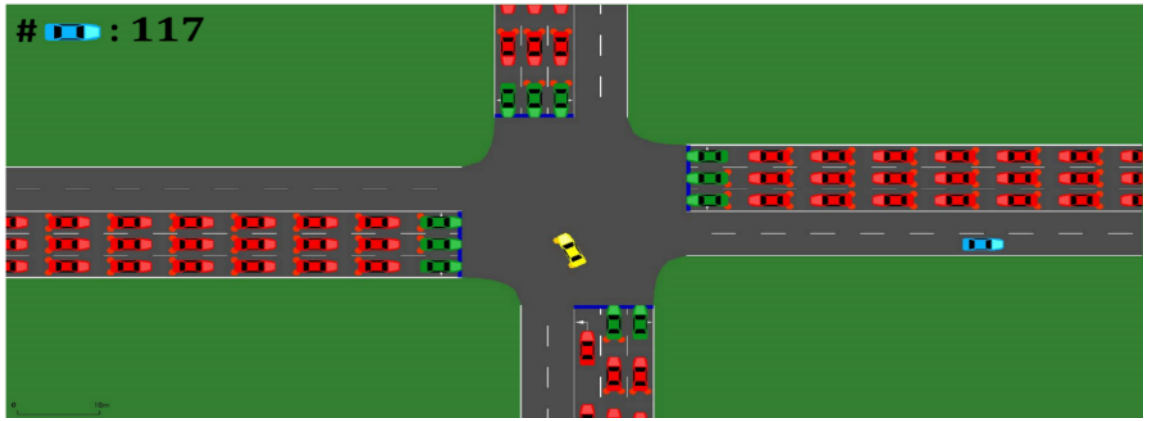
Source: FHWA

CARMA Streets

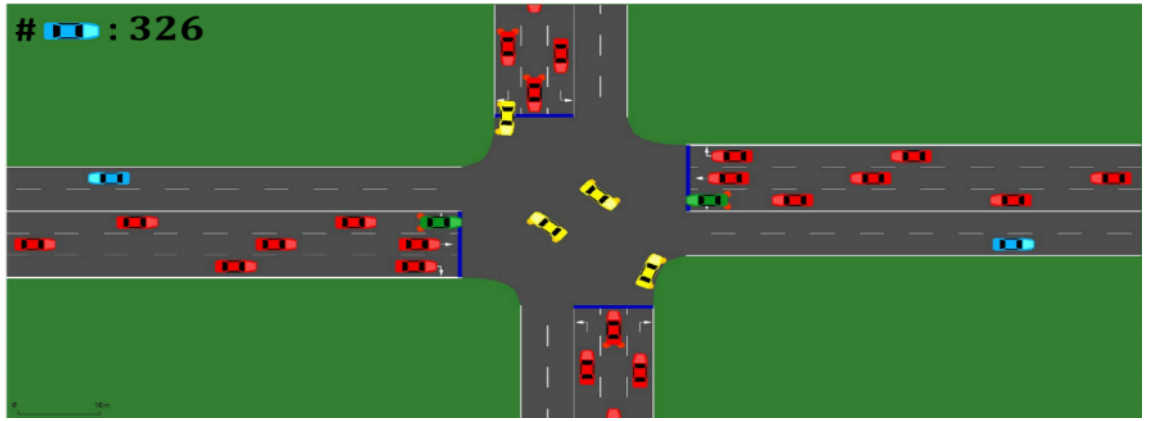
Maintain Safety through Communication



Source: FHWA



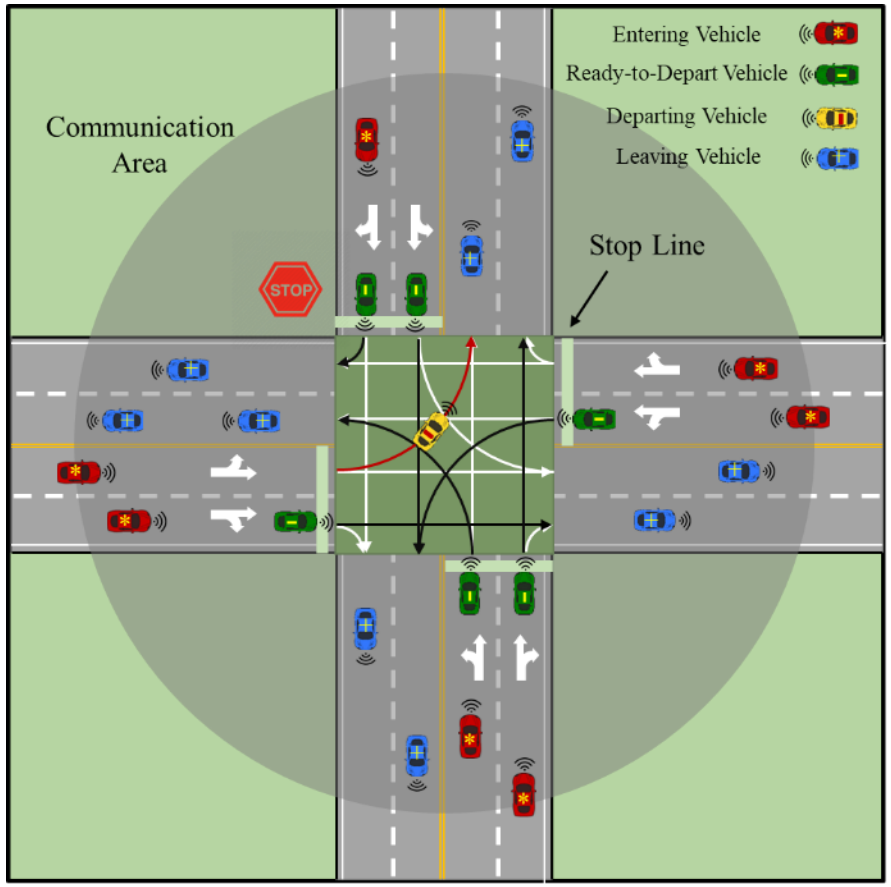
Source: FHWA



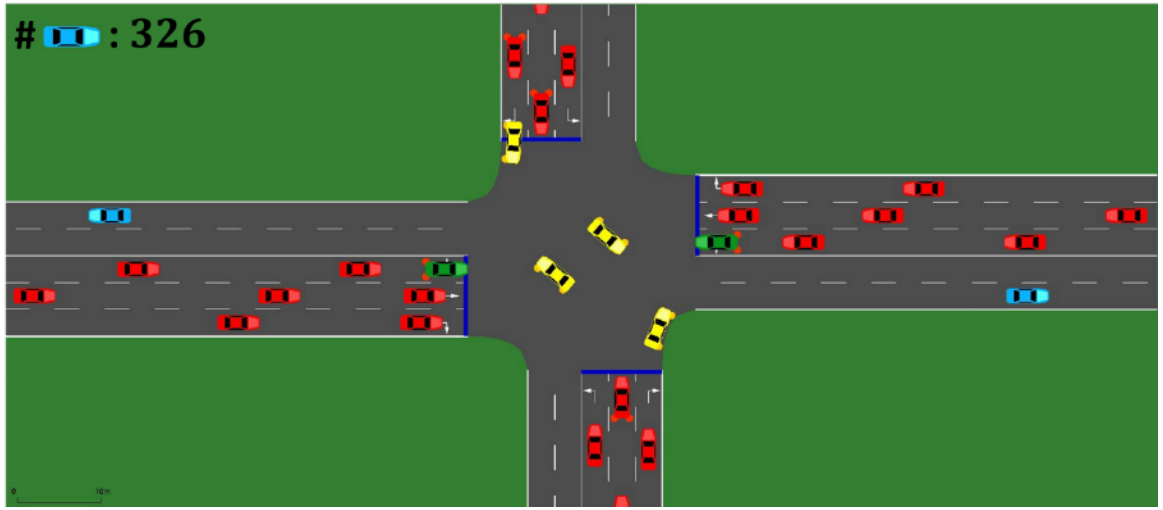
Source: FHWA

CARMA Streets

Reduce Traffic Congestion through Coordination



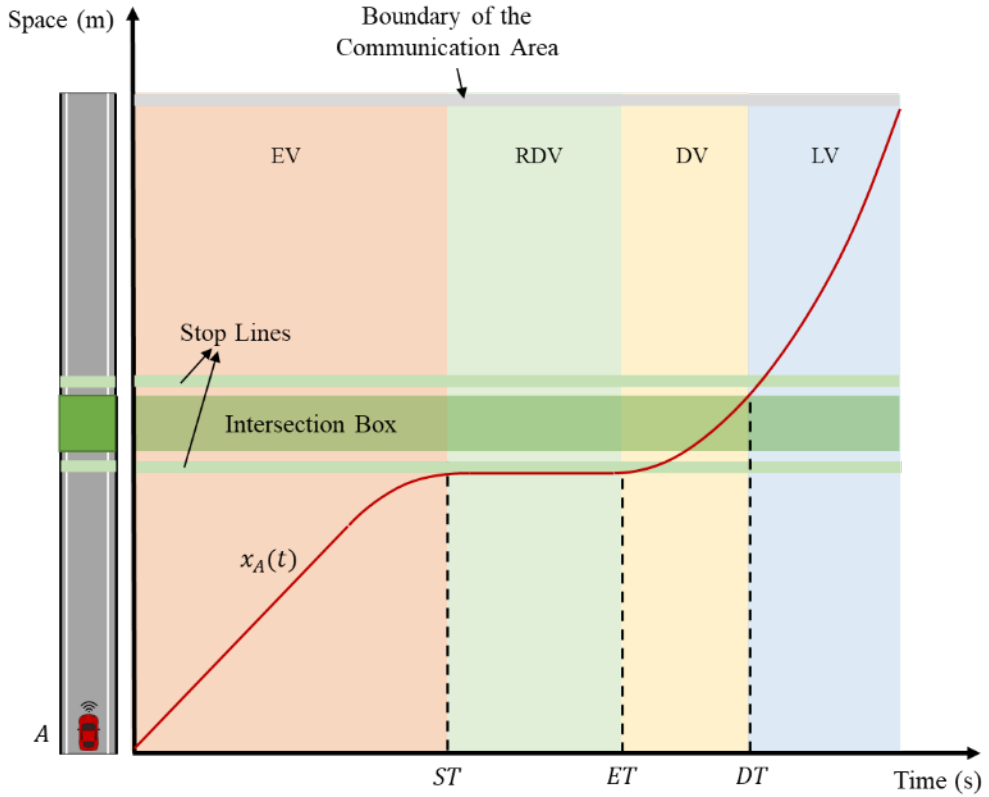
Source: FHWA



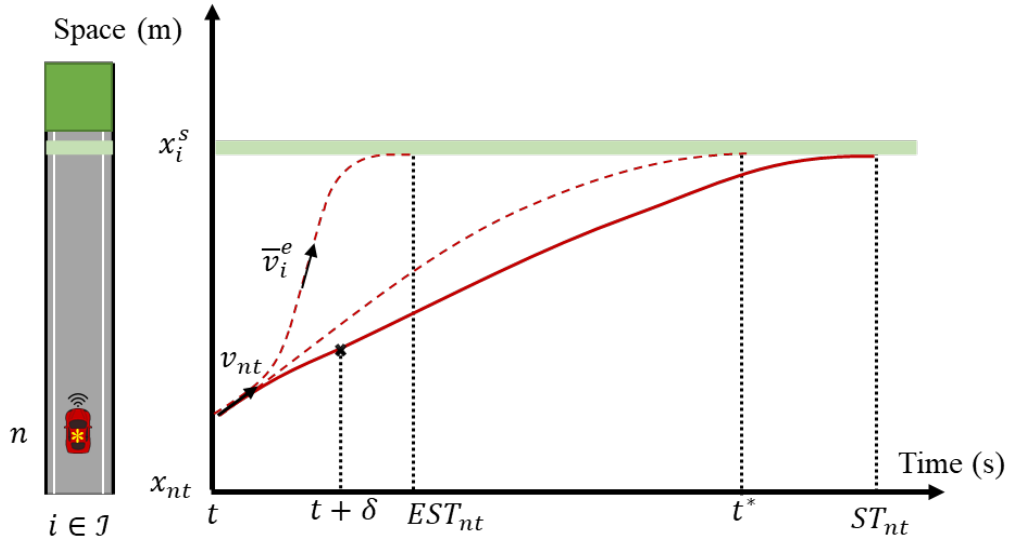
Source: FHWA

CARMA Streets

Improve Energy Efficiency Via Planning



Source: FHWA

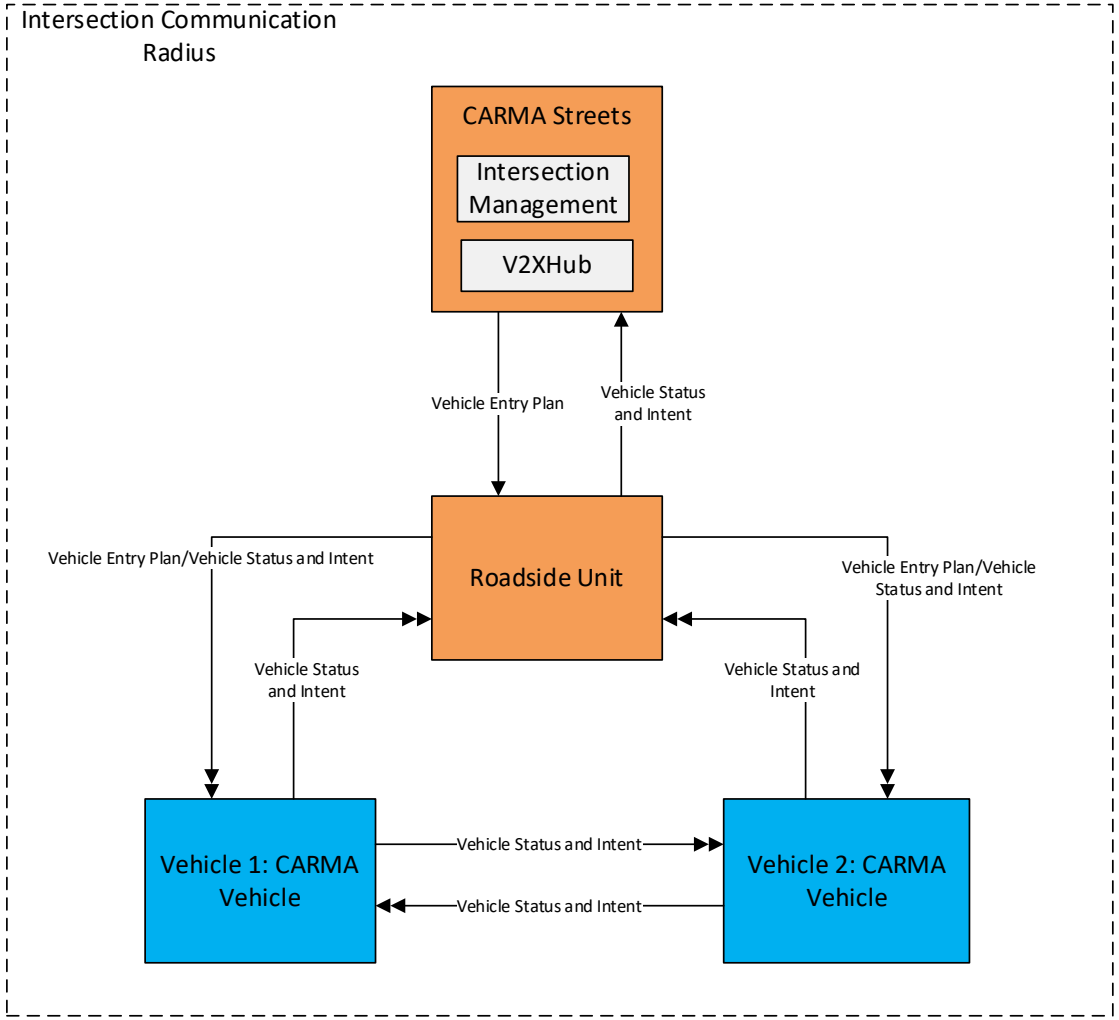


Source: FHWA

EST_{nt}: Earliest possible stopping time at the stop line
ST_{nt}: Desired stopping time at the stop line
<sigma>: time step (~*dt*)
x_i^s: stop line location

CARMA Streets

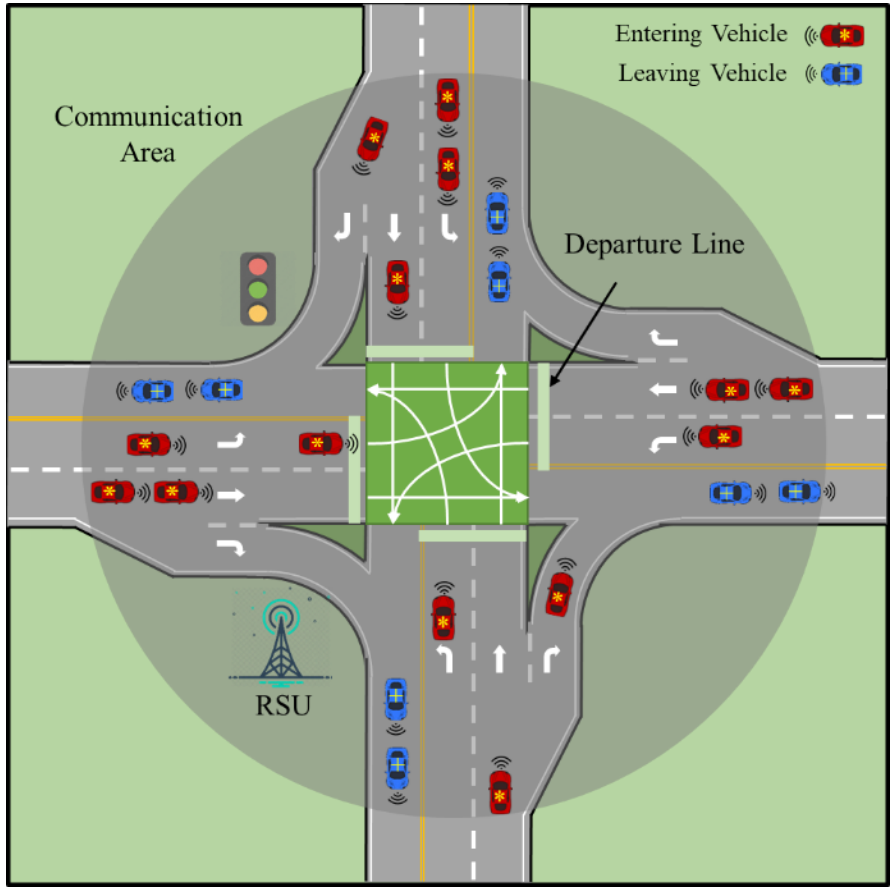
Bringing the Pieces Together



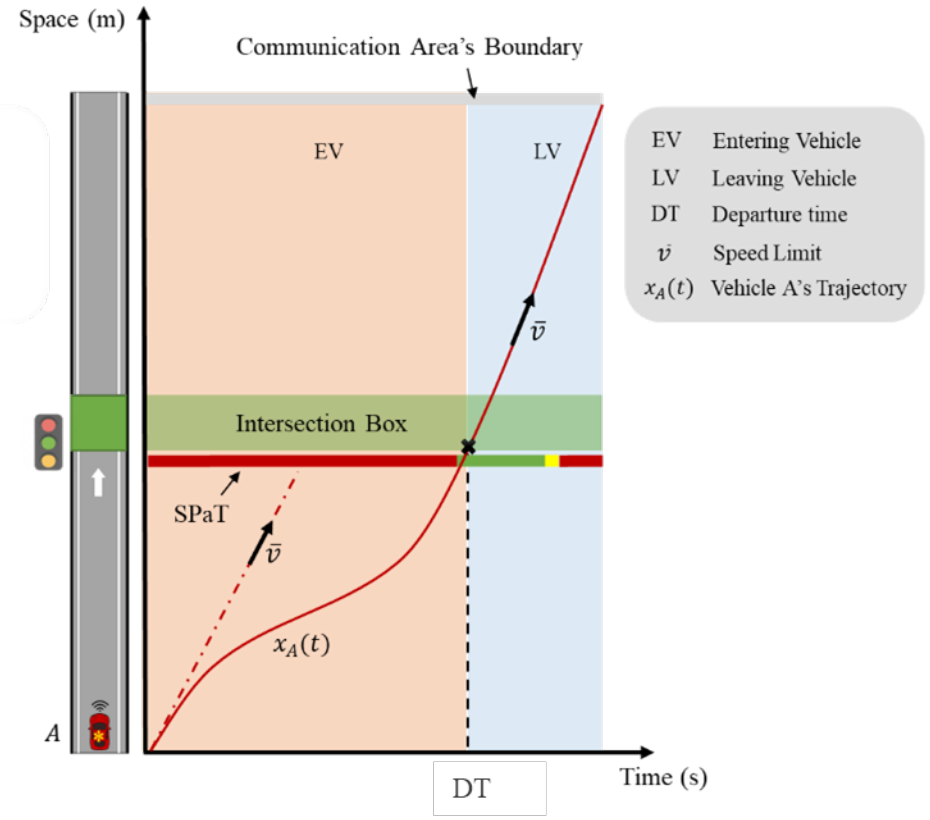
Source: FHWA.

CARMA Streets

Adding a Signal



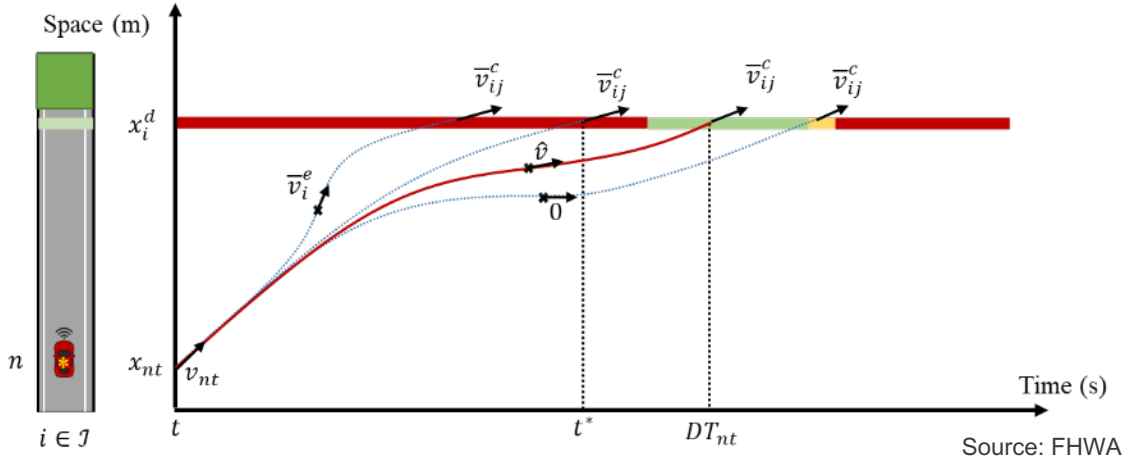
Source: FHWA



Source: FHWA

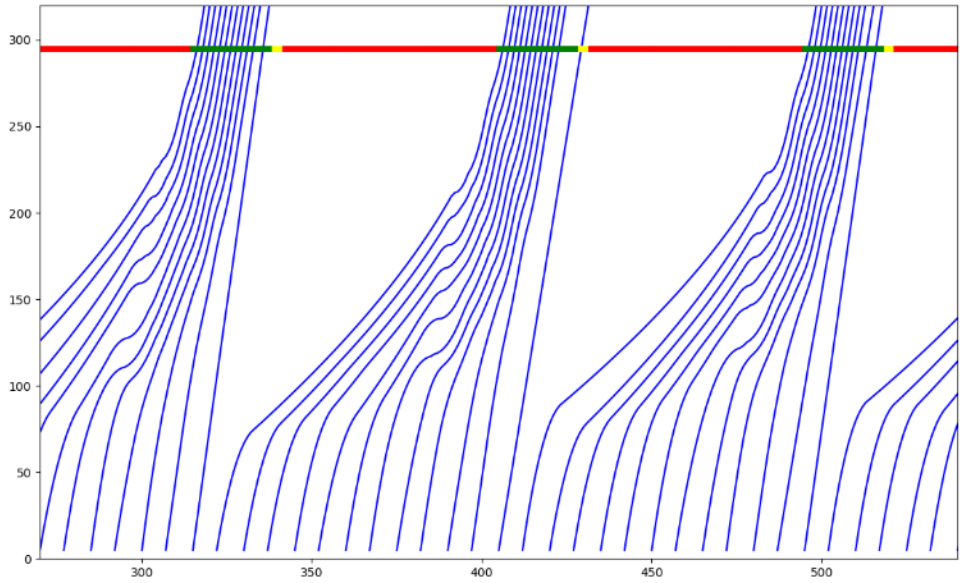
CARMA Streets

Improve Energy Efficiency



Source: FHWA

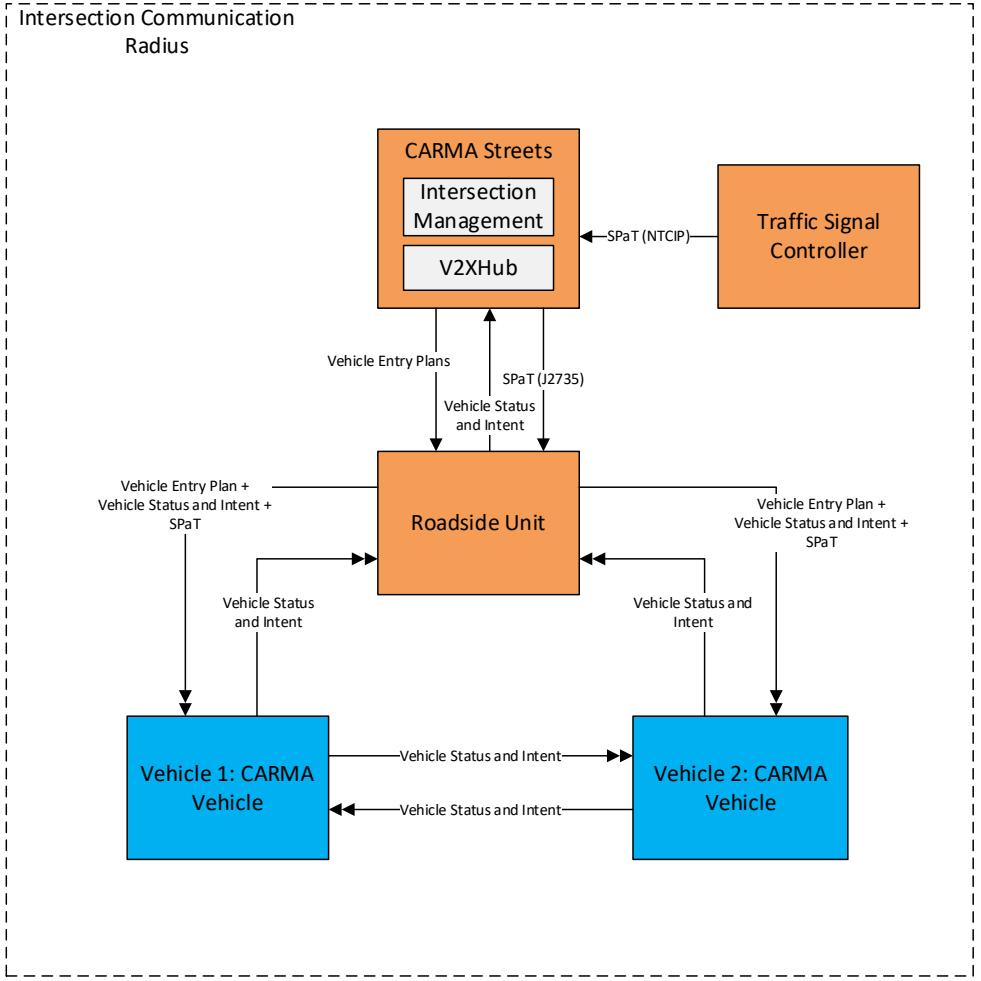
DT_{nt}: estimated or actual departure time from the departure line
t*: First moment in time that vehicle can depart the departure line with one period of deceleration
v_{ij}^{-c}: Velocity at the departure line
x_i^d: Departure line
x_{nt}: Vehicle's present location
v_{nt}: Vehicle's present speed
v-hat: Velocity joining acceleration and deceleration periods
v_i^{-e}: Maximum allowable velocity



Source: FHWA

CARMA Streets

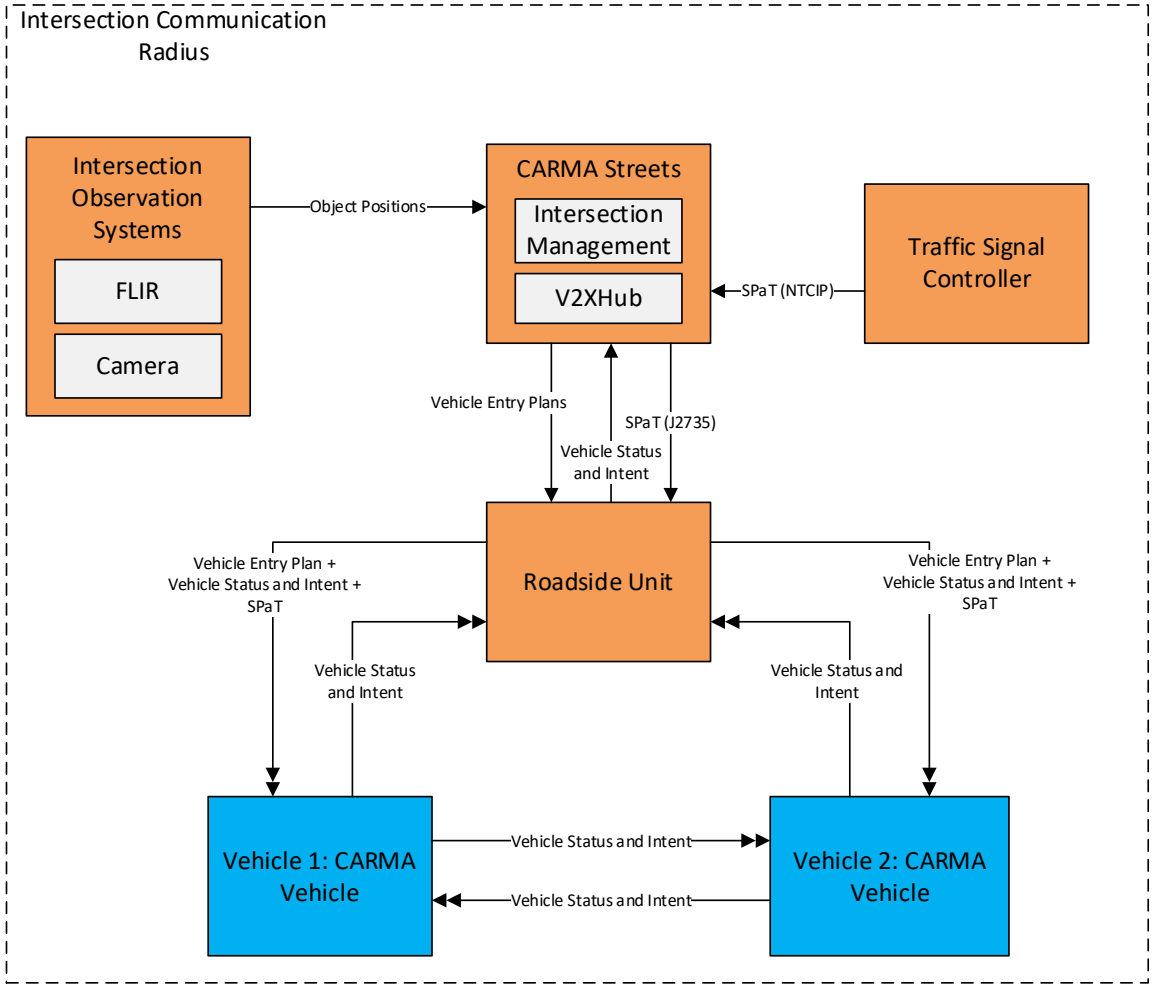
Adding a Piece to the Situation



Source: FHWA

CARMA Streets

Cooperative Perception



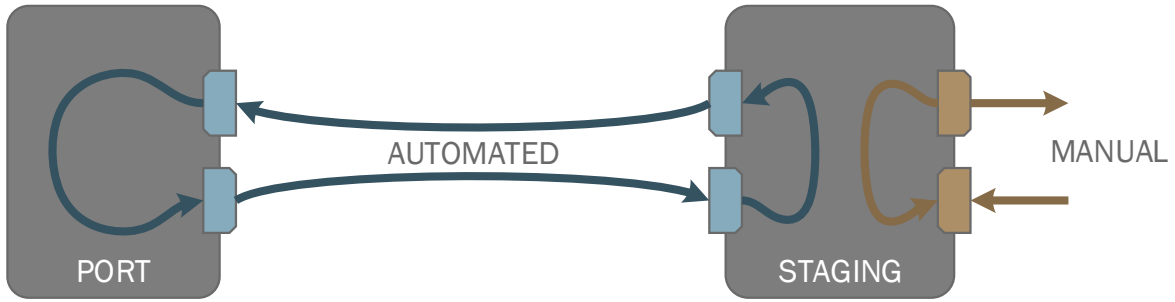
Source: FHWA.

CARMA Streets

Working with CARMA Freight

Objectives

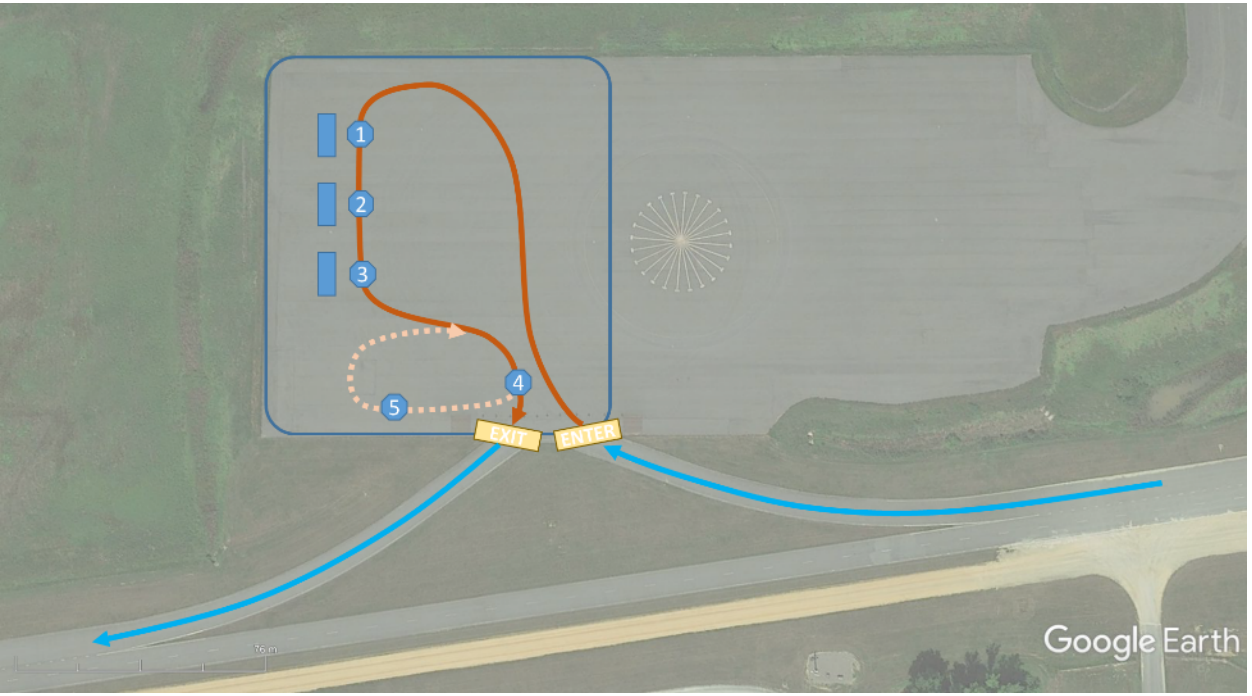
- Reduce idle driver time at port entrance.
- Increase safety and efficiency during loading and unloading operations.
- Reduce idle driver time at inspections.

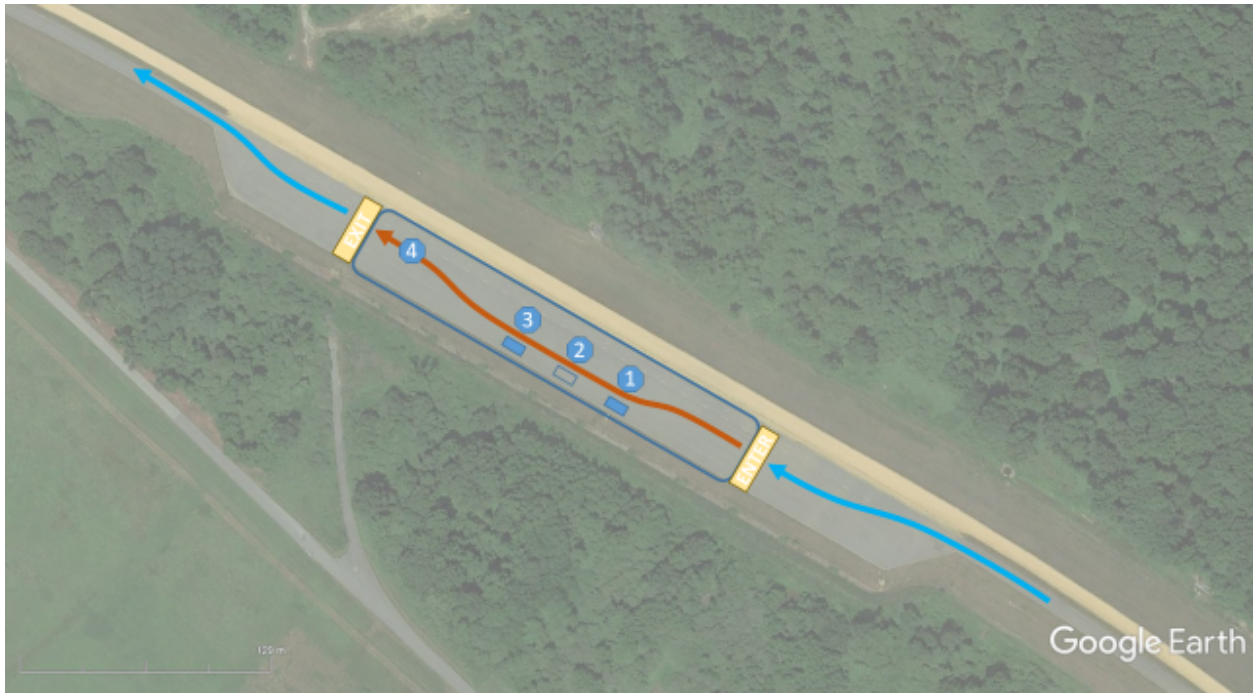


Source: FHWA

CARMA Streets

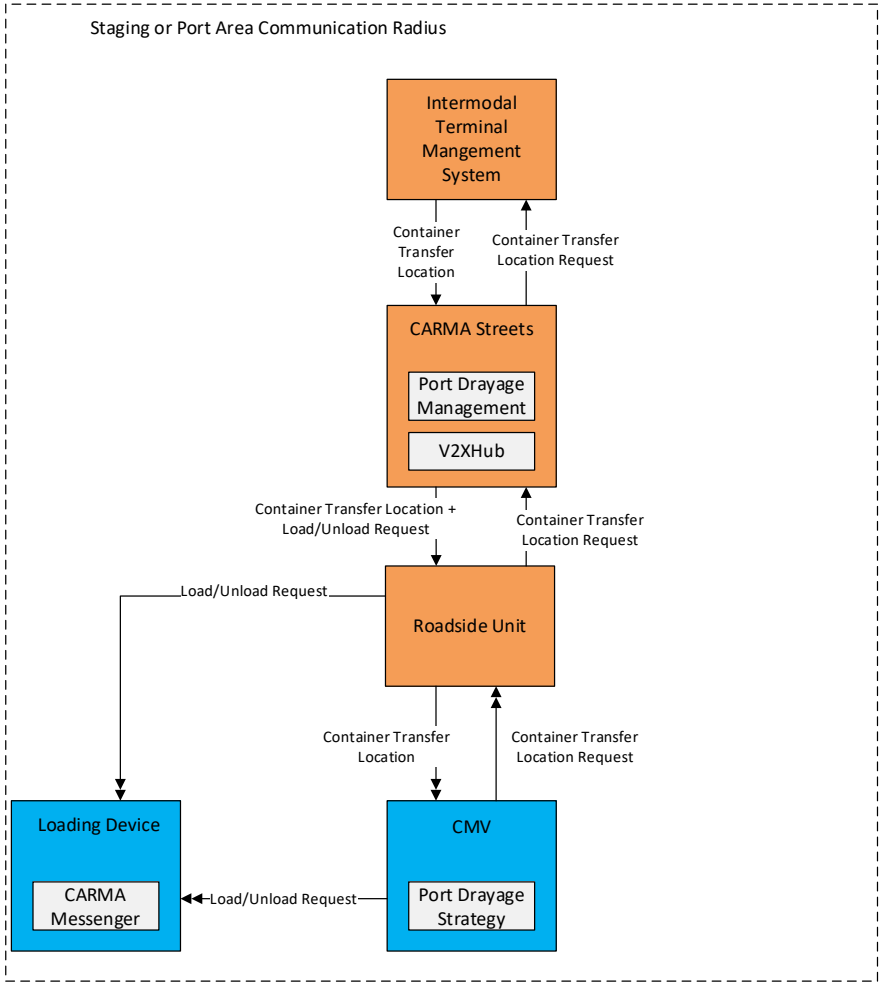
Port Drayage Demonstration Overview





CARMA Streets

Port Drayage System Context



Source: FHWA.

Upcoming Updates

Next in the CARMA Program

- How/when can researchers utilize CARMA Cloud and CARMA Streets in the future?
- CARMA 1Tenth vehicles.
- CARMA Port Drayage research.
- No-cost support from CARMA Support Services.

CARMA 1Tenth

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

- Scaled-down 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.

Multimodal Automated Port Drayage Research

- Mobilization and build of the four trucks to install hardware and software to automate them to SAE C-ADS Level 3 Class A-D.
- Demonstrate a proof-of-concept application to support the port management use case using the fleet of four CARMA-equipped heavy vehicles.
- Conduct research into the emerging cybersecurity field, as pertaining to commercial motor vehicles, utilizing experience found in academia and other communities.

Source: FHWA.

Source: FHWA.

CARMA Collaborative and CARMA Support Services

CARMA COLLABORATIVE

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

CARMA SUPPORT SERVICES

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

Poll Questions

Questions and Answers

Acronyms

USDOT Partners:

- Federal Highway Administration (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)

Disclaimer

This presentation was created and is being copresented by both FHWA and a contractor. The views and opinions expressed in this presentation are the presenters' and do not necessarily reflect those of the Federal Highway Administration (FHWA) or the U.S. Department of Transportation (USDOT). The contents do not necessarily reflect the official policy of the USDOT.

Disclaimer

The U.S. Government does not endorse products or manufacturers. Trademarks or manufacturers' names appear in this presentation only because they are considered essential to the objective of the presentation. They are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

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

CARMA℠

Contact us!

Taylor W.P. Lochrane, Ph.D., P.E.
CARMA Program Manager
FHWA Office of Operations R&D

Email
Taylor.Lochrane@dot.gov

Email
CARMA@dot.gov

U.S. Department of Transportation
Federal Highway Administration