Driving Innovation

Transforming the Transportation Industry
with Cooperative Automation Research Mobility Applications (CARMA)

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U.S. Department of Transportation
Federal Highway Administration

December 18, 2018

Agenda

CARMA Webinar

- Introduction – Laura Dailey
- CARMA overview – Taylor Lochrane
- How to use CARMA – John Stark
- Questions and Answers – Taylor and John
- Closing – Laura Dailey

COOPERATIVE AUTOMATION
Research Program

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

RESEARCH FOCUSED ON ARTERIALS AND FREEWAYS

Source: FHWA.

Reduce fuel consumption at intersections by 20 percent.

Source: FHWA.

Fuel savings of 10 percent.

Source: FHWA.

Double capacity of existing lanes.

U.S. Department of Transportation
Federal Highway Administration

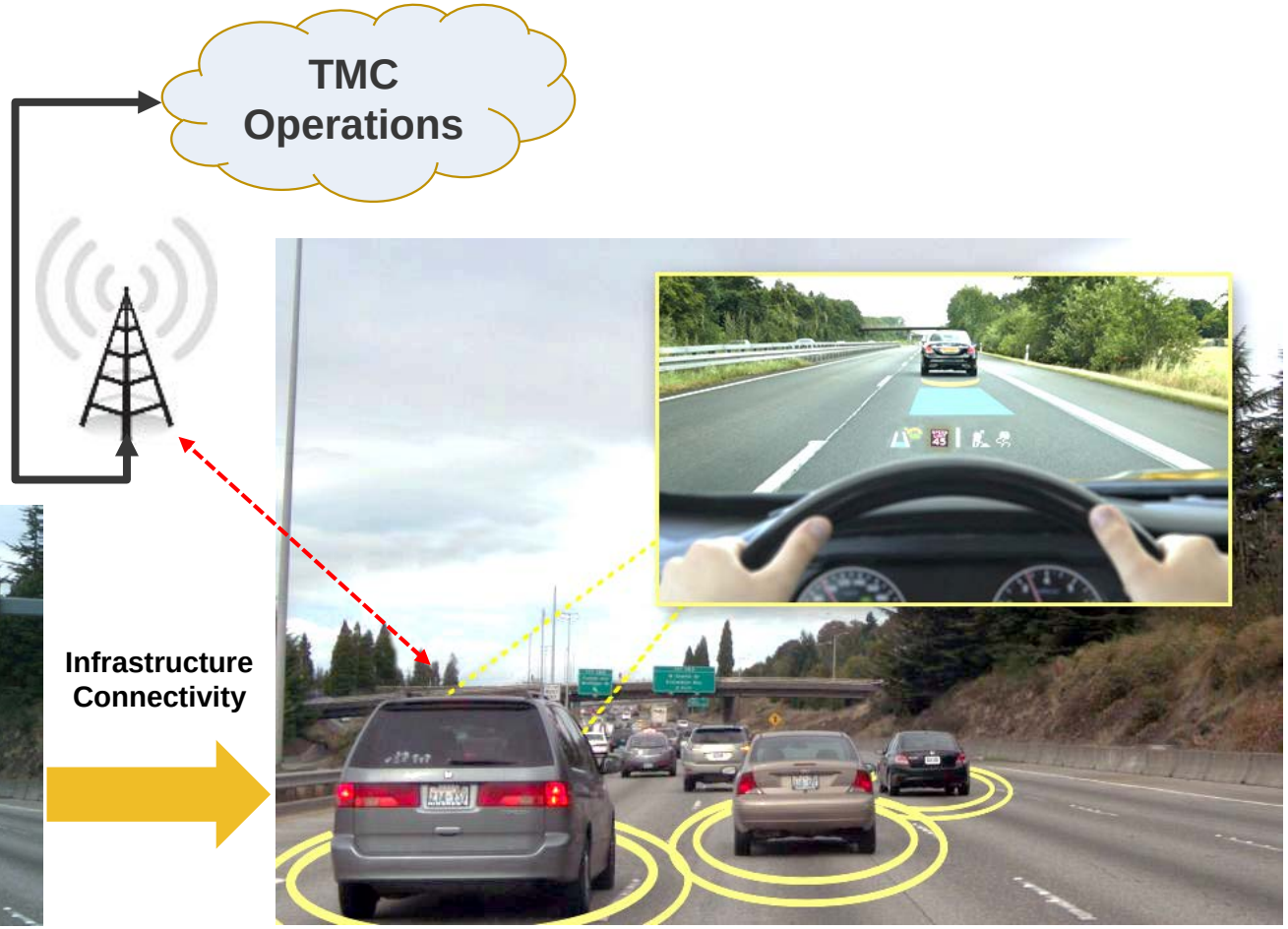
Connectivity

Important for Managing Our Transportation System

- Introduction to Cooperative Automated Driving Systems (CADS).
- New use cases for Transportation Systems Management and Operations (TSMO).

Source: FHWA.

Today – Expensive Infrastructure



Source: FHWA.

Tomorrow – Connectivity

TMC: Traffic Management Center.

TSMO OVERVIEW

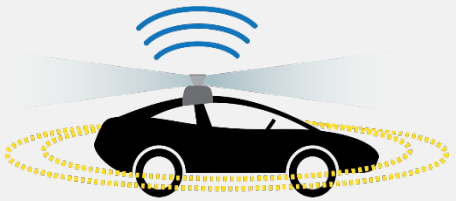
Transportation Systems Management and Operations (TSMO)

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.
- Automated vehicle (AV) deployment.

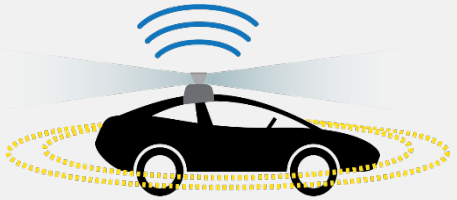
EVOLUTION

Cooperative Automation Research Mobility Applications (CARMA)



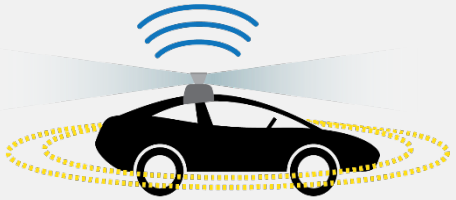
CARMA1 (2014–2016)

- Initial proof of concept.
- Collection of individual applications.
- Simulink/dSpace running on MicroAutobox.
- Demonstrated 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 automation (speed control) and level 2 capable.
- Built on top of Robot Operating System (ROS).
- Flexible – can be installed on several types/modes of vehicles.
- Accepts third-party plug-ins for research applications (guidance algorithms).
- Includes simple applications:
  - Cruising with adaptive cruise control (ACC).
  - Cooperative lane change.
  - Mixed platoons.
  - Signalized intersections.
  - Speed harmonization.



CARMA3 (2018–2020)

- SAE level 2 automation (speed and steering control) and level 3 capable.
- More sophisticated vocabulary of cooperation, vehicle-to-vehicle (V2V).
- Enhanced lane change and merge/weave.
- Enhanced platooning (cars and trucks).
- Emphasis on infrastructure interactions for TSMO.
  - Work zones, traffic incident management, weather events, etc.
- Emergency vehicle applications and interactions.

CARMA 1

COOPERATIVE ADAPTIVE CRUISE CONTROL (CACC)

Objectives:

- Develop automated vehicle testing capability.
- Algorithm Development.
  - Proof of concept cooperative adaptive cruise control (CACC) vehicle platooning.
- Demonstrate CACC enabled on five SAE level 1 AVs.

Source: FHWA.

Source: FHWA.

INTEGRATED HIGHWAY PROTOTYPE (IHP)

Coordination with Virginia Department of Transportation (VDOT) and Transurban on I–95.

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
Plug-ins

24
Days at Aberdeen Test Center (ATC)

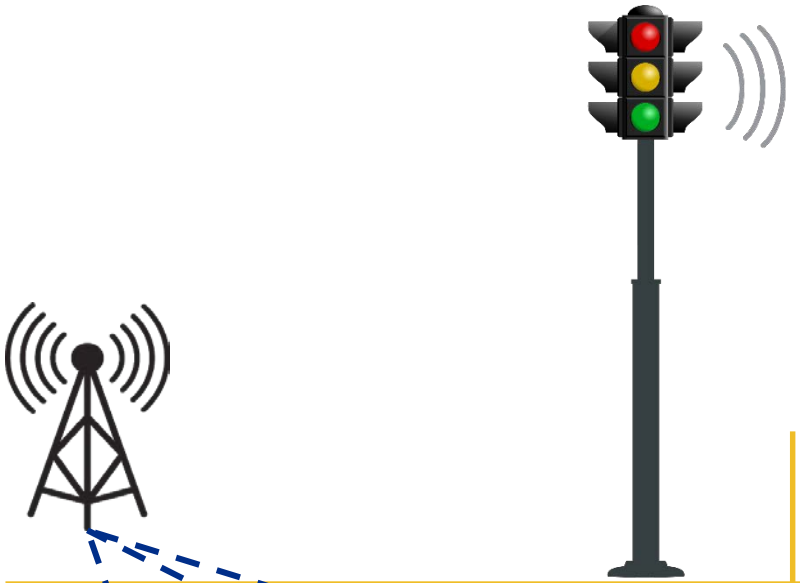
22,000
Miles of closed track testing

42,000
Lines of code

Cooperative Automation Research

ALGORITHMS OVERVIEW

- Speed harmonization *(cloud-commanded speed control).*
- Vehicle platooning *(leader – follower).*
- Cooperative lane change *(V2V Negotiation).*
- Cooperative ramp merge *(V2I Negotiation).*
- Approach and departure *(multisignalized intersection).*



Source: FHWA.

Source: FHWA.

Source: FHWA.

Tested at ATC from November 2017 to May 2018 for a total of 24 days.

Cooperative Automation Research Mobility Applications

SOFTWARE ARCHITECTURE

CARMA FACTS

5
Plug-ins

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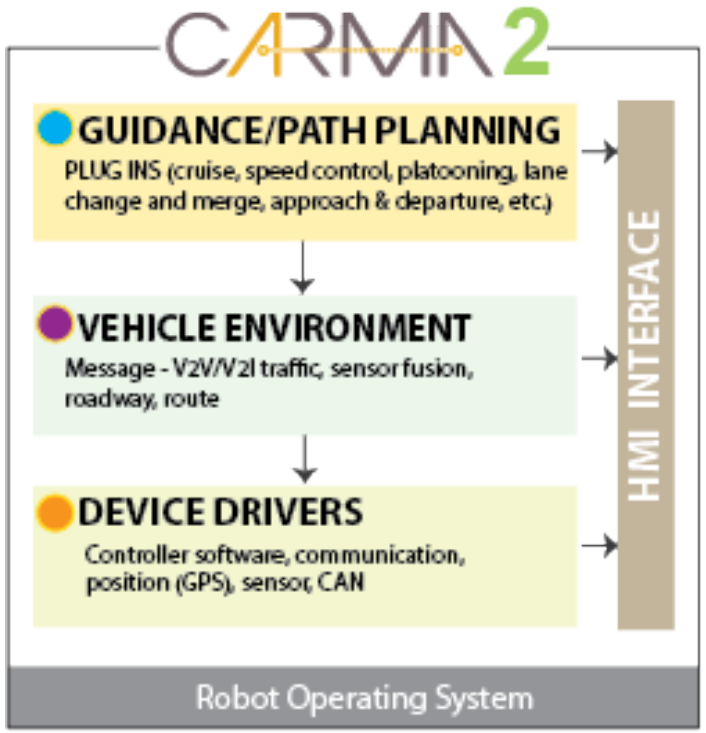
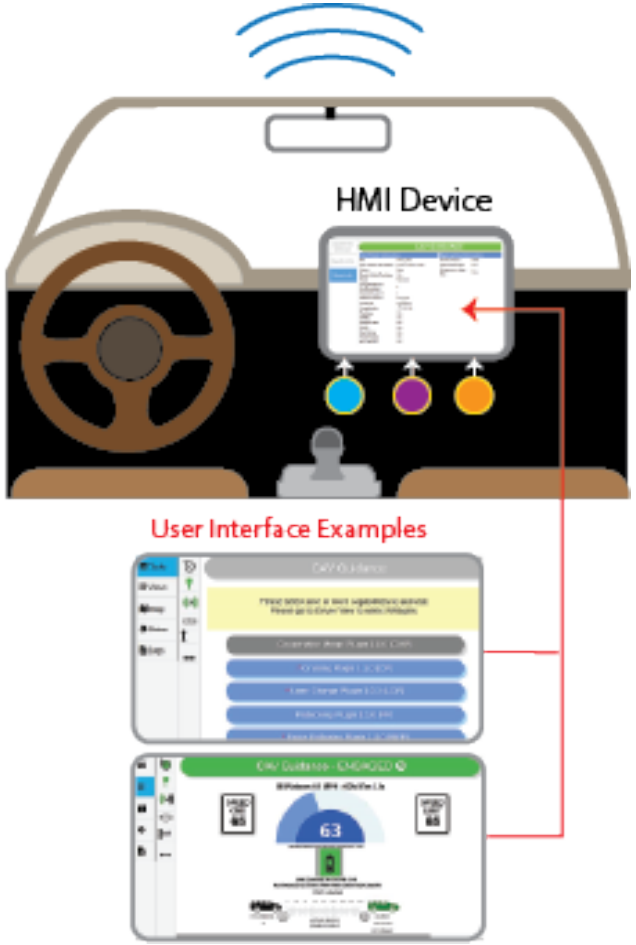
Days at Aberdeen Test Center (ATC)

22,000
Miles of closed track testing

42,000
Lines of code





Source: FHWA.

V2V: Vehicle-to-Vehicle.
V2I: Vehicle-to-Infrastructure.

CAN: Controller Area Network.
GPS: Global Positioning System.

HMI: Human Machine Interface.

A platform that was developed as open-source software (OSS) to engage with industry on cooperative automation.

CARMA 3 USDOT Multimodal Partnership

U.S. Department of Transportation

Federal Highway Administration
Office of Operations
Office of Operations R&D
Office of Safety R&D

Federal Motor Carrier Safety Administration (FMCSA)
Technology Division
Research Division

Intelligent Transportation Systems Joint Program Office (ITSJPO)
Vehicle Safety and Automation Data Program

Volpe National Transportation Systems Center
Advanced Vehicle Technology Division

Source: FHWA.

VOLPE ITS-JPO FMCSA FHWA

CARMA 3 APPROACH

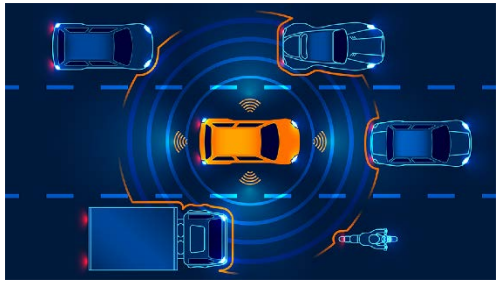
Advancing CADS research with FHWA and FMCSA fleet and partnerships

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 Manufacturers (OEM) community.

Autoware PLATFORM



© 2018 Getty Images.

- Leverage Autoware OSS development.
- Enable automated driving systems (ADS) Level 2–3 capabilities.
- Engage ADS community.

COOPERATIVE ⟷ **AUTOMATION**

CARMA Platform SOFTWARE ARCHITECTURE

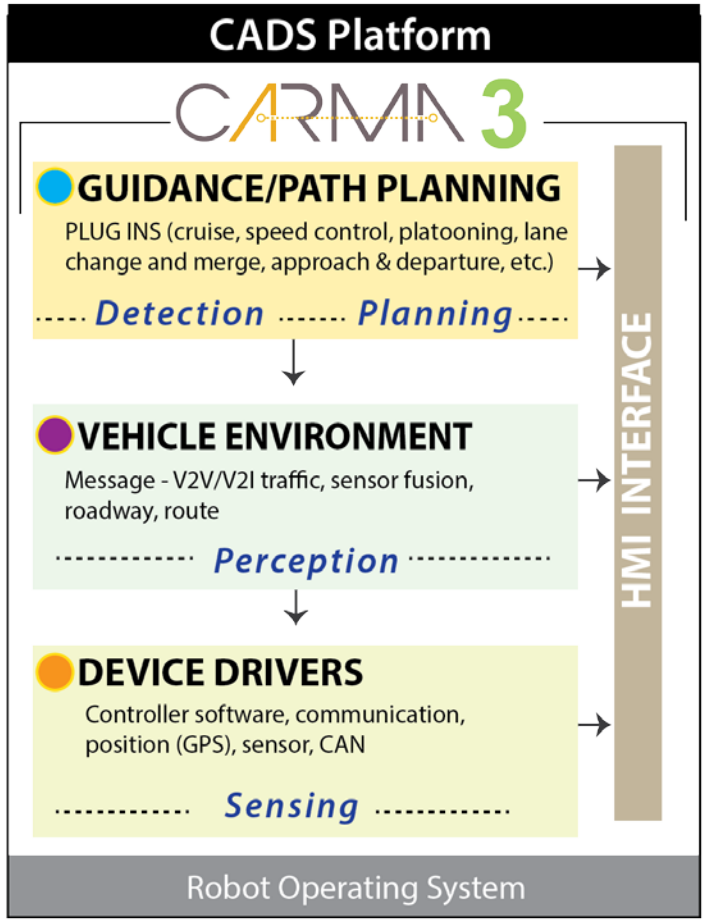
CARMA FACTS

3
Week sprint cycles

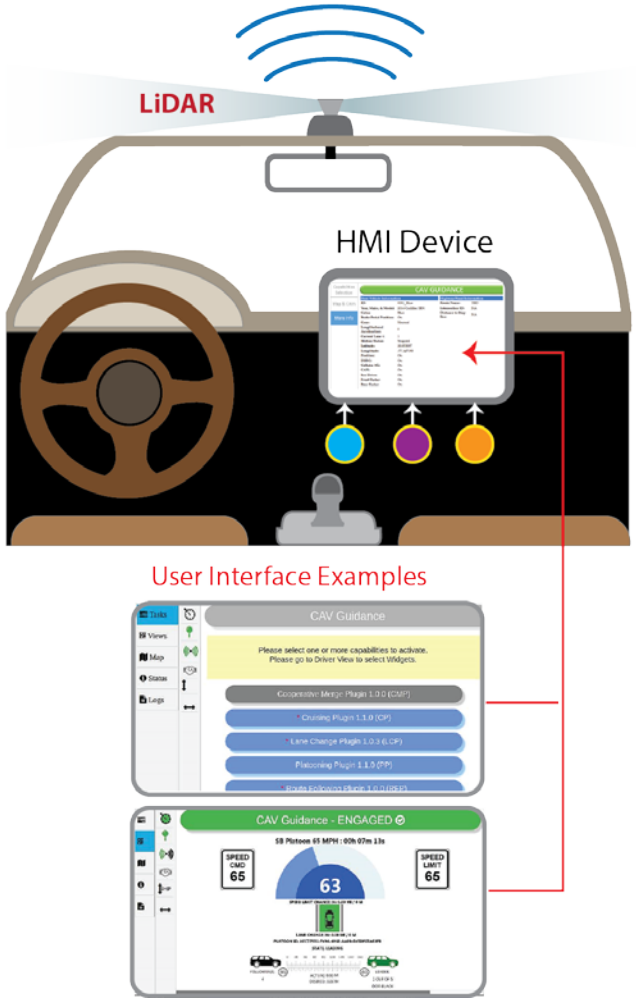
6
Quarterly webinars

7
ADS-equipped vehicles

Unlimited
Partnerships



Source: FHWA.

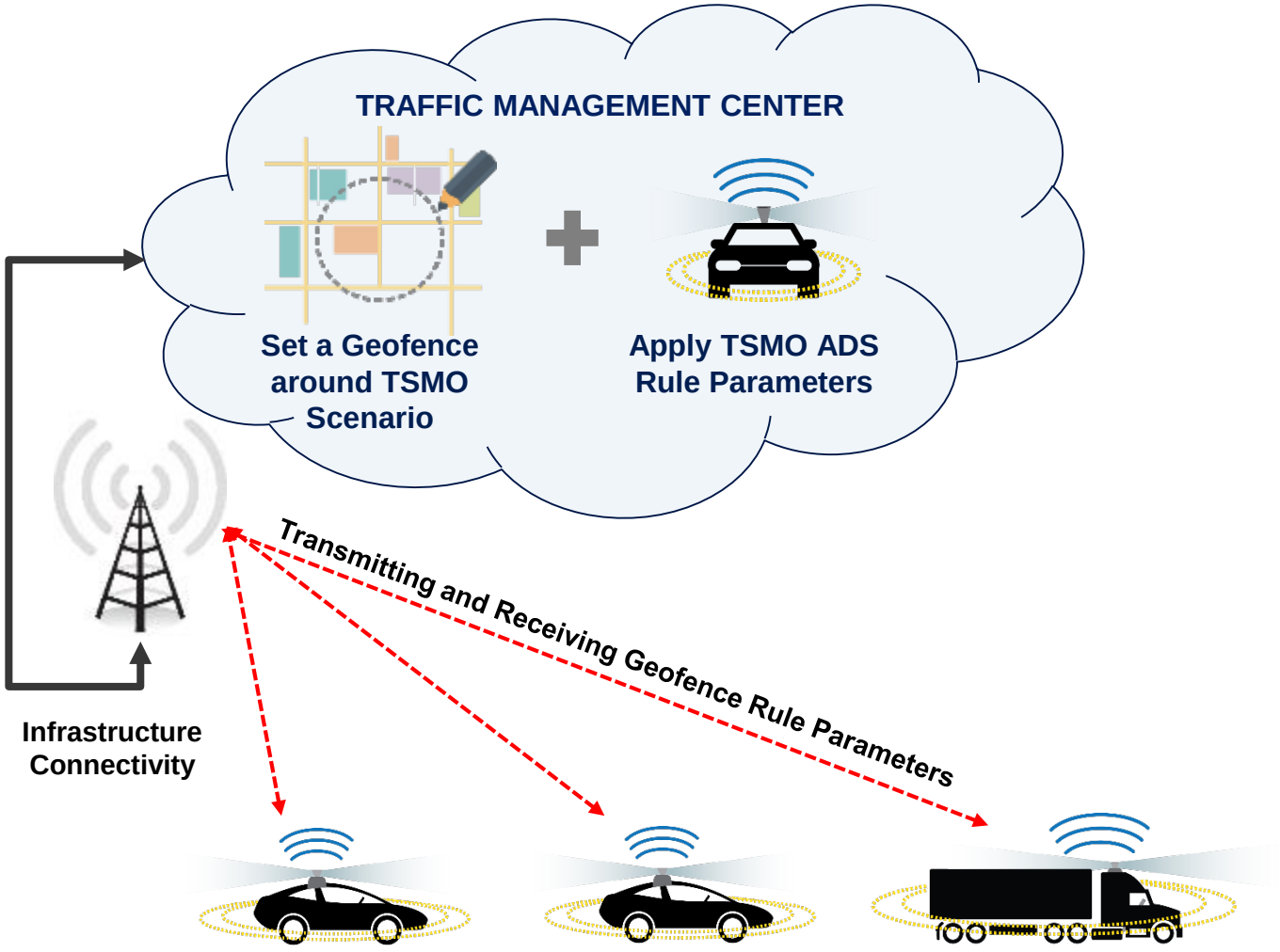


V2V: Vehicle-to-Vehicle.
V2I: Vehicle-to-Infrastructure.
LiDAR: Laser Imaging, Detection, and Ranging.
GPS: Global Positioning System.
CAN: Controller Area Network.
CADS: Cooperative Automation Driving Systems.
HMI: Human Machine Interface.

A platform developed in the open using agile software development process to collaborate with stakeholder community.

CARMA Cloud

CONCEPT FOR TSMO NETWORK MANAGEMENT



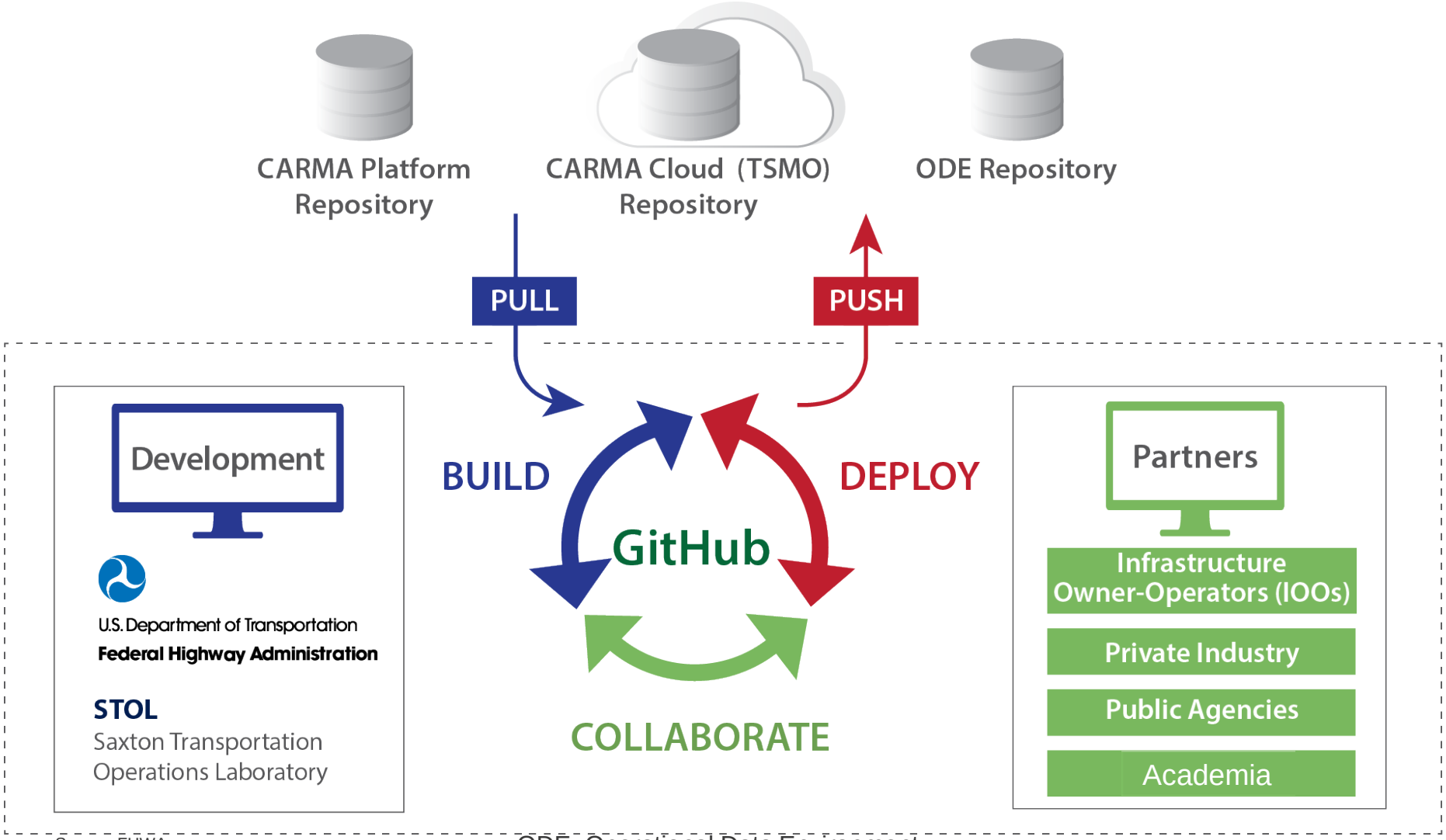
Source: FHWA.

Use of the rule parameters applied in a geofenced area to support TSMO use cases that include but are not limited to:

- **Desired speed:** the ability to send speed limits and/or reductions in speed (e.g., 55 mph).
- **Desired follow gap:** single vehicle gap control measured in seconds (e.g., 1.0-second time gap).
- **Desired intraplatoon follow gap:** intraplatooning gap control measured in seconds (e.g., 0.8 second gap).
- **Platoon size limit:** Set platoon size (e.g., 2, 3, 5 cars).
- **Lane assignment:** Set which lane vehicle should occupy (e.g., lane 1 or 2).
- **Other variables to be defined**.

OPEN SOURCE Collaboration Vision

ADVANCE COOPERATIVE AUTOMATION RESEARCH



Source: FHWA.

ODE: Operational Data Environment.

Transportation Systems Management and Operations

ADS Capabilities TSMO Use Case Development

TIER 1

High level Concept of Operations and Use Cases of ADS for TSMO:

- TSMO strategies enhanced by ADS as well as new TSMO strategies enabled by ADS.

TIER 2

Concept of Operations and Requirements for ADS TSMO as well as Accessibility Use Cases and Scenarios:

- Top four use cases to include ADS with and without connectivity and cooperation.
- Top priority ADS concepts and development for accessibility use cases.

TIER 3

Detailed ADS Scenario Planning and Requirements for First Responders:

- First responder use cases interacting with ADS and the use of ADS for first responders.

Cooperative Automation USE CASES

TSMO PROOF OF CONCEPT TESTING AND EVALUATION

1 Basic Travel

Source: FHWA.

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 CADS-equipped vehicles.

2 Work Zones

Source: FHWA.

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 thought the work zone.
- Possible maneuvers with other CADS-equipped vehicles.

3 Weather

Source: FHWA.

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 Traffic Incident Management (TIM)

Source: FHWA.

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.

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Develop a Taxonomy for Cooperative ADS:

- Develop a white paper defining the capabilities, taxonomy, and classification of cooperative automated driving technology:
  - Engage stakeholders (committees and task forces).
  - Develop a classification taxonomy to define levels of communication.
  - Create a classification matrix between different levels of ADS and communication to define different levels of cooperation capabilities.

- Update to SAE J3016TM to define CADS sufficiently and completely.

Website

United States Department of Transportation

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- Explore Research and Technology
- Operations R&D Overview
- Analysis Modeling and Simulation Project

Cooperative Automation Research Mobility Applications (CARMA) Overview

What Is CARMA?

The Federal Highway Administration (FHWA) developed the innovative Cooperative Automation Research Mobility Applications (CARMA) platform to encourage collaboration with the goal of improving transportation efficiency and safety. FHWA's interest in

Related Links

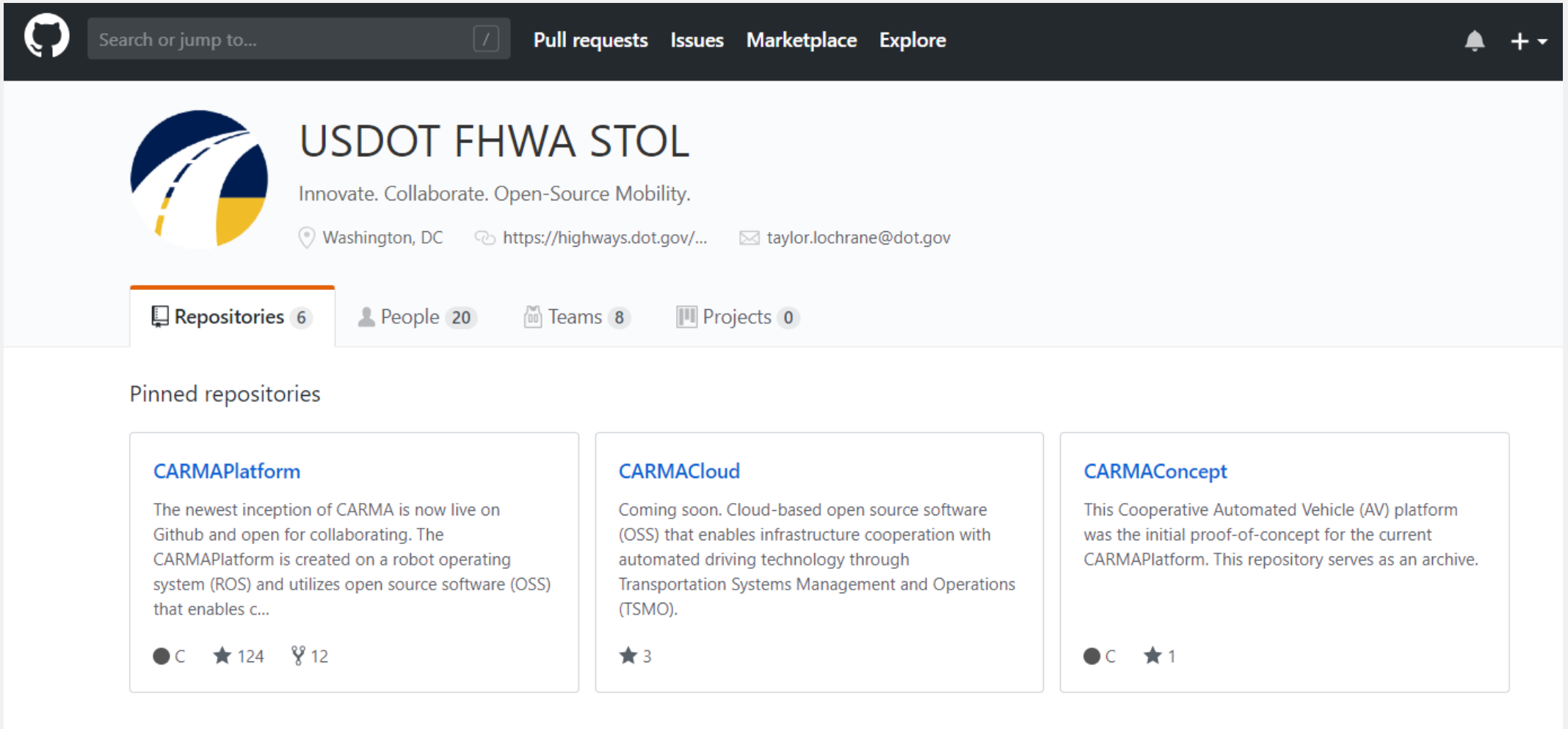
- CARMA Open Platform
- CARMA Collaboration
- U.S. Department of Transportation's Public Data Portal

Contact Us

Turner-Fairbank Highway Research Center
United States Department of Transportation
Federal Highway Administration
6300 Georgetown Pike
McLean, VA 22101
United States
TFHRC.webmaster@dot.gov

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

GitHub Repository



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https://github.com/usdot-fhwa-stol

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Discussion

GitHub Site – https://github.com/usdot-fhwa-stol

Confluence Site – https://usdot-carma.atlassian.net/wiki

Contact Us!

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Federal Highway Administration

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Source: USDOT Intelligent Transportation Systems Joint Program Office.

CARMA Platform

How to Use
Cooperative Automation Research Mobility Applications (CARMA)
Version 2.8

John Stark
Chief Software Engineer, Leidos
Saxton Transportation Operations Laboratory
Office of Operations Research and Development
Federal Highway Administration

U.S. Department of Transportation
Federal Highway Administration

December 18, 2018

REPOSITORY STRUCTURE

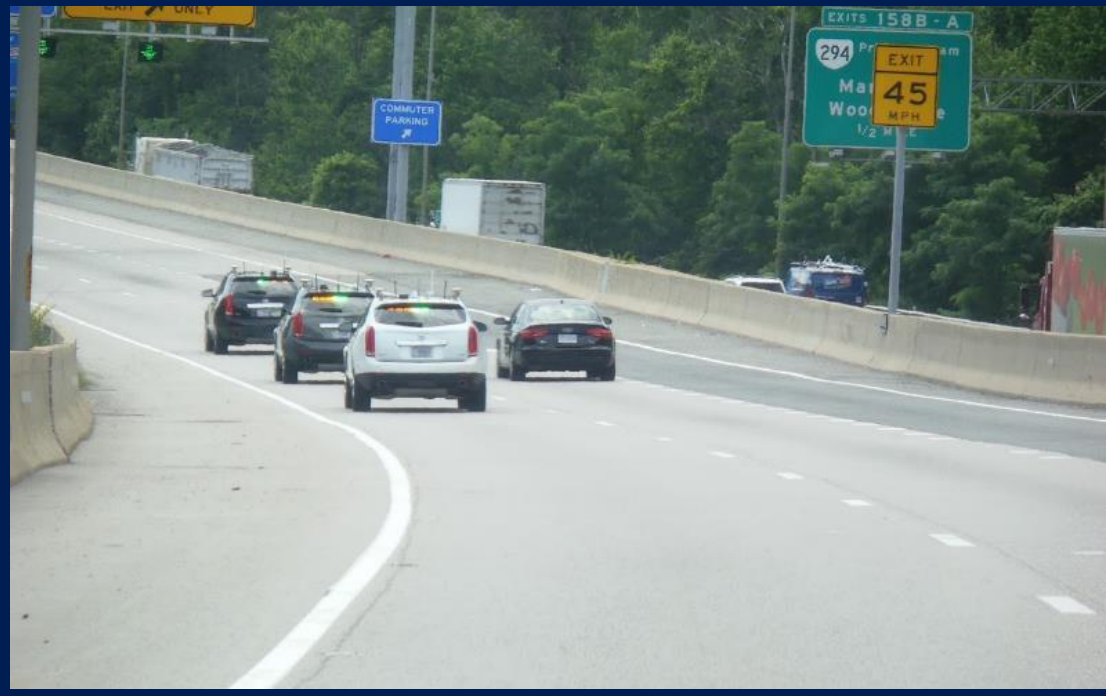
- Live walkthrough: https://github.com/usdot-fhwa-stol/CARMAPlatform.
- Some sensitive components in a private repository:
  - Controller Area Network (CAN) Drivers (Cadillac, Freightliner).
  - Stock radar driver (Cadillac).
  - Abstract Syntax Notation One (ASN.1) specification for J2735 messages.
- New structure for CARMA3, coming soon:
  - Each driver in its own repository.
  - Web application in its own repository.
  - Deployment via Docker images.

Design Philosophy Overview – Part 1

- Vehicle is always operated by a trained safety driver.
- Accommodate faults and continue operating whenever possible; otherwise return control to human operator (don't slam on brakes).
- Vehicle agnostic – driver layer uses a common application programming interface (API) so that higher-level components disregard hardware differences.
- Guidance API geared toward research on cooperative behavior.
  - Allows plug-ins to be added with a simple restart (no rebuild needed).

Design Philosophy Overview – Part 2

- Must be able to operate anywhere in the United States, including extended road trips.
- Automated longitudinal control only (Society of Automotive Engineers (SAE) Level 1), but uses fake lateral controller driver with human steering.
- To meet research needs, startup only on operator command (not at boot).
- While operating, automation can be either engaged or disengaged.
- Disengage automatically at end of route, but continue operating to be ready for next route.
- Built on Robot Operating System (ROS) for extensibility.



Source: FHWA.

Mobility Messages

- Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications based on SAE J2735 / 2016.
- Allow vehicles to pass info about future intentions and ongoing interactions.
- All messages are unencrypted.
- Path is defined by a sequence of latitude and longitude points.
- Targeted broadcast: open broadcast but with an intended recipient identified. Others can ignore.

Mobility Path:

- Announces host's intended path for next 6 seconds.
- Broadcast every 3 seconds.

Mobility Request:

- Requests cooperation from another vehicle.
- May include intended path.
- Targeted broadcast as needed.

Mobility Response:

- Acknowledgement (ACK) / negative acknowledgment (NACK).
- Targeted broadcast as needed.

Mobility Operation:

- Ongoing maintenance of cooperative relationship.
- Broadcast as needed.

Negotiation v. Swarming

- Full negotiation – initial approach:
  - Vehicle proposes a playbook for all others.
  - Neighbors accept, reject, and send counter-proposals.
  - Chatty conversations.

- Reverts to pseudoswarming in some cases:
  - Each vehicle states its intentions, then reacts to neighbors, like a human driver.
  - Driven by relative urgency.
  - Conversations are terse.
  - Latency is not a major factor.

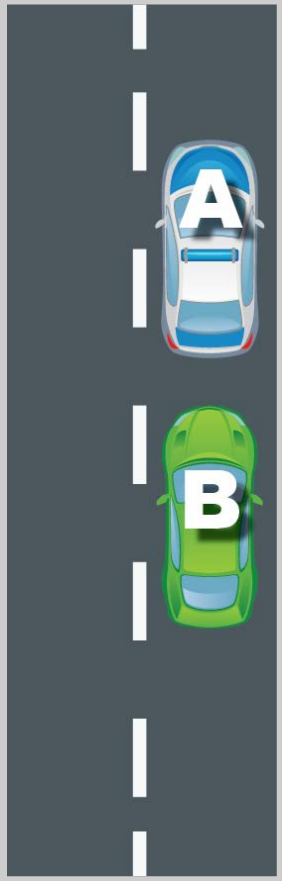
- Hybrid approaches need to be considered.
  - Swarming is powerful, but...
  - We can do better than emulate humans or ants.
  - Politeness – code of conduct.

Overarching constraint: nobody is in charge.

In some cases, infrastructure may be able to dictate guidelines.

Platooning with Mobility Messages

Vehicle Platooning



Source: FHWA.

- Goal is to increase roadway capacity.
- Leader actively manages the platoon with mobility operation (unlike cooperative adaptive cruise control (CACC)).
  - Admits members up to maximum size.
  - Communicates operating parameters (speed, headway, lane, and destination).
  - Decides lane change for entire platoon.
  - Behavior limited by least-capable member.
- Followers join one at a time with mobility request and response.
- Platoon may split; a second leader would emerge.
- Cannot use basic safety message (BSM) identifier.

Platooning with Mobility Messages

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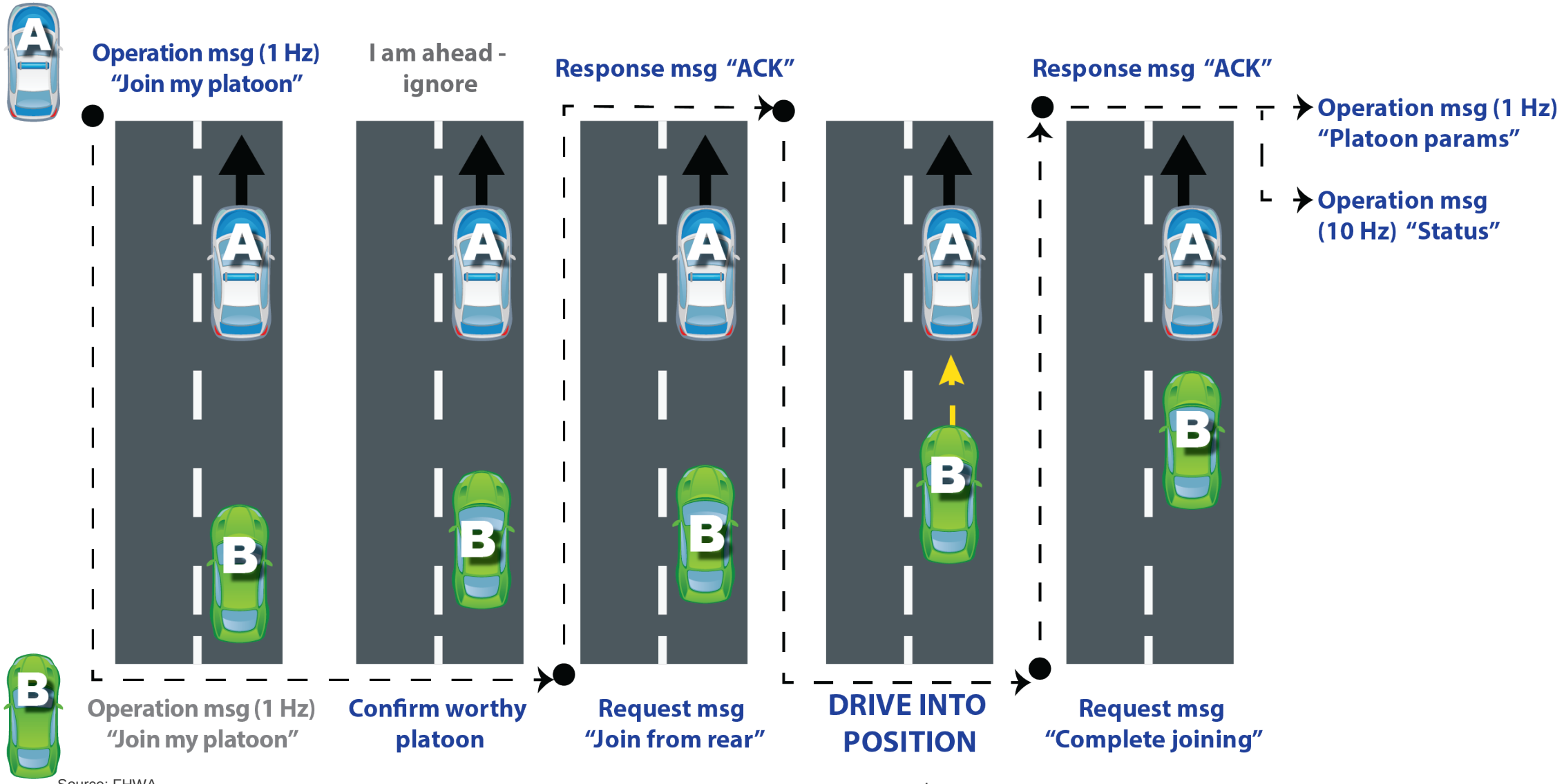


Source: FHWA.

msg: messages. params: parameters.

Lane Merge with Mobility Messages

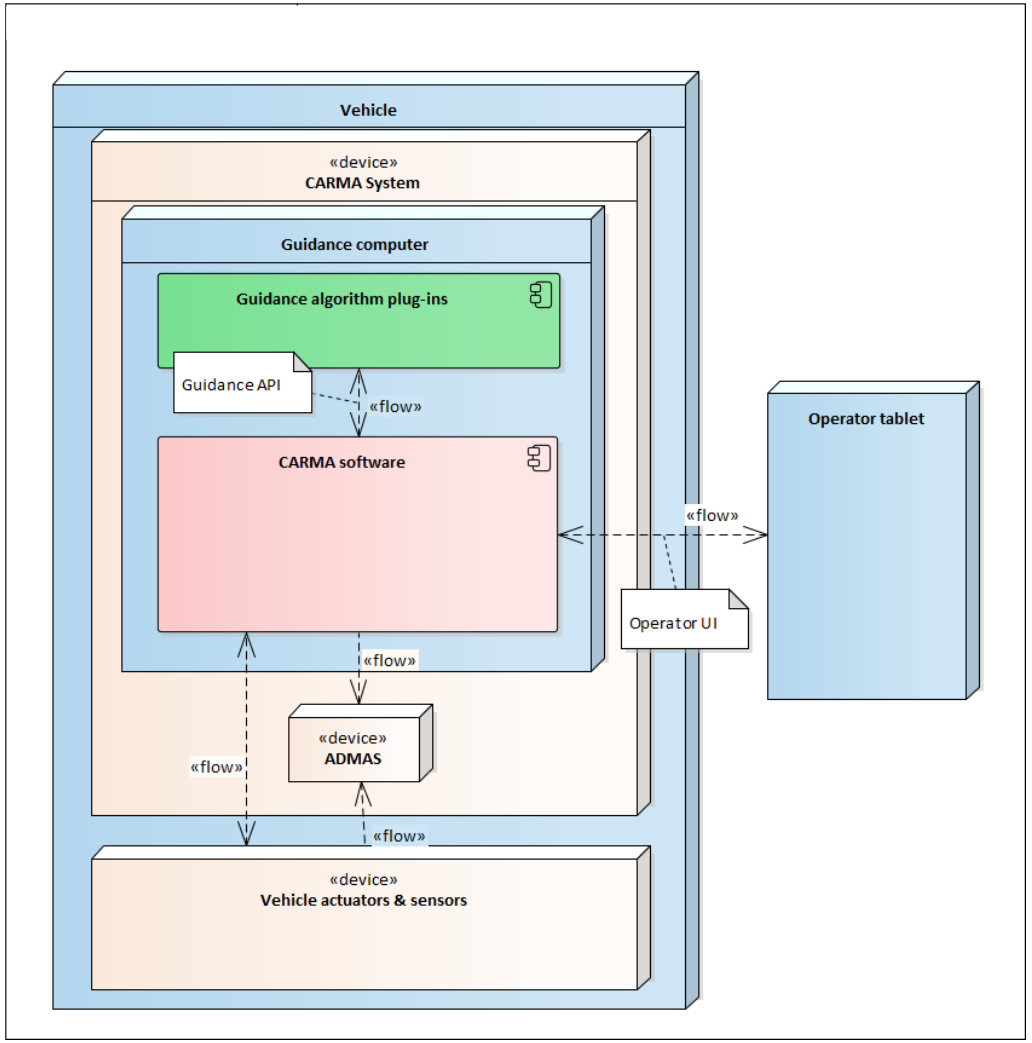
Lane Merge

Source: FHWA.

- Smooth traffic at bottlenecks.
- Relative urgency drives the situation.
- Merging vehicle (A) issues mobility request.
  - Contains intended path data.
- Trailing vehicle (B) attempts to yield, based on merge path.
  - Sends mobility response to ACK / NACK.

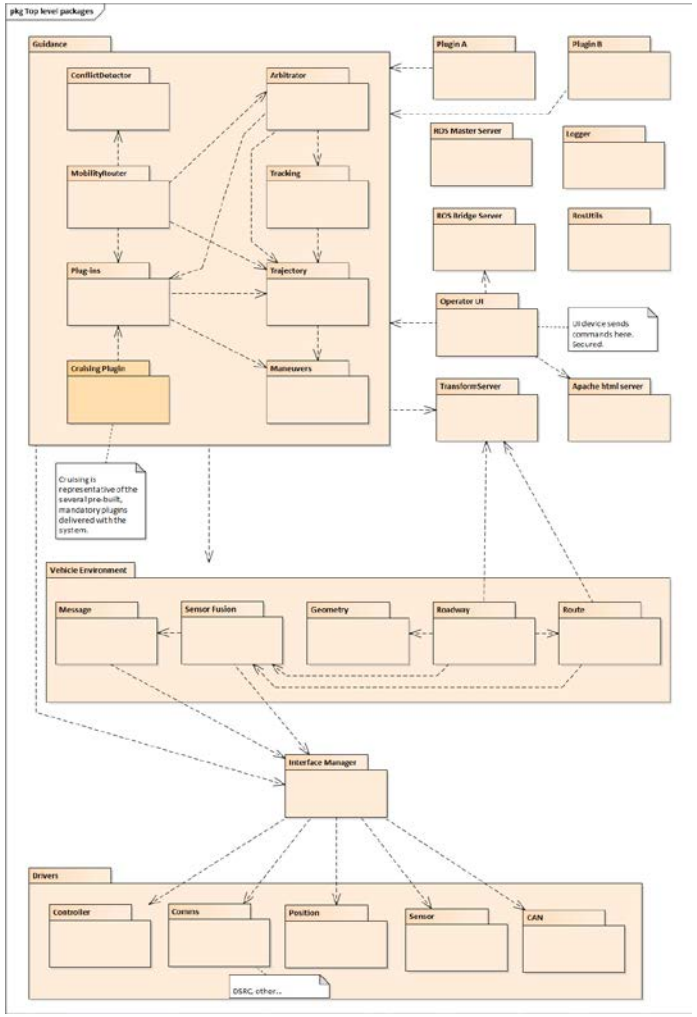
Deployment Overview

- Guidance plug-ins sit on top of the CARMA software, which provides:
  - Vehicle hardware abstraction.
  - Basic automation functions.
  - Communications functions.
- Plug-ins currently need to be written in Java:
  - Also considering making a C++ API.
- Operator tablet provides web graphical user interface (GUI) to control CARMA and receive status.



Source: FHWA. UI: User interface. ADMAS: Advanced Distributed Modular Acquisition System.

CARMA Software Structure Overview

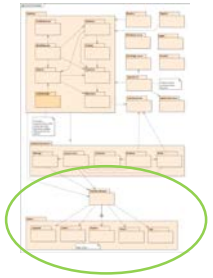


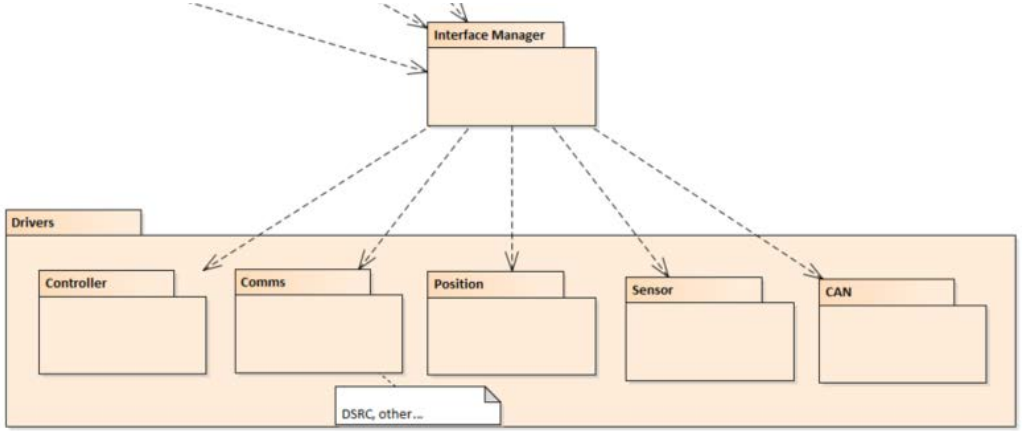
Source: FHWA.

- Uses ROS Kinetic and ROSJava.
- Ubuntu 16.04.
- Most nodes are Java, some are C++.
    - We are open to a gradual migration to C++.
- Layered architecture:
    - Drivers.
    - Environment.
    - Guidance and UI.

Software Structure

DRIVER LAYER



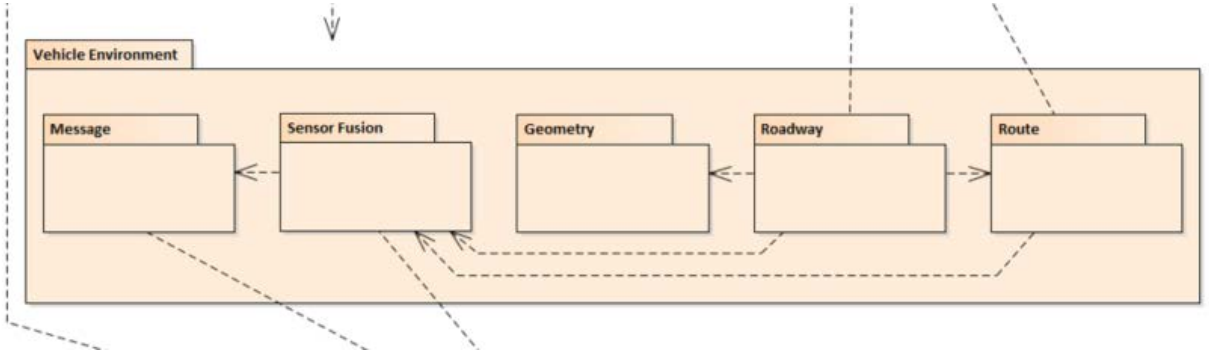


Source: FHWA.

- Controller drivers – send commands to actuators; read hardware status.
- Communications drivers – read incoming radio messages; send outgoing radio messages (V2V, V2I onboard unit (OBU)).
- Position drivers – read vehicle global positioning data (latitude/longitude/elevation and uncertainties).
- Sensor drivers – read data from external sensors (e.g. radio detection and ranging (RADAR), light detection and ranging (LIDAR), video).
- CAN drivers – read-only data from vehicle CAN bus (e.g. wheel speeds, steering wheel angle).
- Each driver is a separate ROS node, as is the Interface Manager.
- Interface Manager provides automatic driver discovery and cataloging, then brokers use of appropriate drivers by higher-level components requesting specific capabilities.
- Interface Manager monitors driver health and initiates system alerts if problems arise (e.g. not always shutdown).

Software Structure

ENVIRONMENT LAYER

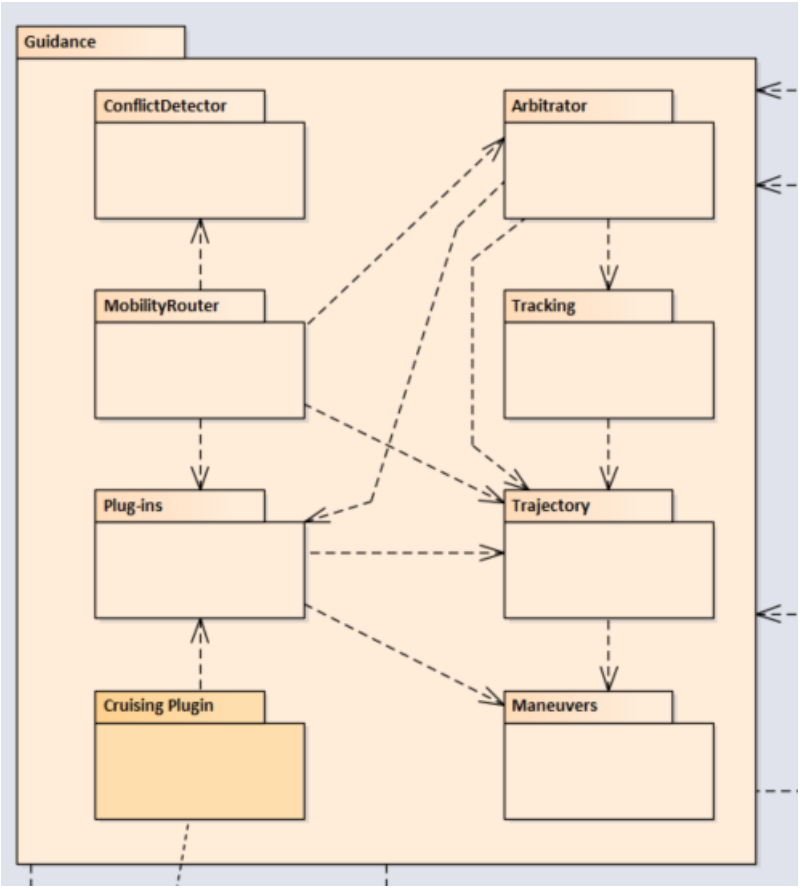


Source: FHWA.

- Each package, except Geometry, is an ROS node.
- Message – composes and decomposes binary messages to/from the comms driver – uses SAE J2735/2016.
- Sensor Fusion – determines locations of neighbor vehicles (radar + dedicated short range communication (DSRC) BSM reports).
- Geometry – math library for Earth-based location calculations and neighbor-relative positions.
- Roadway – builds representation of road surface (lanes, required lane, vehicle position relative to road surface and neighbor vehicles).
- Route – represents the desired route as a simple list of waypoints on road centerline.

Software Structure

Guidance Layer



Source: FHWA.

- Entire outer guidance package is a single ROS node.
- Conflict Detector – compares host intended path to intended paths of neighbor CARMA vehicles or nonconnected vehicles (NCVs).
- Mobility Router – routes incoming mobility messages to the appropriate guidance component.
- Plug-ins (including several preinstalled) – contribute to trajectory definition in applicable situations.
- Arbitrator – determines plug-in priorities and orchestrates all available plug-ins to define a complete trajectory.
- Tracking – monitors vehicle's performance against planned trajectory.
- Trajectory – a collection of maneuvers that describe near-future motion plans (typically a few 100 m).
- Maneuvers – simple, automatic vehicle movements.

Contributing to CARMA
Code Base

- See the GitHub ReadMe file:
  - Architecture documentation.
  - Detailed design documents.
  - Contributing instructions – filing an issue, submitting a suggested change.
  - Administrator guide – how to build and install.
  - Users guide – how to operate.
  - CARMA License (Apache 2.0) – use or modify in accordance with these rules.
- Third-party plug-ins may be included in the core repository if they provide general stakeholder value, or they can live in a separate repository.

GitHub Site – https://github.com/usdot-fhwa-stol

Confluence Site – https://usdot-carma.atlassian.net/wiki

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Running CARMA

In a Developer Environment

Video of interactions:

- Pull from GitHub.
- Run Cmake.
- Configure for mock drivers.
- Execute.
- Study logs.

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U.S. Department of Transportation
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Next webinar topic: Plug-in API and building a sample plug-in.

Source: USDOT Intelligent Transportation Systems Joint Program Office.