U.S. Department of Transportation
Federal Highway Administration

Office of Safety and Operations
Research and Development

Saxton Transportation Operations Laboratory Research Tools to Enhance Connected and Automated Vehicle (CAV) Capabilities

The U.S. Department of Transportation (USDOT) provides infrastructure-focused tools that offer numerous advantages to transportation systems and their users. These tools help optimize traffic flow and management, enhance accessibility for road users, collect valuable data, and educate students at community colleges and trade schools. These open-source tools include CARMA Cloud℠,(1) CARMA Streets℠,(2) Vehicle-to-Everything (V2X) Hub,(3) the CAV telematics tool,(4) CAV education (CAVe)-in-a-box,(5) CAVe-Lite,(5) and the MAP creation tool.(6)

CARMA CLOUD

CARMA Cloud(1) is a cloud-based data storage service designed to facilitate communication and collaboration among the various components of transportation systems. These components include cloud services, vehicles, infrastructure, and other road users, such as pedestrians and other vehicles. A web interface provides a visual representation of road elements and associated data, including speed limits and lane closures. CARMA Cloud's primary objective is to enhance road user experiences by implementing rules and strategies that promote more effective traffic management, ultimately contributing to safer and more efficient transportation systems.

CARMA Cloud includes the following key benefits:

- Enhances traffic management by aiding authorities in optimizing traffic flow, thereby reducing traffic congestion and minimizing travel times.
- Collects data on traffic patterns and road conditions to aid in furthering research.
- Improves mobility for all road users across the transportation system.

CARMA STREETS

CARMA Streets(2) facilitates communication and cooperation between CAV, infrastructure, and other road users. This tool enables testing of various transportation systems management and operations (TSMO) technologies, including stop-controlled intersections, to advance cooperative driving automation (CDA) technology. CARMA Streets' functionality contributes to optimizing traffic flow, enhancing safety, and integrating automated vehicles into transportation systems.

CARMA Streets includes the following key benefits:

- Coordinates traffic flow between CAVs, resulting in shorter travel times and reduced congestion.
- Allocates traffic resources dynamically based on real-time traffic conditions.
- Facilitates the rapid spread of information and enables quick responses of emergency services.

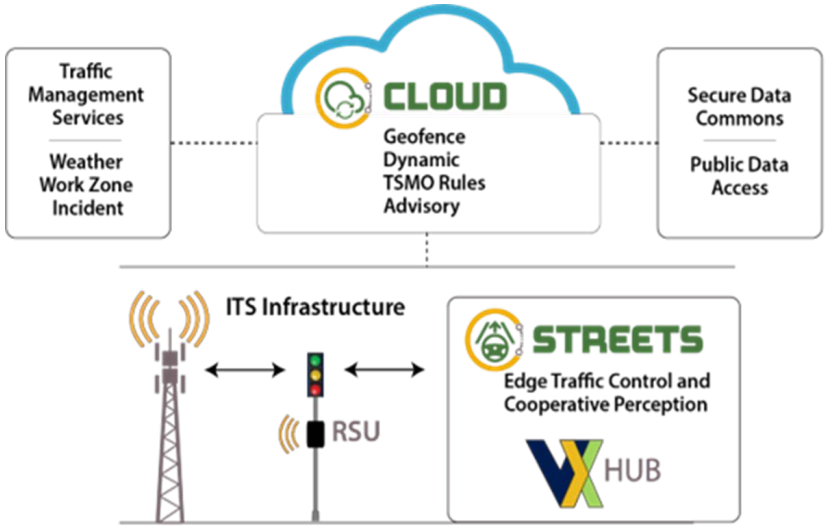
V2X HUB

V2X Hub[3] is an open-source software designed for connected vehicles, facilitating real-time communication and data exchange between vehicles and various elements of transportation infrastructure. This tool enables vehicles to establish communication with other vehicles, roadside infrastructure, pedestrians, cyclists, and the cloud.

V2X Hub includes the following key benefits:

- Facilitates information exchange regarding vehicle surroundings, potential hazards, and other road conditions to enhance safety.
- Coordinates vehicle actions based on real-time traffic conditions, reducing congestion and travel time.
- Enhances traffic-management capabilities.
- Enables safer integration of automated vehicles into the transportation system.

Figure 1 illustrates the CARMA[SM] products.[7]



Source: Federal Highway Administration (FHWA).
ITS = intelligent transportation systems; RSU = roadside unit.

Figure 1. Illustration. CARMA products.[1,2,3]

CAV TELEMATICS TOOL

The CAV telematics tool[4] is an open-source, data-collection system to facilitate sharing and analysis of information related to CAVs. With the ability to track and analyze data in near realtime, the tool enables quick data analysis to ensure systems are functioning as intended.

The CAV telematics tool includes the following key benefits:

- Enables real-time alerts, enhancing transportation system safety.
- Facilitates optimizing traffic flow, leading to reduced congestion.
- Increases efficiency by providing users with timely updates on traffic conditions and road data, enabling more informed travel decisions.

CAVe-in-a-box[5] provides a hands-on learning experience, offering educational tools to facilitate benchmarking connected vehicle equipment and to support onboarding new ITS technicians. The infrastructure and kits in CAVe-in-a-box include transportation radios, networking equipment, traffic control devices, and software necessary to train, deploy, and test scaled ITS in classrooms.

CAVe-in-a-box includes the following key benefits:

- Offers detailed documentation of CAV components.
- Provides hands-on instructions for learning about connected vehicles and technology.

Figure 2 shows a CAVe-in-a-box unit.

Source: FHWA.

Figure 2. Photo. CAVe-in-a-box.[5]

The CAVe-Lite[5] tool enables researchers at educational institutions to test and validate connected vehicle messages. This small, portable CAV testing platform focuses on application development.

CAVe-Lite includes the following key benefits:

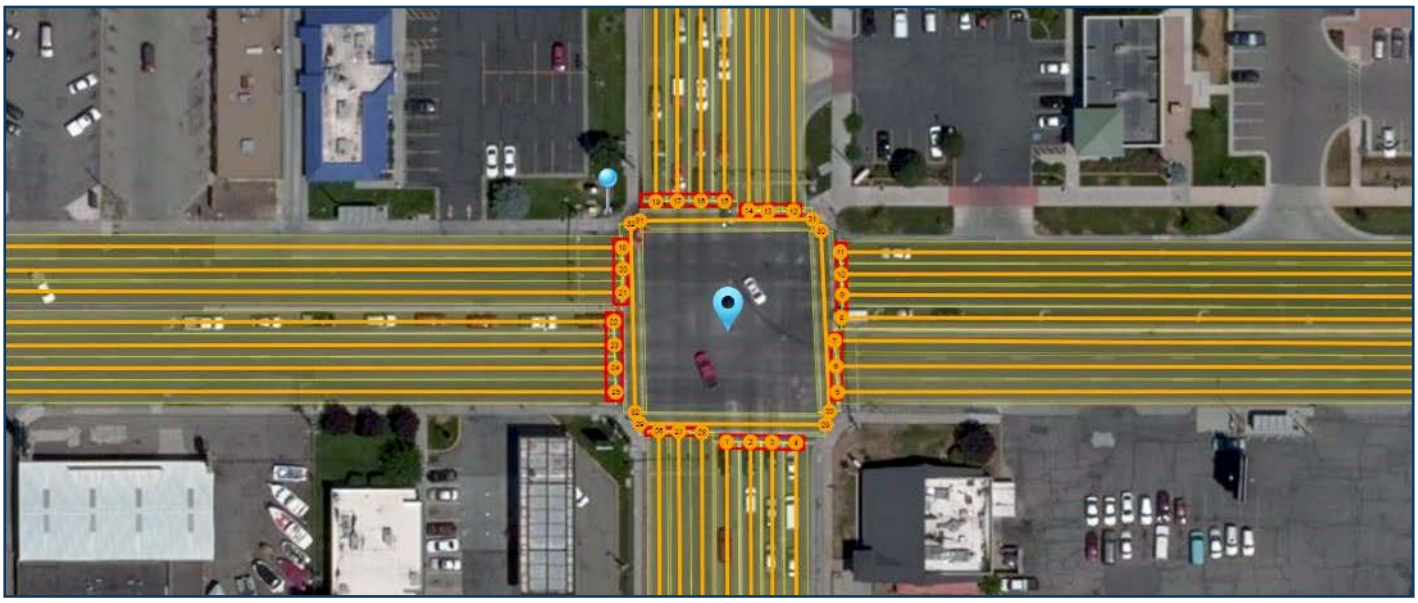
- Enhances access to educational materials by condensing the CAVe-in-a-box[5] toolkit.
- Allows fast and cost-effective setup, as the platform was developed on a Raspberry Pi™ [8] computer.
- Enables the addition of CAV application development and testing to transportation curriculums.

MAP CREATION TOOL

The open-source MAP creation tool[6] provided by USDOT facilitates deploying connected infrastructure by simplifying the development of SAE International® J2735™ [9] MAP messages.[10] This core-connected vehicle message details the layout, geometry, and usage rules of intersections and road segments. FHWA's Saxton Laboratory's[11] ongoing efforts aim to make this tool open source, enhancing flexibility for users. Additionally, Saxton Transportation Operations Laboratory will add support for the forthcoming Road Geometry Attributes message currently being defined by SAE J2945/A™.[12]

The MAP creation tool includes the following key benefits:

- User-friendly graphical user interface for drawing road geometry on aerial imagery.
- Outputs in both geoJSON[13] and unaligned PER[14]encoded formats of the MAP message.
- Well-formatted SAE J2735[9] MAP message ready to be deployed.
- Visual inspection of existing MAP messages for accuracy.



Original map: © 2014 USDOT MAP tool. Modified by FHWA.[6]

Figure 3. Image. Intersection definition in the USDOT MAP tool.[6]

GETTING STARTED

The tools mentioned in the previous sections are available on GitHub, which enables collaboration and contribution that enhances users' understanding and accelerates the market readiness of CDA technologies.

GitHub provides a platform for users to collaborate, gain experience with CDA, and customize the software for their specific needs.

For technical support, please reach out to the CARMA Support Services Help Desk at CARMASupport@dot.gov. Additionally, a frequently asked questions section is available on GitHub that offers solutions to commonly known issues.

1. FHWA. n.d. "carma-cloud" (software and configuration files in GitHub repository). https://github.com/usdot-fhwa-stol/carma-cloud, last accessed April 12, 2023.
2. FHWA. n.d. "carma-streets" (software and configuration files in GitHub repository). https://github.com/usdot-fhwa-stol/carma-streets, last accessed April 12, 2023.
3. FHWA. n.d. "V2X-Hub" (software and configuration files in GitHub repository). https://github.com/usdot-fhwa-OPS/V2X-Hub, last accessed April 12, 2023.
4. FHWA. n.d. "cda-telematics" (software and configuration files in GitHub repository). https://github.com/usdot-fhwa-stol/cda-telematics, last accessed November 12, 2023.
5. USDOT. n.d. "Connected and Automated Vehicle Education" (web page). https://www.pcb.its.dot.gov/CAVEducation.aspx, last accessed March 2022.
6. USDOT. n.d. *MAP Tool* (software). https://webapp.connectedvcs.com/isd/, last accessed November 20, 2023.
7. USDOT. n.d. "CARMA" (web page). https://its.dot.gov/cda, last accessed May 30, 2023.
8. Raspberry Pi Foundation. n.d. "Raspberry Pi Foundation" (web page). https://www.raspberrypi.org/, last accessed October 26, 2023.
9. SAE International. 2023. *V2X Communications Message Set Dictionary*. SAE J2735_202309. Warrendale, PA: SAE International. https://www.sae.org/standards/content/j2735_202309/, last accessed October 26, 2023.
10. USDOT. n.d. "Module 62 - CV273: Introduction to SPaT/MAP Messages" (web page). https://www.pcb.its.dot.gov/standardstraining/mod62/ppt/m62ppt.htm, last accessed October 26, 2023.
11. FHWA. 2023. "Saxton Transportation Operations Laboratory" (web page). https://highways.dot.gov/research/laboratories/saxton-transportation-operations-laboratory/saxton-transportation-operations-laboratory-overview, last accessed October 26, 2023.
12. SAE International. 2019. *Standard for Lane-Level and Road Furniture Mapping for Infrastructure-based V2X Applications.* SAE J2945/A. Warrendale, PA: SAE International. https://www.sae.org/standards/content/j2945/a/, last accessed October 26, 2023.
13. Internet Engineering Task Force. n.d. "GeoJSON" (web page). https://geojson.org/, last accessed November 22, 2023.
14. ETSI. 2010. *Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service.* ETSI TS 102 637-3. Sophia Antipolis, France: European Telecommunications Standards Institute. https://www.etsi.org/deliver/etsi_ts/102600_102699/10263703 /01.01.01_60/ts_10263703v010101p.pdf, last accessed January 2023.

FHWA-HRT-24-035
HRSO-40/12-23(200)E
Recommended citation: Federal Highway Administration. *Saxton Transportation Operations Laboratory Research Tools to Enhance Connected Automated Vehicle (CAV) Capabilities* (Washington, DC: 2023) https://doi.org/10.21949/1521460