



Saxton Transportation Operations Laboratory Web-Based and Open-Source Tools for Connected and Automated Vehicle (CAV) Research and Deployment

OVERVIEW

The U.S. Department of Transportation (USDOT) provides infrastructure-focused tools that offer advantages to transportation systems and their users. These tools help optimize traffic flow and management, improve access for road users, collect valuable data, and support academic institutions in transportation technology education. These open-source tools include CARMA Cloud^{SM, (1)} CARMA Streets^{SM, (2)} Vehicle-to-Everything (V2X) Hub^{SM, (3)} the CAV Telematics tool,⁽⁴⁾ CAV education (CAVe)-in-a-box,⁽⁵⁾ CAVe-Lite,⁽⁶⁾ MAP/road geometry attributes (RGA) Message Creator tool for generating both MAP and RGA messages,⁽⁷⁾ and the traveler information message (TIM) Creator tool.⁽⁸⁾



CARMA Cloud⁽¹⁾ is a cloud-based data service that enables communication and collaboration among transportation system components, including vehicles, infrastructure, cloud services, and other road users. Through a Web interface, CARMA Cloud visualizes road elements and data such as speed limits and lane closures. CARMA Cloud's primary objective is to enhance user experience and traffic operations by implementing rules and strategies that promote safer, more efficient travel.

CARMA Cloud provides the following key benefits:

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

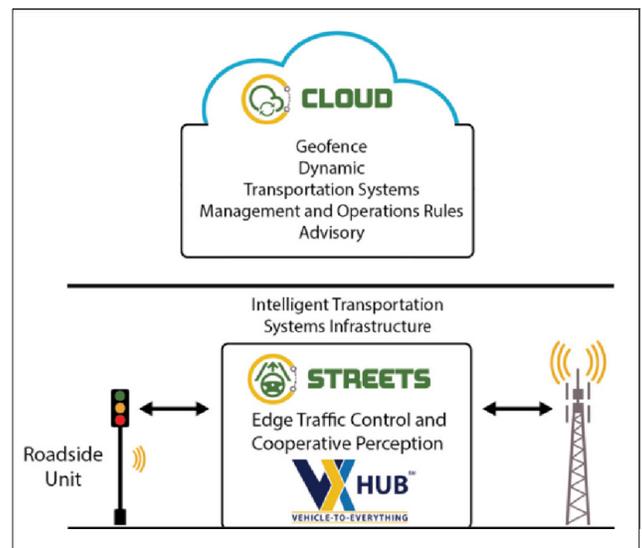
Figure 1 illustrates the CARMASM products.^(1, 2, 3)



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 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 provides 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.



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

Figure 1. Illustration. CARMA products.^(1,2,3)



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

V2X Hub provides the following key benefits:

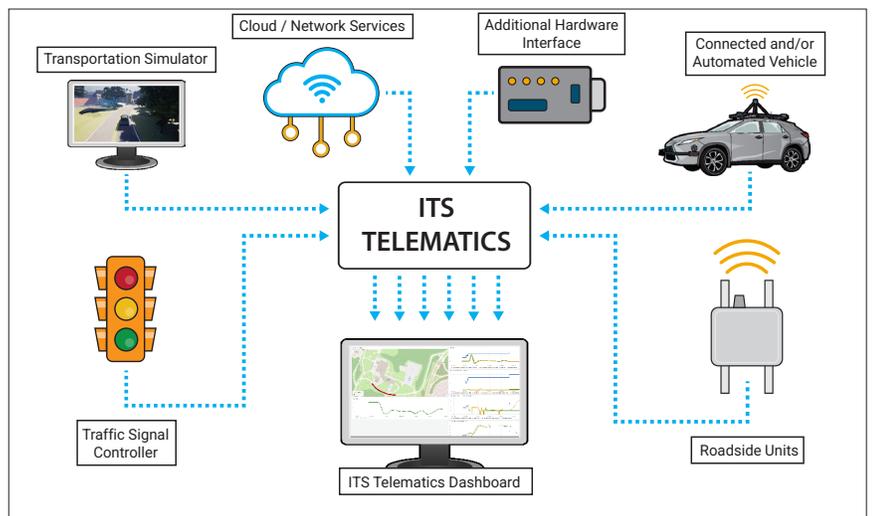
- Facilitates information exchange regarding vehicle surroundings, potential hazards, and other road conditions to enhance safety.
- Coordinates vehicle actions based on real-time traffic conditions, which reduces congestion and travel time.
- Enhances traffic-management capabilities.
- Enables safer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



The CAV Telematics tool⁽⁴⁾ is an open-source, data-collection system to facilitate the 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 provides 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.



Source: FHWA.

Figure 2. Diagram. ITS telematics system architecture.⁽⁴⁾

Figure 2 illustrates the connections between intelligent transportation systems (ITS) telematics and vehicles, infrastructure, and cloud services.



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:

- Detailed documentation of CAV components.
- Hands-on instructions for learning about connected vehicles and technology.

Figure 3 shows a CAVe-in-a-box unit.



Source: FHWA.

Figure 3. Photo. CAVe-in-a-box.⁽⁵⁾

CAVe^{LITE}

The CAVe-Lite⁽⁶⁾ 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.
- Enables the addition of CAV application development and testing to transportation curriculums.

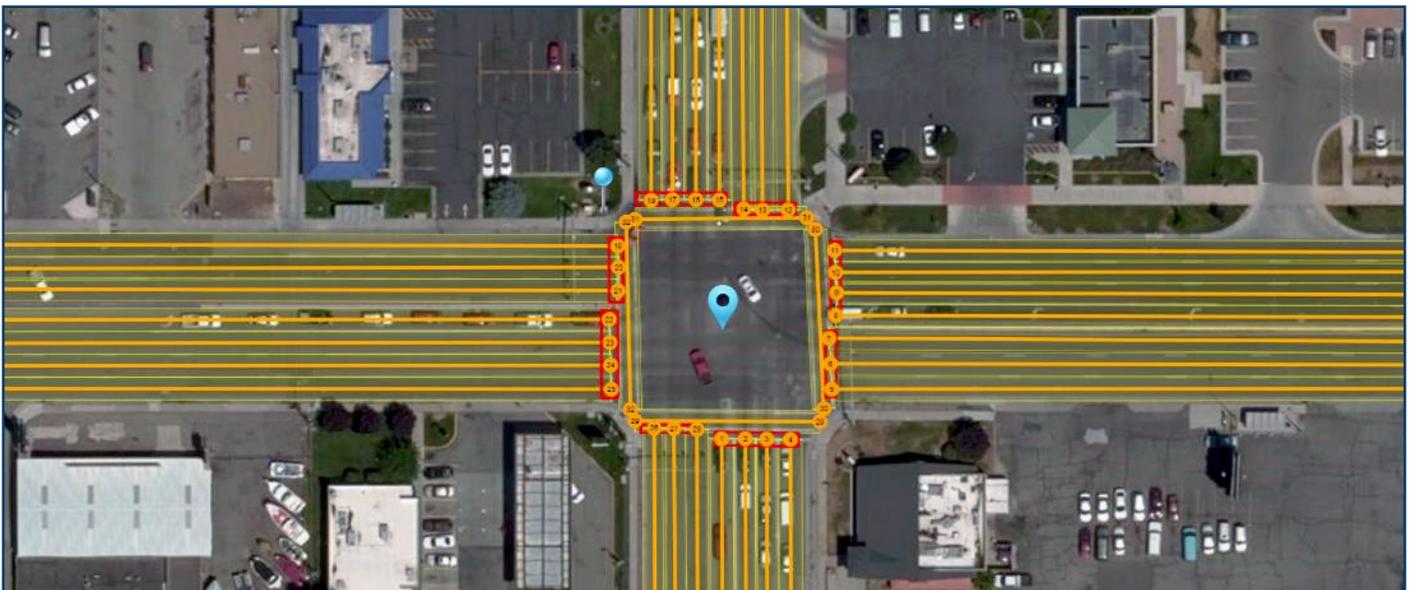
MAP RGA TOOL

The Web-based and open-source MAP/RGA Message Creator tool⁽⁷⁾ provided by USDOT facilitates deployment of connected infrastructure (direct or network V2X) by simplifying the development of SAE International® technical standards—J2735^{TM(9)} MAP and J2945/A^{TM(10)} RGA messages. These core connected vehicle messages detail the layout, geometry, and usage rules of intersections and road segments. FHWA's Saxton Transportation Operations Laboratory⁽¹¹⁾ maintains and enhances this tool to improve flexibility and ease of use for practitioners.

The MAP/RGA Message Creator tool provides the following key benefits:

- User-friendly graphical user interface for drawing road geometry on aerial imagery, providing approximately 75-cm positional accuracy.
- Outputs in both GeoJSON⁽¹²⁾ and ASN.1 unaligned Packed Encoding Rules⁽¹³⁾ encoded formats of the MAP and RGA messages.
- Well-formatted MAP and RGA messages ready for deployment.
- Visual inspection of existing MAP and RGA messages for accuracy.

Figure 4 shows a defined intersection in the USDOT MAP/RGA Message Creator tool.



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Figure 4. Image. Screenshot. Intersection definition in the USDOT MAP/RGA Message Creator tool.^(7,14)

TIM CREATOR TOOL

The Web-based and open-source TIM Creator tool⁽⁸⁾ supports the creation, encoding, and validation of SAE J2735⁽⁹⁾ TIM(s) used for direct or network V2X connected vehicle applications. These messages communicate roadway and traveler information, such as work zone details, detours, speed advisories, and other relevant events. Developed and maintained by FHWA's Saxton Transportation Operations Laboratory,⁽¹¹⁾ the TIM Creator tool enables consistent, SAE standards-compliant message generation to support interoperable deployment across agencies and vendors.

The TIM Creator tool provides the following key benefits:

- Simplifies creation of TIMs through a user-friendly graphical interface, providing approximately 75-cm positional accuracy.
- Validates message structure and data fields against SAE J2735⁽⁹⁾ specifications.
- Exports messages in both human-readable and encoded formats for deployment or testing.
- Enhances interoperability across connected vehicle systems and communication platforms.

These messages and other standard connected vehicle messages can be validated using the open-source Message Validator tool,⁽¹⁵⁾ which verifies message structure, syntax, and encoding against SAE standards. This tool ensures SAE standards compliance and interoperability across platforms, supporting accurate testing and reliable deployment of connected vehicle applications.

GETTING STARTED

The tools mentioned in the previous sections are available on GitHub[®], which enables collaboration and contribution to enhances users' understanding and accelerates the market readiness of CDA technologies. The open-source availability of these tools also allows users to customize the software for their specific needs.

For technical support, please contact the CAV Support Services Help Desk at CAVSupportServices@dot.gov. A frequently asked questions section is available on GitHub that offers solutions to commonly known issues.

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