October 2025

Integrated Highway Prototype Using Cooperative Driving Automation (CDA)

Connectivity helps automated vehicles safely merge and then harmonize across a traffic stream. The Federal Highway Administration's (FHWA's) integrated highway prototype used up to five SAE International® Level 2+ vehicles(1) on a closed track to perform platooning, cooperative merge, and speed harmonization maneuvers. The research team then analyzed the potential benefits of applying CDA to highways. Additionally, vehicles from a university collaborator helped demonstrate the viability of these maneuvers across diverse vehicle platforms, which will be key to successful operation of cooperative vehicle applications in the future.

FACT SHEET

BENEFITS TO TRANSPORTATION

Improved Safety:

Minimal disturbances to the traffic flow and increased confidence in merge locations may lead to safer roads for road users.

Reduced Congestion:

Initial traffic studies conducted via simulation suggest that this approach may lead to an increase in throughput by **up to 28 percent overall and up to 80 percent in a bottleneck area and a reduction in travel times of up to 35 percent.**

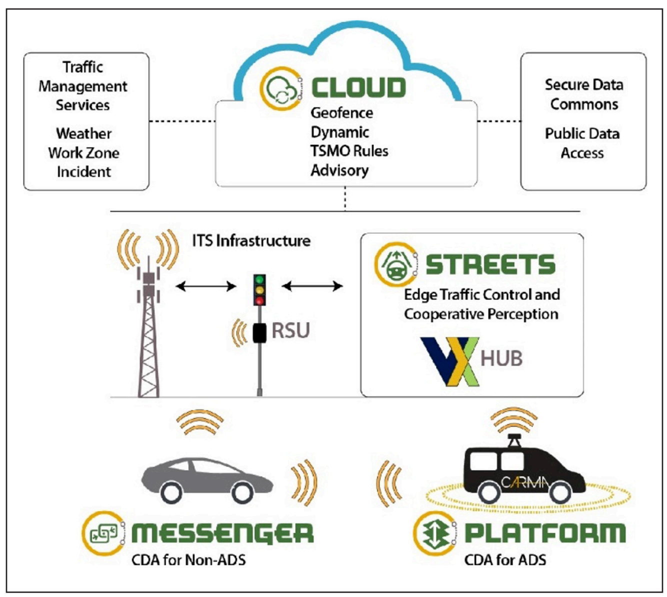
Improved Efficiency:

With a reduction in speed oscillation and stop-and-go traffic, the same simulation traffic studies reveal that energy consumption can be reduced significantly, particularly in bottleneck areas. **Less energy usage means less money drivers have to spend on monthly commuting costs.**

All images source: FHWA.

USE CASE ARCHITECTURE

Figure 1 shows how vehicles communicated when equipped with CARMA Platform℠(2) which enables them to platoon and merge cooperatively. A Vehicle-to-Everything (V2X) Hub(3) served as the roadside interface between the infrastructure and the vehicles. CARMA Cloud℠(4) was used to run the speed harmonization algorithm and provide speed guidance to vehicles based on traffic data (traffic data were simulated for this testing).[1]



Source: FHWA.
TSMO = transportation systems management and operations;
ADS = automated driving systems; RSU = roadside unit;
ITS = intelligent transportation systems.

Figure 1. Graphic. Diagram of CARMA ecosystem.(2,3,4,5,6)

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[1]The algorithms will be published in the report, which is in progress: Ghiasi, A., S. Ramyar, J. Smet, K. Garvis, E. Leslie, J. Ma., Y. Guo, T. Yang, and Y. Yuan. *Project Report for CARMA Proof-of-Concept Integrated Highway Prototype 2*. Washington, DC: Federal Highway Administration.

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FACT SHEET

EVALUATION OF THE CONCEPT

Limited integration testing occurred using the test facilities at Turner-Fairbank Highway Research Center in McLean, VA. Full-integration testing and subsequent test phases were completed at a test facility in Auburndale, FL. The facility has a 2.25-mi oval track that is compatible with testing the freeway applications used by the CDA integrated highway prototype (figure 2).

Original map: © 2022 Google® Earth™, modified by FHWA to show labels and colored lines.

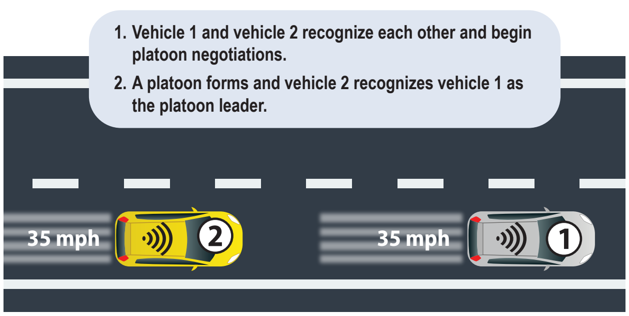
Figure 2. Photo. Aerial view of the test track.[7]

STANDARDS

This technology uses the following standards established by SAE International:

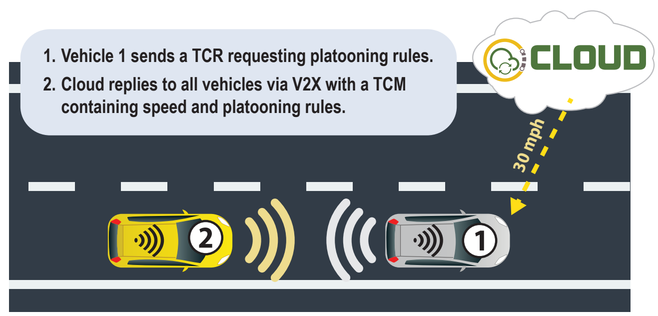
- SAE J3216_202107™: *Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles.*[8]
- SAE J3016_202104™: *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.*[1]
- SAE J2735™: *Vehicle-to-Everything Communications Message Set Dictionary.*[9]

The core testing involved three vehicles carrying out a single scenario that combined the three applications. The steps were carried out to test the scenario shown in figure 3 through figure 10.



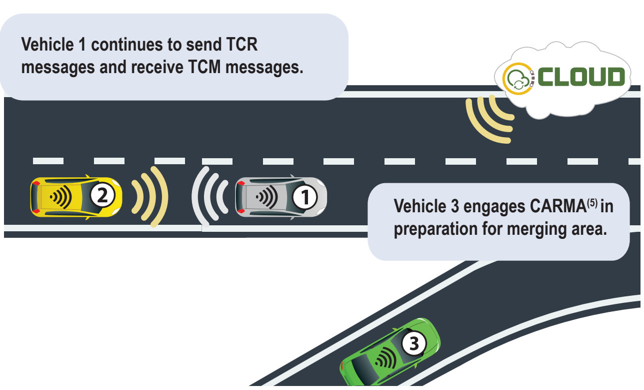
Source: FHWA.

Figure 3. Graphic. Mainline vehicles start their run on the track.



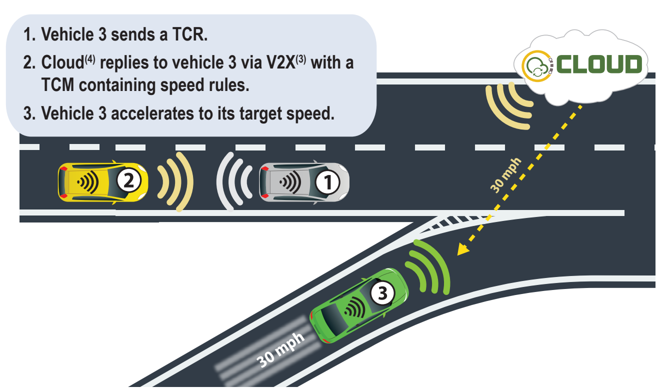
Source: FHWA.
TCM = traffic control message; TCR = traffic control request.

Figure 4. Graphic. Mainline vehicles communicate with CARMA Cloud to receive relevant guidance for platooning.[3,4]



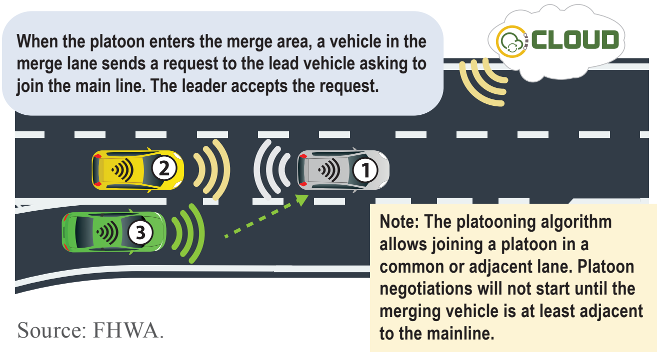
Source: FHWA.

Figure 5. Graphic. Mainline vehicles and merging vehicle approach the merging area.[4,6]



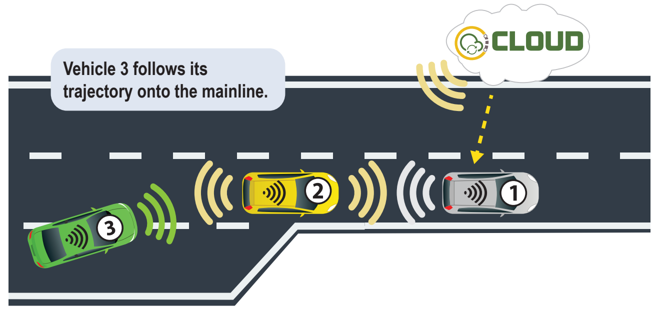
Source: FHWA.

Figure 6. Graphic. Mainline vehicles slow down in response to speed harmonization, and merging vehicle begins communication.[3,4]



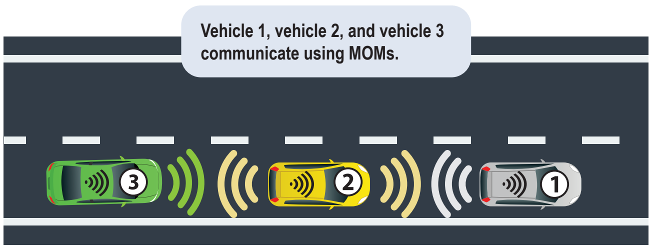
Source: FHWA.

Figure 7. Graphic. Merging vehicle negotiates with mainline platoon leader to identify a trajectory to merge and to receive the platoon rules.[4]



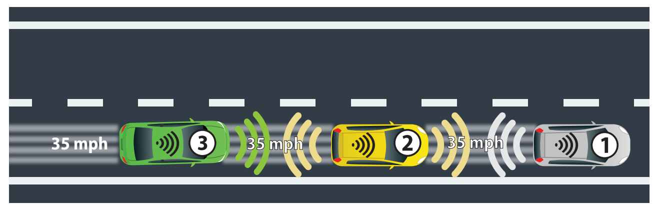
Source: FHWA.

Figure 8. Graphic. Mainline vehicles communicate with CARMA Cloud and begin platooning under received guidance.[4]



Source: FHWA.
MOM = mobility operations message.

Figure 9. Graphic. Merging vehicle has joined the platoon, and the platoon travels together through the remaining speed harmonization zone using MOMs to communicate.

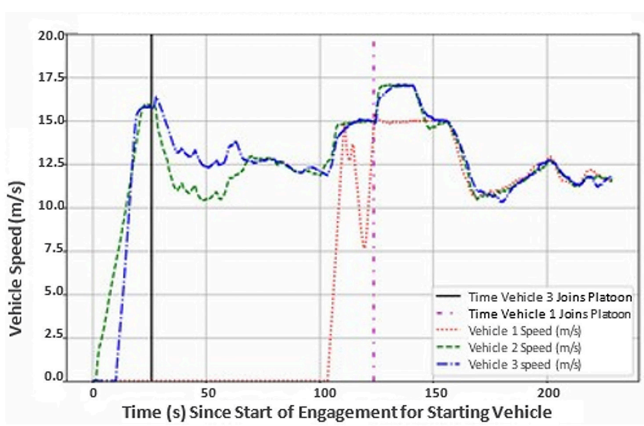


Source: FHWA.

Figure 10. Graphic. All three vehicles exit speed harmonization as noted by a TCM previously received from CARMA Cloud,[4] and all three vehicles resume following the speed.

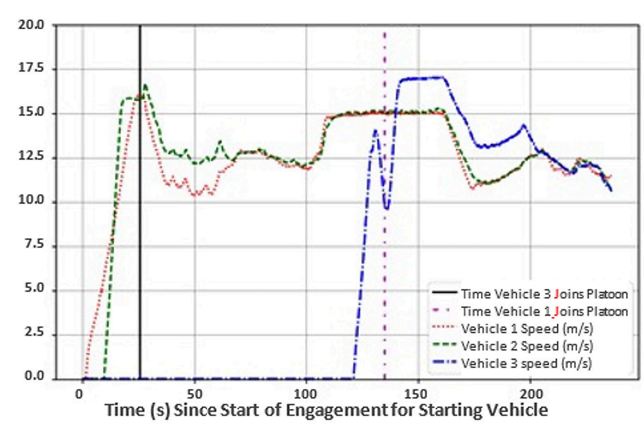
RESULTS AND LESSONS LEARNED

Validation testing conducted by the U.S. Department of Transportation's Volpe National Transportation Systems Center showed that the vehicles could execute front-join (figure 11), rear-join (figure 12), and speed harmonization operations (figure 13) on a closed test track. The plotted results in figure 11 through figure 13 show a subset of data for the front-join, rear-join, and speed harmonization operations, respectively, demonstrating the consistency of speed through the operation's execution. From the validation testing, the team identified potential areas of improvement, such as improved lane-keep abilities and advanced sensing capability integration, to enable object detection and avoidance functions.



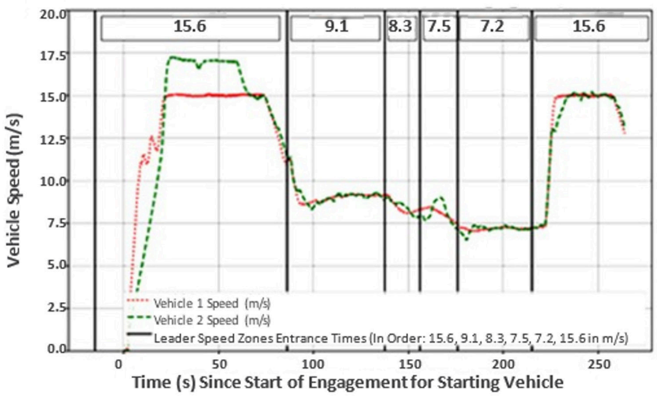
Source: FHWA.

Figure 11. Graph. Results of adjacent lane front runs.



Source: FHWA.

Figure 12. Graph. Results of adjacent lane rear runs.



Source: FHWA.

Figure 13. Graph. Results of speed harmonization (high).

FUTURE POTENTIAL IMPROVEMENTS

- **Simulation**—Continued simulation testing could allow for further refinement of potential standards for features in a wider range of scenarios.
- **Increased number of vehicles**—Increasing the number of vehicles and testing collaborators could allow for further refinement of the technology and testing of more complicated scenarios outside of simulations.
- **Cut-in merge**—The current testing focused on vehicles joining the platoon from the front and the rear. Further testing could study the opening of a gap for a joining vehicle to enter the platoon somewhere in the middle.
- **Cellular communication**—The transportation safety band, which is the standard frequency band used to communicate between vehicles and infrastructure, is in high demand. Investigations can be conducted as to whether messages for this technology can potentially be delivered through other means, such as cellular, to prioritize and better manage the transportation safety band usage.
- **Public road testing**—Testing the concept on public roads could identify how the technology behaves in a real-world environment. Additional improvements to the concept could be considered. For example, vehicle controls could be improved so vehicles can reliably remain in their own lane at highway speeds. Sensing capabilities could also be integrated into the platform to enable object detection and avoidance functions.

REFERENCES

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TO LEARN MORE AND FOLLOW UPDATES:

Saxton Transportation Operations Laboratory
https://highways.dot.gov/turner-fairbank-highway-research-center/labs/STOL

V2X GitHub
https://github.com/usdot-fhwa-OPS/V2X-Hub

CARMA Platform
https://github.com/usdot-fhwa-stol/carma-platform

For more information, please contact the CDA Program at CDA@dot.gov.

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Recommended citation: Federal Highway Administration, *Integrated Highway Prototype Using Cooperative Driving Automation (CDA)* (Washington, DC: 2025) https://doi.org/10.21949/e3en-0a71

FHWA-HRT-25-088
HRSO-40/10-25(200)E