# Truck Platoon Testing Allowed Under SB 719

Caltrans

**Report to the Legislature**

**2017**

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# Table of Contents

Executive Summary ... 1

Background ... 4

- Statutory Reference & Purpose ... 4
- Program Background ... 4
- Previous Report ... 6

Program Status/Program Accomplishments ... 6

Conclusion and Next Steps ... 15

Appendix A.  Statutory Reporting Reference ... 16

## Executive Summary

The California Department of Transportation (Caltrans) in partnership with the University of California at Berkeley, Volvo Group, Cambridge Systematics, Los Angeles County Metropolitan Transportation Authority, Gateway Cities Council of Governments, and Peloton Technologies applied for and received a Federal Highway Administration (FHWA) grant to fund research to develop and test a cooperative adaptive cruise control system (CACC) for heavy trucks. CACC is the next step in the development of vehicle cruise control systems, progressing from cruise control, to adaptive cruise control (ACC), to CACC. CACC, ACC, and cruise control are considered driver-assist technologies where the driver remains in control at all times and is responsible for the operation of the vehicle.

CACC is created by integrating high-speed communications into heavy trucks equipped with commercially available ACC, thus allowing the trucks to communicate with one another. Communication between the trucks enables cooperative and coordinated truck movements. The high-speed communications and coordinated maneuvers reduce the reaction time for braking. This not only improves safety, but also allows the adjacent trucks to travel with shorter gaps between them.

Under this project the three-truck platoon has driven 5,500 miles on the State Highway System at 55 miles per hour (mph) without incident. An additional 2,500 miles were driven on a test track for fuel consumption experiments. The combined incident free mileage driven with CACC assistance totals nearly 8,000 miles.

The requirement to test the CACC system in live traffic with short spacing between the trucks was the reasoning behind Senate Bill (SB) 719’s (Hernandez, Chapter 163, Statutes of 2015) exemption from the Vehicle Code provisions requiring a minimum 100 feet spacing between vehicles in a platoon. The California Highway Patrol (CHP) played a key role in this pilot and worked with Caltrans to develop the language for SB 719.

The project had four major goals: identifying near-term opportunities for CACC to improve heavy truck operations, assessing acceptance of moderately short CACC gaps by truck drivers, measuring energy savings at gaps chosen by drivers, and providing demonstrations to show benefits to industry and public stakeholders. Caltrans and CHP’s overarching goal was to ensure the safety of the traveling public and the researchers during every aspect of CACC development, testing, and demonstration.

After initial CACC system development, the project team explored four potential benefits of heavy truck platooning: increased throughput from shorter gaps between vehicles, reduced fuel consumption due to improved aerodynamics, emission reductions from reduced fuel consumption, and safety improvements due to high-speed communication and coordinated maneuvering. The project team is currently investigating commercial vehicle driver acceptance of the heavy truck CACC system, primarily the comfort level of drivers based on the smaller than normal gaps between vehicles.

Fuel consumption experiments were performed in partnership with Transport Canada (Canada’s Department of Transportation). Fuel savings ranged from 5 to 14 percent, based on a number of factors including the gaps between trucks.

The research team, industry, Caltrans, and CHP collectively deem the CACC testing, allowed under SB 719 thus far, a success and recommend extending the sunset date of SB 719 by two additional years.

## Background

### Statutory Reference & Purpose

- SB 719 (Hernandez, Chapter 163, Statutes of 2015)
- California Statute: Government Code section 14107
- California Statute: Vehicle Code section 21705
- Report findings of the testing to the Legislature on or before July 1, 2017

### Program Background

The rapid development of new technologies under the broad category known as “Intelligent Transportation Systems” (ITS) has brought opportunities to enhance the performance of California’s transportation system. ITS technologies include sensors that can detect the locations and motions of vehicles and other road users (pedestrians, bicyclists, and even animals), wireless communication systems that enable the exchange of data among vehicles and between vehicles and the roadway infrastructure, computer systems and software that can analyze the data, and actuators that can automatically control vehicle motions (steering, acceleration, and braking).

Future ITS technologies will provide vehicles and their drivers with additional and enhanced information and assistive technologies. This will enable future drivers to drive more safely, smoothly, and efficiently than today. One important class of ITS system that is already available for use on many passenger cars and commercial vehicles is ACC, which automatically controls the acceleration and braking of a vehicle so that it maintains a set following distance behind the preceding vehicle in its lane. ACC systems use forward-looking sensors (RADAR, LIDAR and/or video cameras) to measure the distance to the preceding vehicle and the difference in speed between vehicles. This information is used by the ACC system software to determine the acceleration or braking commands that should be implemented to maintain the desired spacing. Approximately 100,000 ACC equipped heavy trucks are now on the road in the United States.

Commercially available ACC systems for passenger cars are typically designed with a minimum time gap of 0.8 to 1.0 seconds between vehicles, while ACC systems for heavy trucks typically provide a minimum time gap of 1.5 or 1.6 seconds. Defining these gaps in terms of time means that the distance between the vehicles will vary with vehicle speed. For example, at a speed of 55 mph, the 0.8 second gap represents a distance of 64.5 feet and the gap of 1.6 seconds represents a distance of 129 feet. The gap gets shorter at lower speeds, but if the speed drops below a minimum threshold value (typically in the range of 20 to 30 mph), the gap stops decreasing and remains at a fixed minimum distance.

Existing ACC systems have some limitations that can be overcome with the addition of vehicle-to-vehicle (V2V) wireless communications of key vehicle data. Existing ACC systems only detect changes in the motion of the vehicle immediately in front of them, not the actions of vehicles further ahead. They are relatively slow to respond to changes in the motion of vehicles ahead, and their minimum gap settings are large enough that drivers of other vehicles freely change lanes into those gaps in dense urban traffic.

With the addition of V2V communication of data, these systems become cooperative ACC (CACC), which provides several performance improvements:

- Receive information from vehicles further ahead than their sensors can detect, and can respond earlier and more smoothly to changes in traffic speed.
- Use safely at shorter time gap settings (0.6 seconds, corresponding to a clearance gap of 48 feet at 55 mph) enabling aerodynamic "drafting" of the vehicles driving closer together.
- Respond more quickly and predictably to braking actions by preceding vehicles, increasing driver comfort and confidence in the systems.
- Smooth out traffic flow disturbances, improving the stability of freeway traffic flow (damping out "stop and go" behavior).

Prior safety analyses and experiments with passenger car drivers have indicated that time gaps in the range of 0.6 seconds (clearance distance of 48 feet at 55 mph) should be considered, and assessment of platoon performance and acceptability by commercial drivers require testing at these shorter gaps on public roads.

CACC systems can increase safety by reducing reaction time. The CACC system in the middle and trailing truck in a three-truck platoon will begin responding within two-tenths of a second when the lead truck brakes or accelerates. Human reaction time is more complex, highly variable, and can range from a few tenths of a second for an attentive experienced younger driver to more than a couple seconds for the average driver, a driver that is fatigued, or not focused on the driving task.

For all project activities thus far, the trucks have traveled almost 8,000 miles in platoon operation without incident. A total of 5,500 miles were driven on California public roads for CACC development and testing, and 2,500 miles were driven on a test track during the fuel consumption experiments.

CACC systems currently exist only as research prototypes, and are not yet commercially available. With the refinement of system designs and definition of technical standards to govern V2V data exchanges, they could become commercially available within a few months to a few years. The first commercially available CACC systems are expected to be implemented on long-haul heavy trucks because of the opportunity to obtain a return on investment through the energy savings associated with "drafting" of heavy trucks in a coordinated platoon.

Caltrans, in partnership with the University of California, Volvo Group North America, and other organizations, have been collaborating on an FHWA-sponsored Exploratory Advanced Research Project to develop and test a CACC system for heavy trucks.

The primary objectives of the project were to develop and test the CACC system on a three-truck platoon, determine driver acceptance of the system, and estimate the potential benefits of CACC systems when deployed. The potential benefits include reduced fuel use resulting in reduced emissions, as well as improvements to freight operations and throughput. The CACC system was implemented on three Volvo Class-8 heavy trucks. The modified trucks were then tested on a closed test track followed by testing on California public roads, first at low speeds on local streets and then at freeway speeds. The next step in the testing and development of the CACC system was to test the trucks on public roads at less than 100 feet spacing between adjacent trucks, which is prohibited by Vehicle Code Section 21705.

To address this issue, SB 719 added Government Code section 14107 to provide an exemption to Section 21705 of the Vehicle Code allowing Caltrans, in coordination with the CHP, to perform testing of technologies that enable drivers to safely operate motor vehicles with less than 100 feet between adjacent vehicles. SB 719 was enacted into law enabling close-spaced public road testing for this project.

Caltrans and CHP began collaborating on the truck platooning project soon after Caltrans received the grant award from FHWA and prior to enactment of SB 719. After passage of SB 719, Caltrans worked with the CHP to establish a process where Caltrans, as the Truck Platooning project manager, submitted a testing or demonstration plan to CHP for review and input on the proposed location(s), times, and other factors. The plans were then revised to everyone’s satisfaction.

### Previous Report

Not Applicable–no previous report.

### Program Status/Program Accomplishments

Figure 1–Volvo Class-8 Heavy Truck Tractor

The CACC system was designed, implemented and tested on three Volvo Class-8 heavy truck tractors (Figure 1). These trucks had already been equipped by Volvo with a production ACC system, so only relatively modest modifications were required to the equipment on these trucks. The additional equipment includes:

- A 5.9 GHz Dedicated Short Range Communication (DSRC) radio transceiver, which broadcasts information about the truck's behavior ten times per second and receives similar information from the other trucks' radios. This is similar to a WiFi system, but designed specifically for use in safety critical applications.
- Two antennas for the DSRC radio, mounted on the side mirrors of the truck.
- A 5 Hz GPS receiver and antenna to provide accurate positioning information.
- A small PC-104 computer to operate the CACC software and collect data about system performance during experiments.
- A tablet computer to provide a supplementary display to the driver about the operation of their truck and the other trucks that it is clustered with under the CACC coordination and control.
- An emergency disengage button to deactivate the prototype CACC system if it is not working correctly.

The truck modifications are shown schematically in Figure 2.

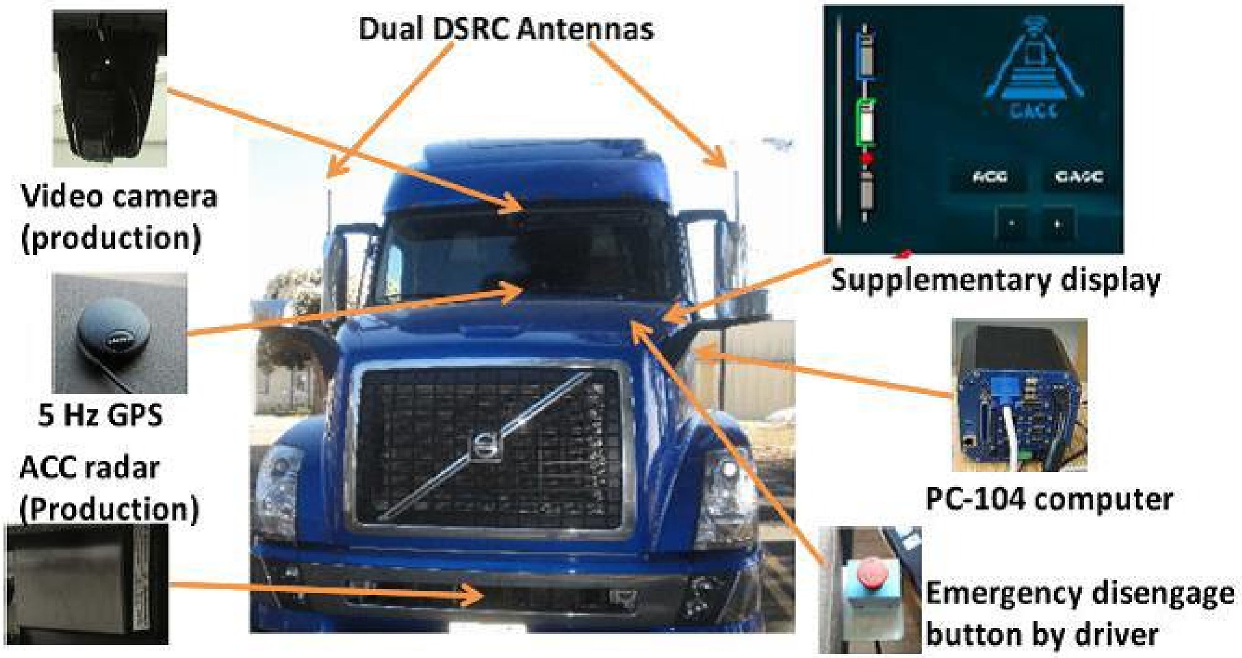

Figure 2–Additions to the Volvo Class-8 Truck Tractor to Implement CACC

This CACC system has been designed to give the driver the choice of five different time gap settings, depending on driver preferences and current local traffic and weather conditions. These settings represent time gaps of 0.6, 0.9, 1.2, 1.5, and 1.8 seconds (corresponding to clearance gaps between the trucks of 48, 73, 96,121, and 146 feet when driving at the California highway truck speed limit of 55 mph). A view of the tablet computer screen that displays the status of the system and allows the driver to change the gap setting is shown in Figure 3.

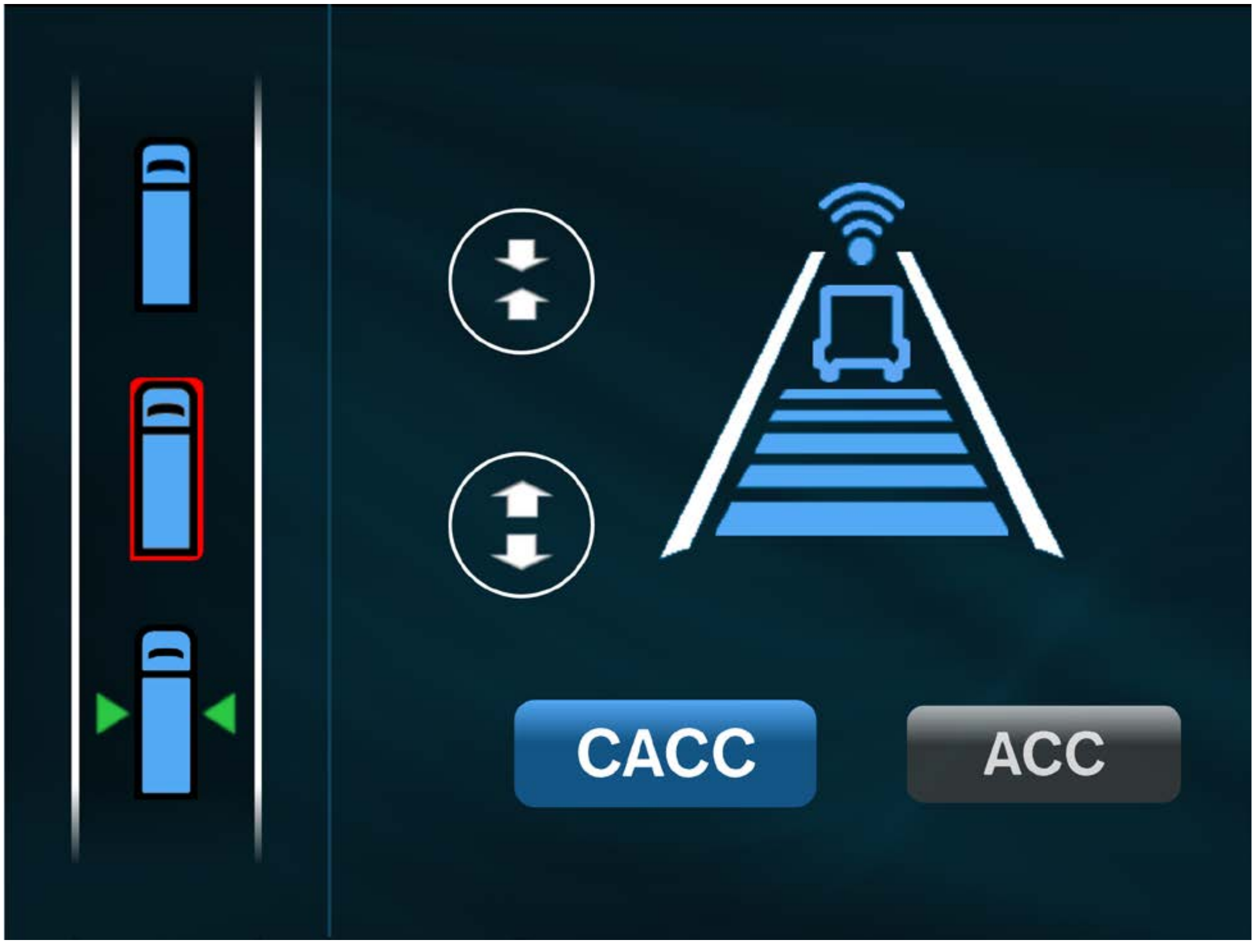

Figure 3–Supplementary Display on Tablet Computer Screen.

The number of bars below the vehicle icon on the right side of Figure 3 indicates the length of the time gap setting that is currently active. The buttons with arrows are used to increase or decrease the gap setting. The schematic on the left of the display indicates the position of this truck (green arrowheads) relative to its peers, and the red boundary on the icon of the middle truck indicates that its service brakes are active. Other symbols can be displayed to show a loss of communication with another truck or to indicate a malfunction on another truck.

The performance of the heavy truck CACC system has been tested to verify that the system is capable of:

- Accurately maintaining the desired gap setting at freeway driving speeds between 30 mph and the legal freeway truck speed limit.
- Smoothly responding when other vehicles cut into the gap between the trucks, gradually increasing the gap to maintain a safe distance behind the cut-in vehicle (this gap needs to be longer than the CACC gap behind the preceding truck because the cut-in vehicle is not part of the cooperative platoon, and cannot communicate its actions and condition).
- Smoothly closing the gap to the preceding truck in the platoon after a cut-in vehicle has vacated the lane (cut-out), leaving the preceding truck as the next vehicle ahead in the lane.

- Tightly coordinating automatic braking, so that whenever any of the trucks in the platoon applies its service brakes, the braking command is sent to the trucks behind it, and they apply their brakes within the next 0.1 second communication update interval (much faster than human drivers are able to perceive brake light activation).
- Displaying information about faults on the other equipped trucks to the drivers of all the trucks in the platoon.

The performance data collected during the platoon tests has been used to calibrate a computer simulation model that predicts the traffic impacts when a high percentage of heavy trucks are equipped with CACC. A simulation has been developed for the Interstate-710 corridor from the Port of Long Beach to downtown Los Angeles, where there is a very high volume of heavy truck traffic. The initial simulation results indicate that if all of the heavy trucks on this freeway were using the CACC system, there is a potential to relieve some of the most serious bottlenecks along that corridor with increases of vehicle throughput of 7 to 11 percent, and increases of travel speed of up to 48 percent, depending on the location along the corridor. These improvements are possible because the CACC system allows the trucks to operate at shorter gaps than normal.

The primary motivation for heavy truck owners and operators to purchase and use CACC technology is expected to be its potential for significant fuel savings. These savings are attributable to two factors: smoother acceleration and deceleration profiles under automatic speed control, based on improved truck platoon operational stability, and reduced aerodynamic drag based on the ability to drive the trucks significantly closer together than they would be driven otherwise. One of the major efforts under the current project has been a series of carefully controlled test track experiments to measure fuel consumption savings due to the reduced aerodynamic drag that can be achieved in steady cruising at highway speeds and various gaps between adjacent trucks. These tests were performed in October 2016 at a test track in Montreal, Canada, in cooperation with Transport Canada and the National Research Council of Canada, which provided extensive experimental support for the tests.

The energy consumption experiments were conducted using rigorous industry standard test protocols to ensure the accuracy of the results. Each test condition was repeated at least three times, representing constant speed driving for at least 172 miles. The trucks were pulling 53-foot dry goods van trailers, the most common configuration for long-haul trucking, and were loaded at a typical weight of 65,000 pounds for the complete tractor-trailer combination. Most of the tests were done at 65 mph, a typical long-haul truck operating speed, with additional cases at 55 mph. Two full sets of tests were done, one set for standard trailers and a second set for trailers with aerodynamic enhancements (side skirts and boat tails) so that the effects of the short CACC gaps could be compared for both configurations.

The baseline case for comparison of energy savings was for each truck to drive independently, separated from the others by one mile along the track, and pulling a loaded standard trailer. The CACC test cases chosen were for four of the available CACC gap settings 0.6, 0.9, 1.2, and 1.5 seconds, corresponding to clearance distances of 57, 86, 114, and 143 feet at 65 mph. (Note: the 1.8 second gap setting was not used in the fuel consumption experiment because the researchers believed that testing with that gap would not provide any additional information related to fuel consumption). Using these gap settings at the California truck speed limit of

55 mph produced gaps of 48, 73, 96, and 121 feet respectively. An aerial view of the trucks on the test track at the distance of 57 feet at 65 mph is shown in Figure 4.

Figure 4–Truck CACC System Driven on Test Track at 65 mph, 0.6 second time gap (57 foot clearance gap)

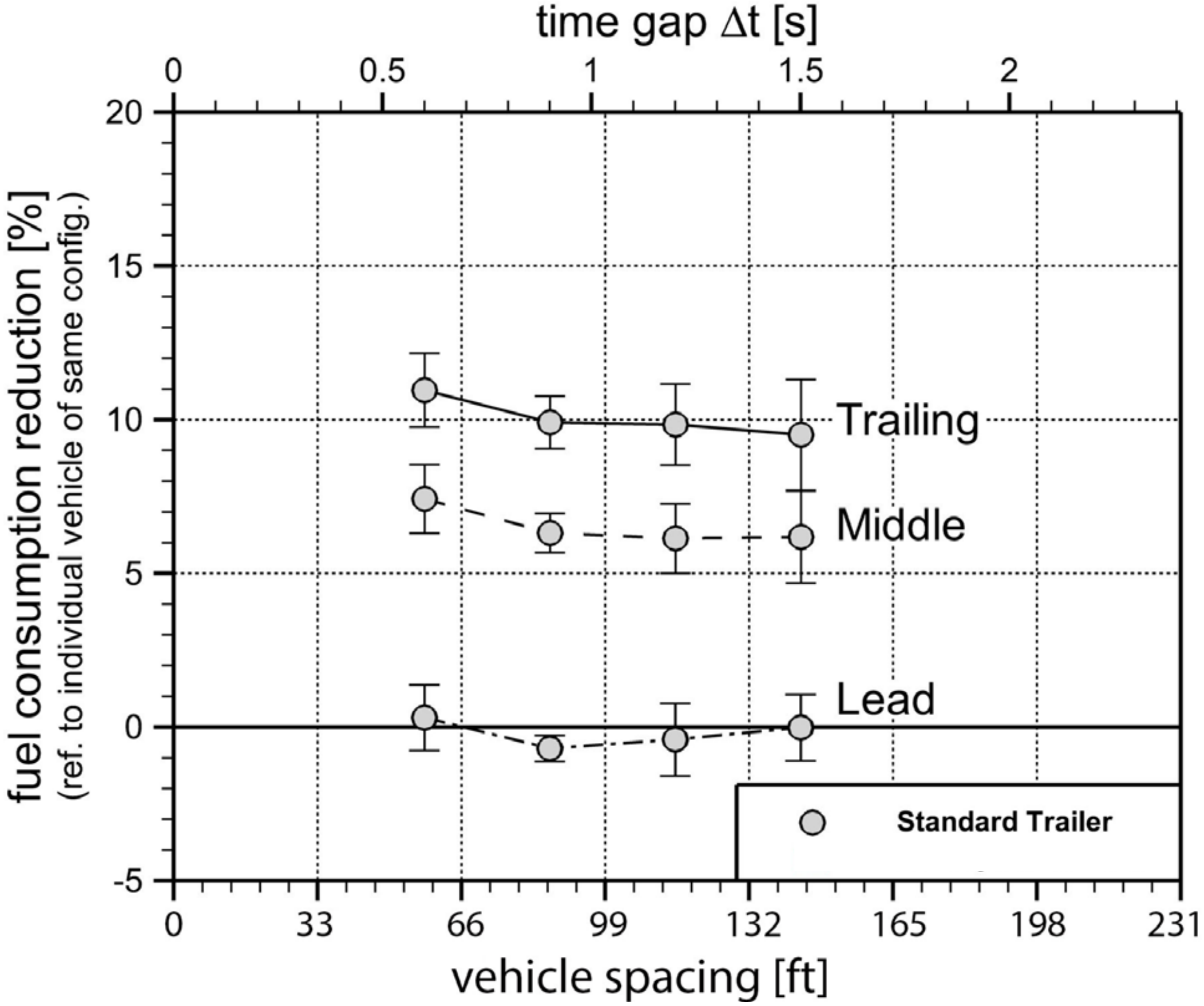

Figure 5–Energy Savings at 65 mph for CACC Trucks Pulling Loaded Standard 53-foot Trailers Compared to Driving Independently at 1 Mile Separation

The primary energy saving results from the truck tests are summarized in Figures 5 and 6. The first set of results was obtained using loaded standard trailers, without aerodynamic improvements, as displayed in Figure 5. It can be seen from this figure that the lead truck did not save any energy, while the middle truck saved 6 to 7 percent and the trailing truck saved 9 to 11 percent compared to the fuel consumption when driven individually. The trends on these plots show that shorter gaps lead to increased fuel savings. The test data from other research in the United States, Europe, and Japan, has shown that the energy savings increased dramatically when the gaps get shorter than the gaps that were tested in this project.

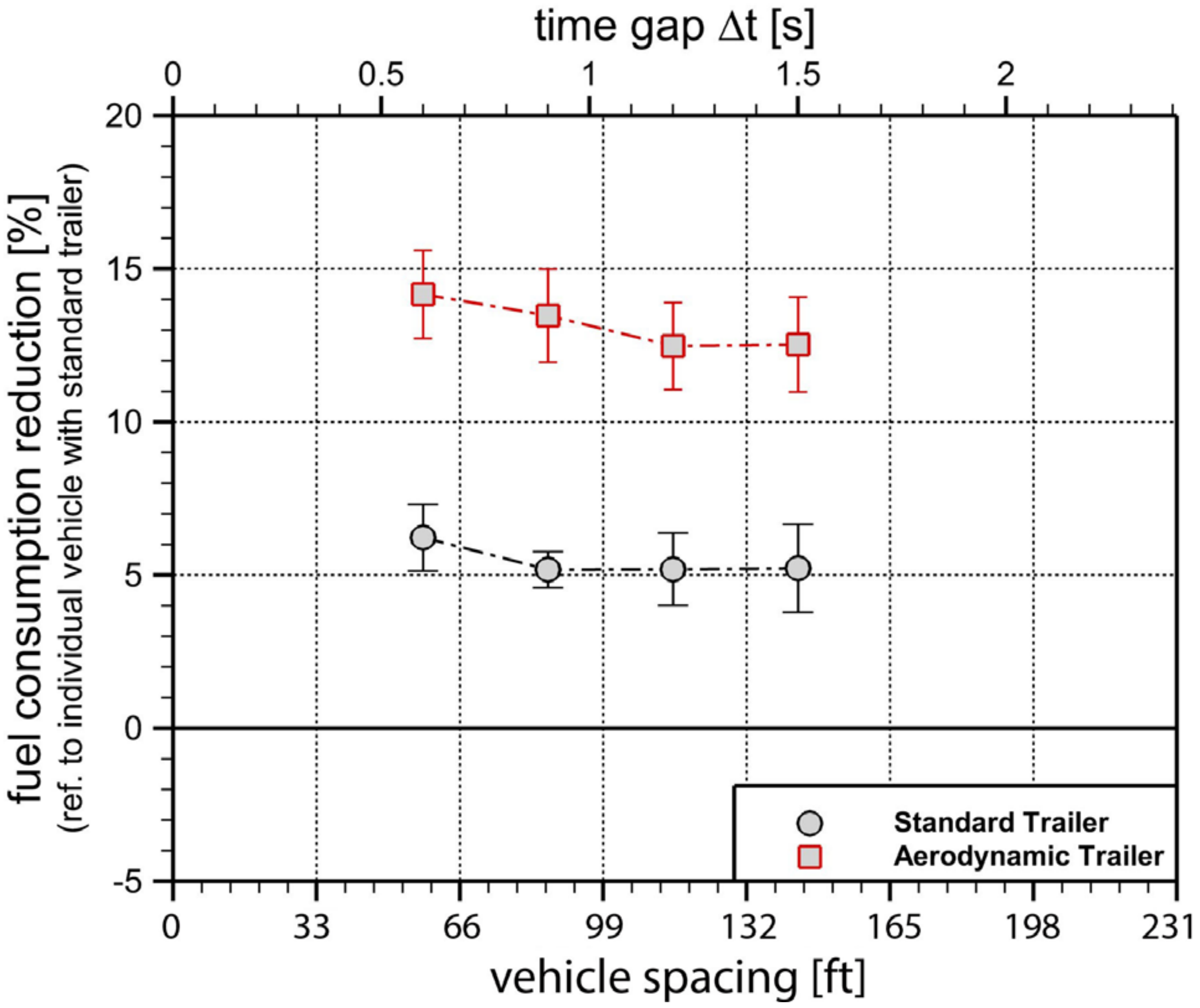

Figure 6–Average Energy Saving at 65 mph for CACC Trucks with Loaded Standard and Aerodynamic Trailers, Compared to Independent Operation Using Standard Trailers

Figure 6 shows the average energy savings for the three-truck platoon for different gap settings in both configurations, with loaded standard trailers and then with loaded aerodynamically enhanced trailers. The standard trailer configuration had an average fuel saving of 5 to 6 percent, depending on the gap setting. The aerodynamic trailer configuration produced an average savings of 13 to 14 percent depending on the gap setting, which represents an improvement of about 8 percent compared to the standard trailers. When the aerodynamic trailers were pulled by the trucks at large separations, the measured improvement was 7 percent, so the shorter gaps enabled by the CACC system resulted in twice the fuel savings.

The three-truck platoon was driven almost 5,500 miles on California highways without incident. An additional 2,500 miles were driven on the test track for the fuel consumption experiment. The total miles driven without incidents was almost 8,000. Mileage when the heavy trucks were in platooning operation includes CACC development, fuel consumption tests, driver acceptance experiment, two major demonstrations, as well as a number of smaller demonstrations. The three-truck CACC platoon has been driven on San Francisco Bay Area freeways dozens of times over that last several months for testing and development purposes and driven along the southern section of Interstate-110 between the Port of Los Angeles and Sepulveda Blvd. for a public demonstration on March 7 and 8, 2017. In all cases, drivers of other vehicles cut in between the trucks at all separation gaps. The coordinated operations of the truck platoon at the shorter gaps did not impede the ability of other drivers to change lanes when they needed to. This indicates that the truck CACC system was not creating the type of obstruction to traffic addressed in Vehicle Code section 21705.

Additional testing will be performed on freeways in the San Francisco Bay Area throughout the remainder of 2017. CACC trucks are being driven by a sampling of long-haul fleet truck drivers so they can provide their comments regarding the user interfaces and the relative merits of the different gap settings. The results of those experiments will be used to refine the estimates of energy savings potential that can be expected from heavy truck CACC systems.

### Related Projects and Activities

Caltrans has partnered with Arizona, New Mexico, and Texas to develop an Interstate-10 (I-10) connected corridor. The corridor coalition charter specifically mentions truck platooning as one of its goals to improve freight movement, safety, and efficiency along the corridor. The first corridor project is development of a connected freight corridor concept of operations. Testing of two truck platoons along the four state, I-10 corridor, including that portion east of the inland empire in California, is proposed. Elements of this project will require an extension of the provisions of SB 719.

A California Energy Commission project demonstrating truck platooning and other intelligent transportation systems around seaports to reduce congestion was recently awarded to a team led by the San Diego Port Tenants Association. The demonstration project runs through 2019. Successful completion of this project will also require an extension of the provisions of SB 719.

In a separate but parallel FHWA-sponsored Exploratory Advanced Research project, Auburn University led a team that examined two truck CACC truck platooning. The Auburn team utilized Peloton's CACC technology platform. The project had objectives very similar to those of the Caltrans led truck platooning project including, CACC system development and testing, test track evaluation of fuel economy, and calculation of system benefits stemming from improved traffic flow and mobility. Figure 7 shows the fuel savings from the Auburn project's fuel economy experiment.

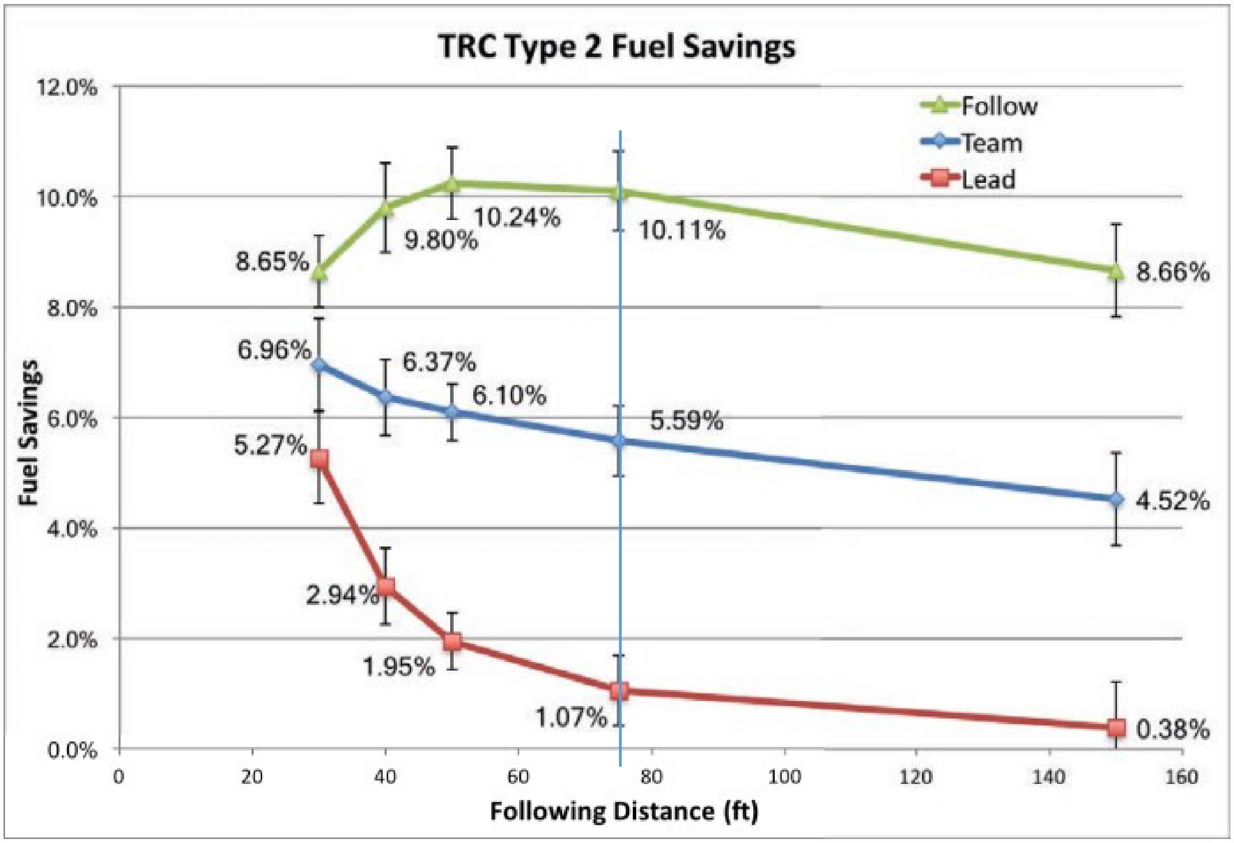

Figure 7–Percent Fuel Saved from TRC Type II Fuel Economy Testing

Although there are differences between Peloton's two-truck platoon and the Berkeley-Volvo three-truck platoon configuration as well as differences in the fuel consumption testing methodologies, there were similar results between the two sets of experiments when testing with a standard trailer and similar gaps.

| Platoon | Truck Position | Gap Distance | Fuel Savings |
|---|---|---|---|
| Berkeley-Volvo<br>Auburn-Peloton | Lead trucks | 57 feet<br>50 feet | 0.5%<br>2.0% |
| Berkeley-Volvo<br>Auburn-Peloton | Lead trucks | 86 feet<br>75 feet | -0.5%<br>1.0% |
| Berkeley-Volvo<br>Auburn-Peloton | Last truck | 57 feet<br>50 feet | 11.0%<br>10.2% |
| Berkeley-Volvo<br>Auburn-Peloton | Last truck | 86 feet<br>75 feet | 10.0%<br>10.1% |

Figure 8–Comparison of Fuel Savings from Two Fuel Consumption Experiments

Figure 8 compares the results of Figures 5 and 7. The Berkeley-Volvo platoons smallest gaps (57 feet and 86 feet) are similar to the two largest gaps (50 and 75 feet) tested by Auburn University. The fuel savings for the lead trucks varies from -0.5 and 2 percent, and the fuel savings for the last or following truck varies from 10 to 11 percent.

In a separate independent effort, Peloton has developed their own truck platooning technology, and has worked with Caltrans and CHP for approval to test their technology on California highways. They recently began testing their system in California under the authority of SB 719. Peloton refers to their CACC system as Driver Assistive Truck Platooning (DATP). DATP is similar to the Caltrans-Volvo-UC Berkeley CACC system for heavy trucks.

In addition to California, the following states have approved testing and demonstration of close-spaced partial automation technologies either through legislative or administrative means. Arizona, Florida, and Utah have passed enabling legislation; and Colorado, Nevada, and Oregon are allowing testing through administrative action.

Arkansas, Georgia, Michigan, South Carolina, Tennessee, and Texas have all passed legislation approving routine use of driver-assist close-spaced heavy truck platooning technologies.

### Conclusion and Next Steps

The tests of the heavy truck CACC system performed under the authority of SB 719 have advanced the maturity of CACC technology. These tests have validated that operation of vehicles at gaps shorter than the statutory 100 feet minimum, normally prohibited for caravans of vehicles traveling together, confer benefits when under close coordination. These closely coordinated vehicles have been demonstrated to:

- Reduce fuel consumption. In the case of heavy trucks, these savings can be in the range of 10 to 15 percent depending on a variety of factors.
- Enhance safety through coordinated braking with minimal delay.
- Improve traffic flow stability, reducing stop-and-go effects.
- Increase the effective capacity of highway lanes, reducing the adverse effects of congestion.
- Permit the free movement of other vehicles.

The closely coordinated CACC heavy trucks showed that they were able to interact safely and smoothly with drivers of other vehicles. During the course of the project testing and demonstrations, other drivers did not hesitate to change lanes into the gaps between trucks that were driving under CACC coordination. This persistence of lane changing demonstrated that close-spaced CACC trucks did not create an impediment to traffic movement and lane choice.

The authorization for carefully controlled testing at shorter gaps that was provided by SB 719 should be extended for two additional years. This extension will allow additional development and testing work needed to refine CACC technology such as:

- Understanding lane changing behavior and how other vehicles interact with platooning trucks.
- Determining the implications of cut-ins at various gap settings.
- Incorporating input of commercial vehicle drivers and fleets into the CACC design.
- Collecting and analyzing enough data for assurance that adequate testing has been performed.
- Allowing previously mentioned truck platooning research to continue in California.

## Appendix A. Statutory Reporting Reference

Senate Bill No. 719

CHAPTER 163

An act to add and repeal Section 14107 of the Government Code, relating to transportation.

[Approved by Governor August 10, 2015. Filed with

Secretary of State August 10, 2015.]

LEGISLATIVE COUNSEL'S DIGEST

SB 719, Hernandez. Department of Transportation: motor vehicle technologies testing.

Existing law provides that the Department of Transportation has full possession and control of the state highway system. Existing law requires the department to adopt a balanced, multimodal research and development program, including the research and development of new technologies, and to consult with affected state agencies, including, among others, the Department of the California Highway Patrol, in the performance of those duties.

Existing law establishes rules of the road for the operation of a vehicle on state highways and roads. These rules require motor vehicles being driven outside of a business or residence district in a caravan or motorcade, whether or not towing other vehicles, to be operated so as to allow sufficient space and in no event less than 100 feet between each vehicle or combination of vehicles so as to enable any other vehicle to overtake or pass.

This bill would authorize the department, in coordination with the Department of the California Highway Patrol, to conduct testing of technologies that enable drivers to safely operate motor vehicles with less than 100 feet between each vehicle or combination of vehicles and would exempt motor vehicles participating in this testing from the above-described rule. The bill would require the department to report its findings from the testing to the Legislature on or before July 1, 2017, and would repeal these provisions on January 1, 2018.

The people of the State of California do enact as follows:

SECTION 1. Section 14107 is added to the Government Code, to read: 14107.

(a) The department, in coordination with the Department of the California Highway Patrol, may conduct testing of technologies that enable drivers to safely operate motor vehicles with less than 100 feet between each vehicle or combination of vehicles.

(b) Notwithstanding Section 21705 of the Vehicle Code or any other provision of law, motor vehicles participating in testing of those technologies pursuant to subdivision (a) may be operated with less than 100 feet between each vehicle or combination of those vehicles.

(c) The department may only use motor vehicles and streets and highways in testing conducted pursuant to subdivision (a) that the Department of the California Highway Patrol authorizes for those uses.

(d) The department shall report its findings from the testing conducted pursuant to subdivision (a) to the Legislature on or before July 1, 2017. The report required by this subdivision shall be submitted in compliance with Section 9795.

(e) This section shall remain in effect only until January 1, 2018, and as of that date is repealed, unless a later enacted statute, that is enacted before January 1, 2018, deletes or extends that date.