



Automated Vehicles: Truck Platooning

ITS Benefits, Costs, and Lessons Learned: 2018 Update Report



Photo Source: USDOT

Driver Assistance

- Navigation / Route Guidance
- Driver Communication
- Vision Enhancement
- Object Detection
- Adaptive Cruise Control
- Connected Eco-Driving
- Intelligent Speed Control
- Lane Keep Assistance
- Roll Stability Warning
- Drowsy Driver Warning
- Precision Docking

Platooning

- In-Vehicle Monitoring

Highlights

- Class-8 trucks with standard-trailers net a fuel savings of between 5.2 and 7.8 percent in a three-truck CACC platoon. With aerodynamic-trailers, these savings can grow to 14.2 percent.
- Vehicle platooning has great potential to combine several technologies for safety, mobility, and environmental benefits for drivers and the transportation system.

Introduction

This factsheet is based on past evaluation data contained in the ITS Knowledge Resources database at: www.itskrs.its.dot.gov. The database is maintained by the U.S. DOT's ITS JPO Evaluation Program to support informed decision making regarding ITS investments by tracking the effectiveness of deployed ITS. The factsheet presents benefits, costs and lessons learned from past evaluations of ITS projects.

The United States Department of Transportation (USDOT) highlights truck platooning as an early application of automated vehicle deployment in the freight industry. As a cooperative system, fully and partially automated trucks, ships, and intermodal freight-transfer facilities can interoperate with automated logistics-driven supply chain management systems to fundamentally transform the global movement of goods. Although autonomous vehicles are not expected to suddenly appear on our nation's roadways, cooperative systems that can connect trucks with infrastructure systems, and exchange information critical to vehicle control and operations are at the forefront of research in the commercial arena.

On trucks, on-board computers monitor sensor systems and integrate data from adaptive speed control, automatic braking, lane-departure warning systems, and vehicle-to-vehicle (V2V) dedicated short-range communication (DSRC) systems. By allowing sensors on one truck to communicate with sensors on another truck, partially automated trucks can travel more closely together to improve fuel efficiency, in a practice known as truck platooning or truck trains.

“Platooning and CACC could provide significant increases in highway efficiency. Our research shows that it can reduce the workload for drivers as well as vehicles, reduce emissions, and reduce the enormous fuel expenses involved in freight transportation”
- Osman Altan (USDOT)¹

Truck platooning works by creating a close, constant coupling between platooning vehicles, providing fuel benefits for both the lead and following truck(s). Operating as a unit, truck platoons can also smooth traffic flow to increase efficiency and roadway capacity. Several technologies work together to support this type of interaction: Adaptive Cruise Control (ACC), Cooperative Adaptive Cruise Control (CACC), and truck automation.

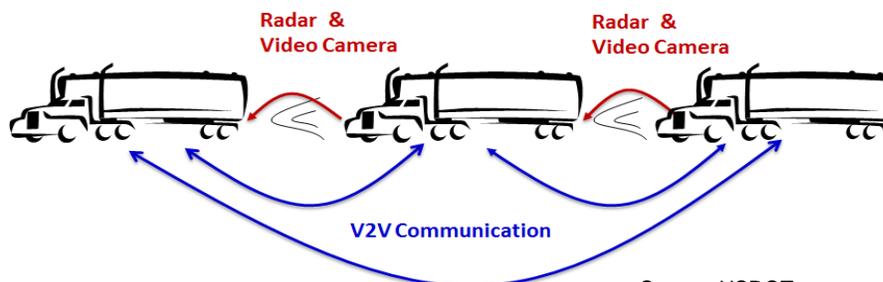
ACC supports truck platooning but is not considered a truck platooning system in its own right. ACC systems permit the driver to choose a set speed and activate automated brake and throttle systems to maintain safe following distances. However, the driver is still responsible for steering the vehicle and maintaining an awareness of road conditions in order to minimize headways and maximize performance.

Although approximately 100,000 ACC-equipped Class 8 trucks currently operate on U.S. roadways, ACC has not been used for truck platooning as it lacks the coordination and control mechanisms needed to safely manage very short headways between large trucks.

CACC was developed to address coordination shortfalls between ACC-equipped vehicles and safely minimize following gaps. CACC extends an ACC system by including V2V communication to provide important speed and location information from the vehicle in front of the platoon and supplement in-vehicle sensors (including radar, LiDAR, cameras, ultrasonic sensors). This additional information allows following vehicle(s) to adjust speed quickly enabling shorter following gaps, and consequently, smoother acceleration and deceleration profiles to reduce aerodynamic drag and improve fuel economy and emissions for vehicles in the platoon.

Although ACC and CACC are examples of Level 1 automation as defined by both SAE and NHTSA, a higher level of automation would be needed for anything more than the lowest level of vehicle-following performance where only speed is controlled. As with ACC systems, drivers using CACC systems are required to actively steer the vehicle and monitor roadway and traffic conditions. In the future, global coordination strategies that support fleet operations will be required for higher levels of automation. For maximum benefit, operators can use global, local, or ad hoc coordination strategies to form platoons. Researchers at the California Partners for Advanced Transportation Technology (PATH) describe four primary stages of truck platooning.²

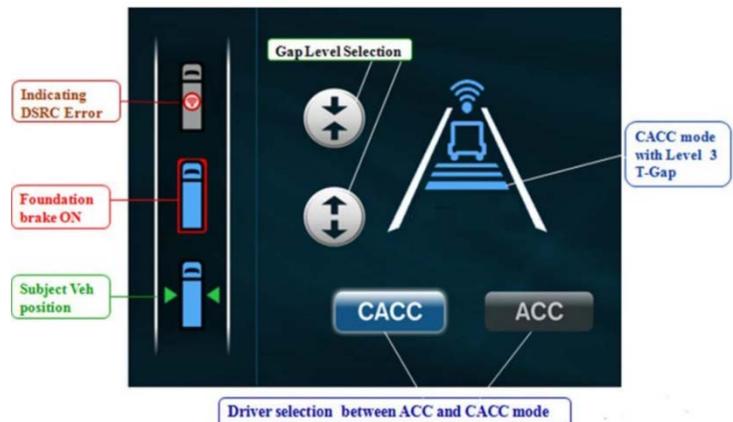
1. Forming – During the first stage of truck platooning, trucks must identify potential platoon partners based a range of characteristics, including their current location, destination, the number of stops, type of truck, and other variables. This information may be difficult to ascertain if other drivers work for competing firms. To mitigate this issue, current research is evaluating three different methods for forming the platoon:
 - a. Scheduled Platooning - A transport company planner can schedule multiple trucks to form a platoon at a given departure time and location. Trucks assigned as part of the platoon know when to break off.
 - b. Platooning Service Provider (PSP) - Similar to scheduled platooning, in this method an external specialized company works with multiple trucking companies and individual truck drivers to match them up based on their starting location, departure time, and final destination. The trucks would need to be outfitted with platooning technology and devices allowing the PSP to know where they are headed and their travel times. Using this information, the PSP matches trucks for given sections of their trips and then forms new platoons later with different trucks going in other directions.
 - c. On-the-fly platooning - As platooning becomes more mainstream, trucks will not need a single entity like the PSP to coordinate travel. Trucks will be able to form platoons spontaneously with required information being transmitted between partnering trucks. This method provides the most flexibility over the other methods but also requires the largest market penetration of platooning-equipped trucks for proper execution.
2. Steady-State Cruising - The cruising stage occupies the largest period of time while the platooning system is activated. Once a platoon is formed, the drivers will operate the vehicle based on the level of automation in the vehicle. Steady-state cruising would be modified as trucks join or drop out of the platoon or when an unequipped vehicle cuts in. A majority of truck platooning benefits accrue during the cruising stage.
3. Departing or Splitting - Trucks may depart from the platoon when needed in order to complete their trips or make a trip deviation. Once the departing truck has left, the trucks that were following it rejoin the original platoon and close the gap left by the departing vehicle.
4. Abnormal Conditions - This last stage accounts for other situations that are not addressed in the previous three stages. This stage can include potential errors in the system or abnormal operating conditions. Any truck platooning system will need to be able to identify and resolve these unexpected abnormalities.



Source: USDOT

Truck platooning technology typically includes the following:

- **Sensors** - A combination of both short and long range sensors are used to evaluate the complete environment around the vehicle so it can track not only other vehicles in the platoon but all other objects in the road, including pedestrians and cyclists. Sensors such as LIDAR (light detection and ranging), radar, and cameras all work in conjunction to provide a complete image of the surroundings. The use of different types of sensors provides redundancy in the system.
- **Localization services** - Global positioning systems (GPS) and inertial navigation systems (INS) are used to determine the location of the vehicle. These systems provide the necessary information to the vehicle to accurately establish the spacing between the platoon vehicles. As with sensors, the system needs to be redundant so if the GPS temporarily fails (as in low coverage areas or tunnels) the INS can use motion sensors and rotation sensors to determine the vehicle orientation until the GPS reestablishes its connection.
- **V2V communication** - DSRC is utilized for low latency exchange of vehicle performance parameters between vehicles. An extension of Wi-Fi technology, DSRC communicates passing speed and locational information, which allows CACC system to quickly adjust to changing speeds and positions, facilitating an effective platoon.
- **Software** - Each CACC system requires software-based algorithms that are used to process all of the information from the sensors, the vehicle, and V2V communications. These algorithms are the core of the CACC systems as they are required to predict the movement and speed of the vehicle in front to set the new speed of the following vehicle.
- **Hardware** - There is a broad range of hardware components distributed throughout the vehicle that houses the software for the CACC, connects critical systems, and controls the vehicle speed and braking.
- **Human interface** - The Human Machine Interface informs the user about changes in the CACC stages. As CACC matures, methods that provide CACC information without causing driver distraction will need to be developed and tested.



The list below describes how platooning can be incorporated into the SAE scale of automation.³

- **Level 0: No Automation** – Truck platooning is not possible at this level.
- **Level 1: Driver Assistance** – ACC is currently at this automation level, as the truck platooning technology is only assisting the driver. The driver is mostly in control of the vehicle and each automated function is separate.
- **Level 2: Partial Automation** – At this level vehicle communication and acceleration functions combine with lane centering technologies to control the majority of vehicle functions. However, the driver is still present and retains control of dynamic driving functions.
- **Level 3: Conditional Automation** – At this level drivers cede full control of vehicle functions in certain traffic, roadway, or weather conditions. The automated driving system is now tasked with monitoring the external traveling environment. Drivers are still responsible for promptly responding to requests to intervene and resume control of the vehicle.
- **Level 4: High Automation** – At this level there is a designated driver, but the truck can drive itself under certain roadway, traffic, and weather conditions and the driver does not need to be aware of the roadway or the actions of the lead truck while in a specific driving mode.
- **Level 5: Full Automation** – At this level there is no designated driver. Level 5 allows for fully autonomous driving in all driving modes, including freeway cruising, merging, lower speeds, traffic jams, and other conditions. This level of automation is still in its early stages of research and will not be seen on roadways in the near future.

Benefits

Evaluation studies of truck platooning focus on improved fuel economy (and lower operating costs) due to the aerodynamic effects of closer vehicle spacing, and more efficient use of highway facilities through increased mobility and throughput.

- Connectivity between trucks equipped with automated vehicle technology allow them to operate more smoothly as a unit and automatically reduce and control following gaps between vehicles. Class-8 trucks with standard-trailers net a fuel savings of between 5.2 and 7.8 percent in a three-truck CACC platoon. With aerodynamic-trailers, these savings grow to 14.2 percent at a minimum separation distance of 17.4 m (57.1 ft). ([2018-01246](#))
- The tractor trailer platooning demonstration funded by the Department of Energy NREL using DSRC V2V communications demonstrated fuel savings for the lead truck (up to 5.3 percent) and the trailing truck (up to 9.7 percent); with the platooned pair saving up to 6.4 percent. Variable conditions—ambient temperature, distance between lead and trailing truck, and payload weight—influence the savings. ([2015-01054](#))
- The UC PATH program in California modeled the influence of wind resistance and shorter following made possible with CACC and estimated potential peak fuel efficiency benefits of 20 to 25 percent. Researchers noted, however, that such short following gaps (10 to 20 feet) would likely require dedicated truck lanes as the ability of other traffic to change lanes across platoons would be limited and platoons would have difficulty responding safely to emergency conditions. ([2016-01066](#))
- The FHWA-sponsored research conducted by Auburn University has produced preliminary findings on travel time savings from truck platooning. A traffic microsimulation study of driver assistive truck platooning (DATP) found a travel time reduction benefit for each of the simulation cases featuring current traffic and two increased levels (115 percent and 130 percent) of traffic volumes on a five-mile section of I-85 in Alabama. Travel time savings during peak hour traffic conditions ranged from a two percent improvement (with 20 percent market penetration) to 69 percent improvement (with 100 percent market penetration). ([2017-01200](#))
- A truck platooning business case study conducted in the Netherlands for three logistics service providers found that compared to conventional cruise control, fuel savings alone from platooning already offsets annual costs, and labor cost savings are pure profits. ([2017-01135](#))

Costs

Although promising, the business case or return on investment (ROI) for truck platooning is still not clear. When surveyed by the American Trucking Research Institute (ATRI) regarding the business case for truck platooning as part of the FHWA-sponsored study of DATP, owner-operators expected a mean payback on investment period of 10 months, while fleet respondents expressed a mean payback expectation of 18 months. Freight companies are currently analyzing the benefits and costs of adopting platooning technology. Additional costs may include equipment acquisition, driver training, logistics and coordination, testing, and insurance costs.⁴

Lessons Learned

In Europe, a large scale demonstration project provided insight into the challenges faced when attempting to coordinate participation from multiple carriers, manufactures, and roadway authorities to achieve interoperability across jurisdictional boundaries.⁵ The platooning project called the European Truck Platooning Challenge involved six bands of automated trucks (DAF, Daimler, Iveco, MAN, Scania, and Volvo) that traveled on public roads from several European cities to a common destination in the Netherlands. The following key challenges and knowledge gaps were identified by 69 participant stakeholders who envisioned wide-ranging support for truck platooning by 2025.

Safety and Security

- Demonstrate functional safety of platooning; Cyber security, hacking, and wireless communication security; Safe and reliable braking behavior in emergency situations; Reliability of sensors, components, parts, wireless communication; Safety administration (logging of platooning-related accidents, traffic situations and driver status); Privacy of truck drivers and logging data security; and Immunity to wireless signal jammers.

Technology

- Multi-brand platooning and standardized communication protocols; Active platoons using signaling lights for visibility by other road users; Platoon sequencing (accommodating trucks with various torque ratings, brake capacity and loading weights); Wireless V2X communication reliability; Full platoon control under all mixed traffic situations; Technology development roadmap disparities among truck manufacturers; Effective and real-time estimation of safe inter-vehicle gap distance.

Legal

- Responsibility and liability in the event of an incident when control has been transferred to the system; Driving and resting time regulations amended for driverless vehicles; Vehicle approval procedures; Vehicle following gap distance legislation, Platoon length restrictions (number of vehicles per platoon); Labor rules to assess what is permitted for drivers while platooning.

Logistics Business

- Identifying and guiding trucks that could meet-up together to dynamically form an ad-hoc platoon; System cost and business case for SAE Level 1 or 2 platooning; Platooning service provider to execute platoon formation from differing fleet-owners and brands; Certification of trucking companies and drivers to promote confidence; Logistics process integration to adapt to platooning (routing, inventory management, warehouse operations); Promote business benefits (explain the value of platooning); Decide on the best method of platoon formation (scheduled or ad-hoc platooning or a combination of both); Minimal haul length required to efficiently allow diversion/detours to form platoons; Use real-time data logistics control towers for ad-hoc platoon formation; Urge shippers and carriers to make platooning more attractive by consolidating more loads in the same direction.

User Acceptance and Human Behavior

- Interaction with other road users, e.g. when entering and exiting motorways; Driver acceptance by demonstrating safety and learning to trust the system; Train other road users to accommodate platoons; Driver task trade-off attention versus boredom; Driver job satisfaction insecurity issues; Public opinion backlash against 'wall of trucks'; Promote societal benefits through positive communication; Anxiety and exhaustion due to small gap distance; Driver training and certification for platooning.

Case Study – FHWA’s Exploratory Advanced Research (EAR) Program

In the United States, the FHWA’s Exploratory Advanced Research (EAR) Program is currently evaluating automated truck technologies to assess feasibility for platooning operations. In a recent field test conducted in live traffic on I-66 in Centreville, Virginia the concept of truck platooning was demonstrated using state-of-the-art Level-1 cooperative adaptive cruise control (CACC) technology. The system installed on three Volvo trucks used advance onboard DSRC (5.9 GHz) wireless radios as to transmit and receive SAE J2735 basic safety messages (BSM) such as position, speed, heading, and brake status at a rate of 10 times per second while automated cruise control (ACC) radar systems measured following distances and communicated with the on-board computers to actuate brake and throttle controls automatically as needed to maintain a headway distance of 45 to 50 feet at 55 mi/h.⁷ Drivers were responsible for steering, but relied on CACC systems to detect cut-in passenger vehicles and increase or decrease following gaps as needed for safe operations.

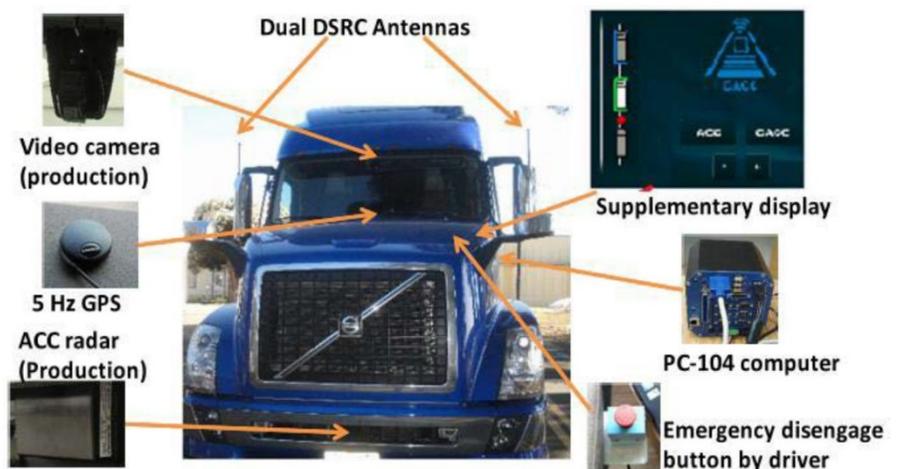


Photo Source: USDOT

Benefits of CACC⁸

V2V wireless communication enabled closer vehicle following between equipped trucks to support:

- Aerodynamic drafting to save energy
- Higher capacity of truck lanes, with higher traffic density but reduced congestion
- Enhanced stability of traffic flow
- Improved safety through faster responses to potential problems ahead
- Reduced driver stress by reducing frequency of cut-ins by other drivers.

References

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[2] *Cooperative Adaptive Cruise Control (CACC) for Truck Platooning: Operational Concept*, University of California, PATH Institute of Transportation Studies. Berkeley, CA. March 2015. <https://cloudfront.escholarship.org/dist/prd/content/qt7jf9n5wm/qt7jf9n5wm.pdf>

[3] "Automated Driving: Levels of Driving Automation," SAE International Standard, SAE J3016. 2016. http://www.sae.org/misc/pdfs/automated_driving.pdf

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[7] "FHWA Demonstrates 3-Truck Platoon in Virginia," Transport Topics. Arlington, VA. 15 September 2017. <http://www.ttnews.com/articles/fhwa-demonstrates-3-truck-platoon-virginia>.

[8] "Measuring Truck Energy Savings Using Cooperative ACC in 2016," USDOT FHWA Website. https://www.fhwa.dot.gov/research/truck_platooning/TruckPlatoonDevelopment%20POSTERS%20FOR%20DO WNLOAD.zip. Last Accessed 14 February 2018.

All other data referenced is available through the ITS Knowledge Resources Database, which can be found at <http://www.itsknowledgeresources.its.dot.gov/>.