CONFIDENCE REPORT: Two-Truck Platooning

ABSTRACT This report documents the confidence that North American Class 8 trucking should have in the emerging technology of two-truck platooning. The study team engaged with the entire industry in generating the findings that are presented here. Thanks to all of those who contributed to this important work.

Trucking Efficiency is a joint effort between NACFE and Carbon War Room to double the freight efficiency of North American goods movement through the elimination of market barriers to information, demand and supply.

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Executive Summary

The fuel costs faced by the tractor-trailer industry have been swiftly and steadily rising over the past decade. In 2014, diesel fuel costs were $0.58 per mile, costing the industry as much per annum as the costs of drivers' wages and benefits combined. Despite recent fuel cost decreases, all indications are that fuel price volatility will continue, forcing the industry to find solutions that increase its fuel efficiency in order to stay profitable. Additionally, the U.S. EPA and NHTSA have finalized the details of the Greenhouse Gas Phase 2 regulations requiring tractor, trailer, and engine OEMs to offer and produce more fuel-efficient equipment.

Fortunately, myriad technologies that can cost-effectively improve the fuel efficiency of Class 8 trucks are readily available on the market today. Unfortunately, multiple barriers have stymied industry adoption of such technologies, including a lack of data about the true performance gains these technologies offer, and a lack of confidence in the performance-testing data that does publicly exist today. To overcome those barriers and facilitate the industry's trust in and adoption of the most promising fuel efficiency technologies, the North American Council for Freight Efficiency (NACFE) partnered with Carbon War Room (CWR) to form Trucking Efficiency. The work of Trucking Efficiency has begun by producing a series of Confidence Reports, of which this report on two-truck platooning is the fourteenth.

However, this report represents the first in a subset of reports to be published on emerging technologies. Widespread innovation and technological advances are seeing the emergence of technologies and practices that could affect decisive opportunities across the transportation industry. As novel concepts, new applications, and innovative modes of behavior reach the market, fleets and manufacturers need information on their benefits, challenges, and risks so that everyone can profit in this evolving landscape. NACFE will lead this effort, with plans to publish Confidence Reports on technologies such as variable engine accessories, waste heat recovery, powertrain electrification, and others.

Methodology

This report's conclusions were generated through desk research, conversations at a variety of trucking industry events around the country, and a series of structured interviews with fleets, truck OEMs, and platooning technology developers/manufacturers active in the North American market today.

This study differs from past Confidence Report efforts in which the Trucking Efficiency team reviewed products available in the marketplace. As platooning is an emerging technology, only available in limited deployment, the team is using its common approach to understanding the confidence fleets should have in adopting the devices before they become available. Thus, this work does not report known benefits and consequences of adoption, but rather what the industry believes the benefits and challenges of the new technology will be.

"TWO-TRUCK PLATOONING IS SHOWING REAL PROMISE AS A FUEL-SAVING TECHNOLOGY, EVEN WHEN CONSIDERING THE ACTUAL PERFORMANCE IN REAL-WORLD USE."
Mike Roeth, Operation Lead, Trucking Efficiency and Executive Director, NACFE

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The goals of this Confidence Report are: (a) to give the industry a foundational understanding of two-truck platooning; (b) to put it in context with the longer-term autonomous trucking initiative; (c) to provide an unbiased overview of the benefits and challenges related to platooning; and (d) to help fleets rationalize their investment in two-truck platooning.

Truck platooning is an emerging transportation technology designed to boost fuel economy performance for tractor-trailers engaged in long- and regional-haul highway applications. Platooning combines existing commercial vehicle safety technology with emerging vehicle-to-vehicle communications and autonomous vehicle control technology to electronically "tether" tractor-trailers together in a convoy formation at highway speeds. Once a platoon of trucks is established, the vehicles' safety systems work in unison to draw the trucks together at significantly reduced following distances to overcome each vehicle's inherent aerodynamic drag.

FUEL SAVINGS OF PLATOONING

Without question, truck platooning is a valid method of reducing fuel consumption for tractor-trailers engaged in long-haul applications. Once the trucks have moved into close following distances, all of the engaged vehicles receive a significant fuel economy boost thanks to increased aerodynamic efficiencies. The lead vehicle, which bears the brunt of the aerodynamic load, typically sees only a modest fuel economy boost. But the trailing truck in a platoon, which is now operating in a low air pressure aerodynamic "sweet spot," can see significant increases in fuel economy performance at highway speeds. Moreover, overall fleet operations remain largely intact in terms of vehicle routing and operations.

The potential fuel consumption savings versus an isolated single vehicle varies depending on the separation distance of the trucks (as shown for the lead vehicle in Figure ES1). Multiple fuel consumption tests have been conducted over the past few decades to better understand this efficiency improvement. A separation distance of 40 to 50 feet could lead to average savings of about 10% for the following vehicle and 4% for the lead vehicle.

However, real-world factors such as congestion, terrain, weather, and road construction will reduce these savings, so fleets will have to estimate this reduction depending upon the routes on which they plan to operate the trucks; a reasonable estimate would be a reduction of about a quarter of the savings, but very little data exists for this prediction. A fleet must also apply the percentage of operating time that the truck equipped with platooning will actually be involved in a platoon, which NACFE research suggests will be less than 100%. If that were 75%, then the real-world, expected savings would be on the order of 4% average for both trucks. Even if a truck is platooning 50% or less, it still represents significant potential improvement in fuel use for the following vehicle in a platoon.

FIGURE ES1: FUEL CONSUMPTION REDUCTION VS. SEPARATION DISTANCE—LEAD VEHICLE

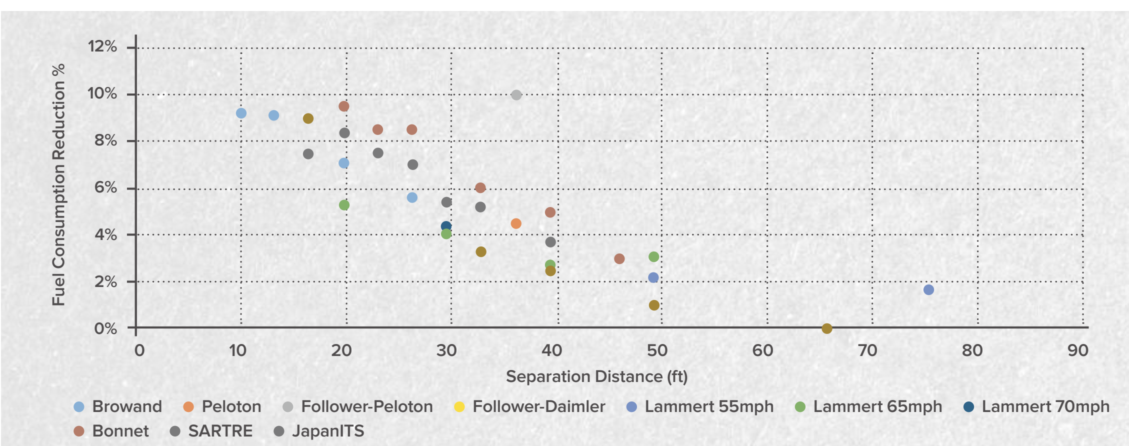
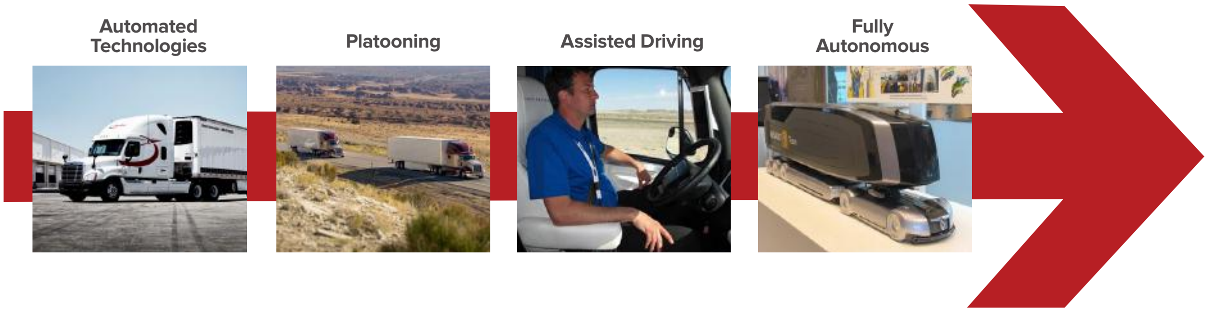


FIGURE ES2: EVOLUTION TO AUTONOMOUS TRUCKING



IMAGES, LEFT TO RIGHT: RYDER, PELOTON, DAIMLER TRUCKS, UMEA INSTITUTE OF DESIGN

PLATOONING AND AUTONOMOUS TRUCKS

Platooning is a catchall term for a broad range of possible implementations of fuel economy improvement through controlled operation of two or more trucks in tandem. The term may have different meanings for different people. One future vision is a fully autonomous vehicle with no driver that is operating in a road train.

The initial platooning steps are technology building blocks toward this eventual fully autonomous vehicle, which could be decades away. The Confidence Report includes background on where these technologies are headed to add perspective. However, NACFE's goal is to stay grounded in reality with near-term two-truck platooning opportunities where human drivers have their hands on the wheel and the technology is assisting the driver in getting better fuel economy by reducing aerodynamic drag through safely following another vehicle at shorter distances than an unassisted driver could safely maintain.

OVERCOMING PERCEIVED AND REAL CHALLENGES

The challenges of implementing two-truck platooning include:

Payback—The payback for platooning is driven by many factors, including the upfront cost for the equipment, any subscription costs for platooning, the savings in fuel, the costs to mitigate any of the challenges, and the level to which the fleet is already investing in safety technologies. A payback calculator is provided with the report.

Driver acceptance—Drivers must learn, and become comfortable with, an entirely new operational dynamic behind the steering wheel. However, despite widespread industry concerns of driver physiology and safety, it appears that platooning technology and its integrated safety systems are powerful and fast enough to substantially overcome reduced driver fields of view and reaction times. Platooning also has an extremely shallow learning curve and requires minimal additional training for drivers to become proficient.

Platoon integrity—A commonly cited concern is how the platooning trucks and the individual drivers will react if passenger cars move into the gaps between platooning trucks to get out of a passing lane or get to a highway exit ramp. However, each vehicle's active safety systems would react exactly as they would if a vehicle cut a single truck off in traffic today: The brakes would immediately engage and slow the truck until it achieves a safe following distance behind the intruder vehicle. Likewise, any trucks behind the threatened truck would react accordingly.

System security—In order to prevent "hackers" from breaking into platooning communications systems, security will be paramount. Primary concerns will be to develop encryption that will protect systems from hackers looking to obtain proprietary information about a specific vehicle or fleet specifications as well as prevent the ability to disable safety systems or assume control of autonomous vehicle systems with the intent to deliberately crash or divert a vehicle.

Amount of viable platooning time—It is an open question whether platooning might be a viable option only a small percentage of the time and whether any fuel savings would justify the outlay in acquisition and operational costs. This cannot be answered until more information concerning platooning's durability, flexibility, and ease-of-use in day-to-day fleet operations has been gathered.

Legislative efforts and public awareness—Changes to traffic laws that reflect the impact this new technology will have on our highway transportation need to be considered on both the state and federal levels. OEMs and platooning technology developers are working with the American Trucking Association and state-level trucking associations to raise awareness about truck platooning and its potential fuel-saving benefits with lawmakers. On September 20, 2016, the U.S. Department of Transportation issued its Federal Automated Vehicle policy, which will facilitate technology research, testing, and implementation, including aspects of two-truck platooning.

Sharing fuel savings—A concern is how competing fleets will compensate each other to maximize the benefits of fuel economy credits. Solutions range from a cloud-based "banking" system that would record overall platooning participation and allocate credits, to relying on the law of averages to even out penalties and benefits for fleets that regularly engage in platooning operations.

Reliability—Reliability of platooning technology systems remains unknown, as there is little field history on these systems. This is critical because as platooning separation distances decrease, reaction times required for safe operation become too short for the human driver to be a viable back-up system. However, on-highway platooning research demonstrations will evolve into production systems and reliability will improve based on feedback from actual use.

Litigation—Imbedded in operating costs is a need to address the potential impact of litigation. While a detailed discussion is beyond the scope of the Confidence Report, NACFE has identified key operating cost questions needing clarification for platooning to progress.

TECHNOLOGIES

NACFE's focus with this report is on the potential for fuel economy improvement with near-term two-truck platooning that makes use of current production driver-assistance systems and emerging vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication systems. These are real-world systems that fleets will be encountering in the next five years rather than futuristic visions.

Required technology to enable platooning includes:

- **Collision avoidance system:** The ability to safely brake the vehicle faster than human reaction times, and to sense surrounding traffic conditions.
- **Adaptive cruise control:** A system for maintaining a set distance (or time) to a lead vehicle using a variety of methods such as laser and radar systems.
- **MPG optimization systems:** Software, sensors, and hardware that can optimize individual vehicle fuel economy performance based on surrounding traffic and environmental conditions.
- **Vehicle transmission of sensor data:** Ability to transmit collision avoidance and adaptive cruise information to other vehicles.
- **Vehicle reception of sensor data from other vehicles:** Ability to receive and process the sensor data from other vehicles.
- **Platooning software:** Software that makes use of the other vehicle's sensor data to adjust performance of your vehicle.
- **Platoon MPG optimization software:** Software that allows two vehicles to perform even better by concurrently optimizing their individual performance knowing they are in a group.
- **Enhanced platoon MPG optimization software:** Software that allows a group of vehicles to optimize performance as a group.

Many of these systems are already being spec'd on North American tractor-trailers in large numbers, and purchasing trends indicate the "take rate" for these systems is growing. Equally important is NACFE's strong suspicion that many—if not all—of these safety systems will be mandated as standard equipment on all new Class 8 vehicles in the near future, as will V2V communication systems. Moreover, it is extremely likely that similar safety systems and V2V communication systems will be mandated for all new passenger cars and vehicles in the same general timeframe as well. Therefore, it is extremely likely that in the near future, Class 8 tractors will be sold as platooning capable "right out of the box," making it extremely easy for fleets to take advantage of platooning as a fuel-saving technique.

"SAFETY SYSTEMS ON THE TRUCK REACT MUCH, MUCH FASTER THAN A HUMAN DRIVER CAN."
Jack Roberts, NACFE Study Manager

CONCLUSIONS AND RECOMMENDATIONS

Given the current availability of information on two-truck platooning, the study team found:

- The real-world fuel savings of two-truck platooning is likely to be a 4% average across the two trucks.
- The bulk of the required technology is currently available and being purchased by many fleets.
- Intervals of 40 to 50 ft. will likely have sufficient payback for early adopting fleets, and then shorter distances, with their higher fuel savings, can be implemented with product improvements.
- Two-truck platooning is not fully autonomous/driverless trucking and it is actually being improperly grouped with that concept.
- Driver stress will likely be less than perceived to date.
- Platooning will accelerate the adoption of other technologies such as collision avoidance and adaptive cruise control.

The recommendations for the industry to focus on and expedite the speed with which platooning is introduced and adopted include:

- Evaluate the real-world fuel economy possible with platooning in a set of tests with real trucks on real routes with varying levels of truck and passenger car congestion.
- Expedite standard communication protocols and security measures within the groups already working on them.
- Expand OEM and fleet testing to ensure appropriate functionality and reliability of all system components.
- Develop driver education to increase the understanding and performance of driving trucks in platoons.

IMAGE: MERITOR WABCO

- Ensure all costs and benefits are monetized and improved in total cost of ownership and payback analyses.

Over time, as both industry and general-public comfort levels concerning platooning rise, it is likely the scope and scale of platooning as an industry practice will grow and fleets will see the percentage of time trucks spend in platooning mode rise accordingly. Therefore, NACFE predicts that initial platooning operations in North America will be limited to intra-fleet activity until the industry has a better feel for how platooning works in the real world and concerns regarding data transmission between vehicles have been alleviated.

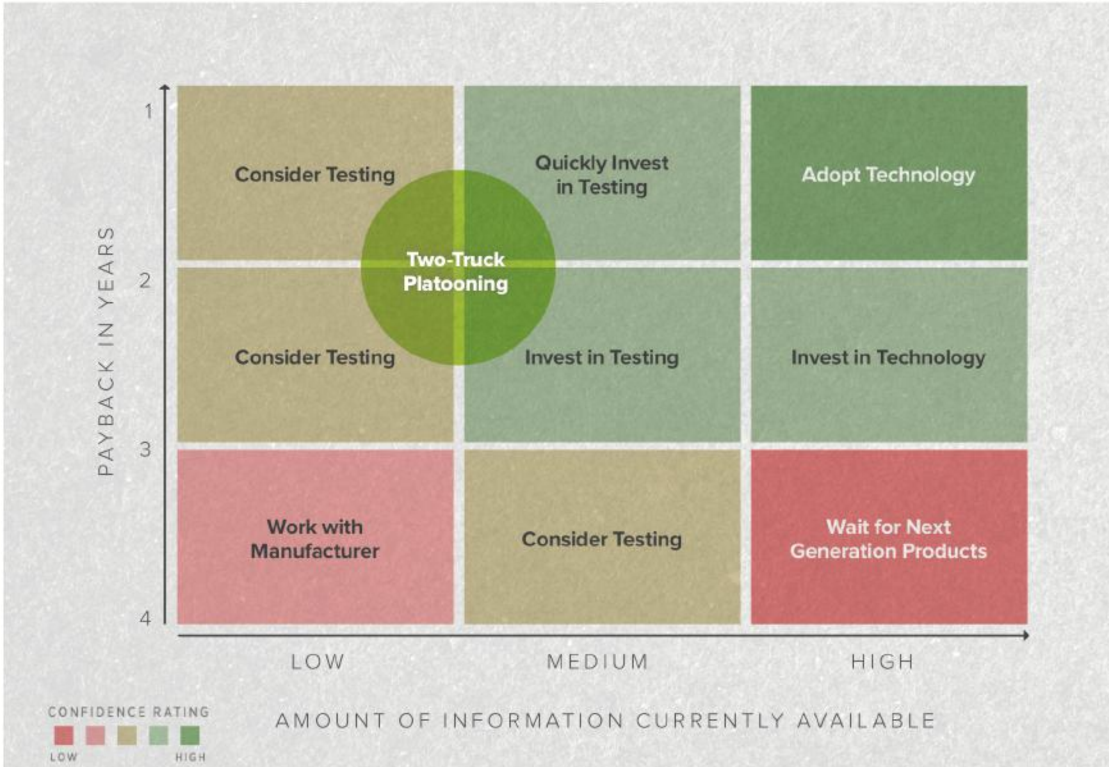
CONFIDENCE RATING

For each of the Confidence Reports completed by Trucking Efficiency, the various technologies assessed therein are plotted on a matrix in terms of their expected payback in years compared to the confidence that the study team has in the available data on the performance of that technology—that is, not only how quickly fleets should enjoy a payback on their investment, but how certain Trucking Efficiency is in the assessment of that payback time. Technologies in the top right of the matrix have a short payback, usually thanks to their low upfront cost and, moreover, are found to have enough performance data that fleets can be highly confident in those short payback times, usually because the technology is more mature or otherwise has a more substantial track record of results.

Trucking Efficiency is confident that the potential for fuel savings with platooning is strong, but it is likely that platooning opportunities in real-world fleet operations will initially be extremely limited. Early platooning adopters will be large, dedicated fleets with numerous trucks operating on a given stretch of highway. The potential for some fuel savings for regional and super-regional fleets pulling similarly enclosed trailers exists, but will likely not materialize until platooning becomes a widely accepted industry practice and opportunities for extra-fleet platooning become commonplace.

Trucking Efficiency is always seeking to expand the data or case studies that we can provide to the industry. We invite you to share your own experiences with tractor aerodynamic technologies.

CONFIDENCE MATRIX: TWO-TRUCK PLATOONING



TRUCKING EFFICIENCY

Trucking Efficiency is a joint effort between NACFE and Carbon War Room to double the freight efficiency of North American goods movement by eliminating barriers associated with information, demand, and supply.

Worldwide, heavy-duty freight trucks emit 1.6 gigatons of CO_2 emissions annually—5.5% of society's total greenhouse gas emissions—due to the trucking sector's dependence on petroleum-based fuels. With fuel prices still commanding nearly 40% of the cost of trucking, the adoption of efficiency technologies by all classes of trucks and fleets offers significant cost savings to the sector while reducing emissions. These technologies are relatively cheap to implement and widely available on the market today.

Trucking Efficiency provides detailed information on cost-effective efficiency technologies, including data from across a variety of fleets and best practices for adoption. This Confidence Report series from Trucking Efficiency aims to serve as a credible and independent source of information on fuel efficiency technologies and their applications.

In order to generate confidence on the performance claims of efficiency technologies, Trucking Efficiency, via these reports, gathers and centralizes the multitude of existing sources of data about the performance results of different technology options when employed in a variety of vehicle models and duty cycles, and makes all of that data openly accessible and more easily comparable. Furthermore, we assess the credibility of the available data, and provide an industry-standardized ranking of confidence in performance results, including ROI and efficiency gains.

www.truckingefficiency.org

Trucking Efficiency welcomes outside views and new partners in our efforts to help accelerate the uptake of profitable, emission-reducing trucking technologies.

CARBON WAR ROOM

Carbon War Room (CWR) was founded in 2009 as a global nonprofit by Sir Richard Branson and a group of likeminded entrepreneurs. It intervenes in markets to accelerate the adoption of business solutions that reduce carbon emissions at gigaton scale and advance the low-carbon economy. CWR merged with Rocky Mountain Institute (RMI) in 2014 and now operates as an RMI business unit. The combined organization engages businesses, communities, institutions, and entrepreneurs to transform global energy use to create a clean, prosperous, and secure low-carbon future. The combined organization has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

www.carbonwarroom.com

NACFE

The North American Council for Freight Efficiency works to drive the development and adoption of efficiency-enhancing, environmentally beneficial, and cost-effective technologies, services, and methodologies in the North American freight industry by establishing and communicating credible and performance-based benefits. The Council is an effort of fleets, manufacturers, vehicle builders, and other government and non-governmental organizations coming together to improve North American goods movement.

www.nacfe.org

1. Introduction

This Confidence Report forms part of the continued work of Trucking Efficiency, a joint initiative from the North American Council for Freight Efficiency (NACFE) and Carbon War Room (CWR) highlighting the potential of fuel efficiency technologies and practices in over-the-road (OTR) goods movement. Prior Confidence Reports and initial findings on nearly 70 available technologies can be found at www.truckingefficiency.org.

The fuel costs faced by the tractor-trailer industry have been extremely volatile over the past decade, as shown in Figure 1. Truck operating costs have seen steady inflationary increases for labor, but, as Figure 2 shows, in 2013 fuel costs surpassed those for the driver, while in 2014 they began decreasing to $0.58 per mile, on par with the costs for the driver (wages plus benefits). By 2015, through an unexpected combination of global political and economic forces, fuel prices had actually dropped to 50% of their 2008 levels. These significant swings in fuel cost are expected to continue into the future, motivating the trucking industry to find solutions that increase its fuel efficiency in order to stay profitable.

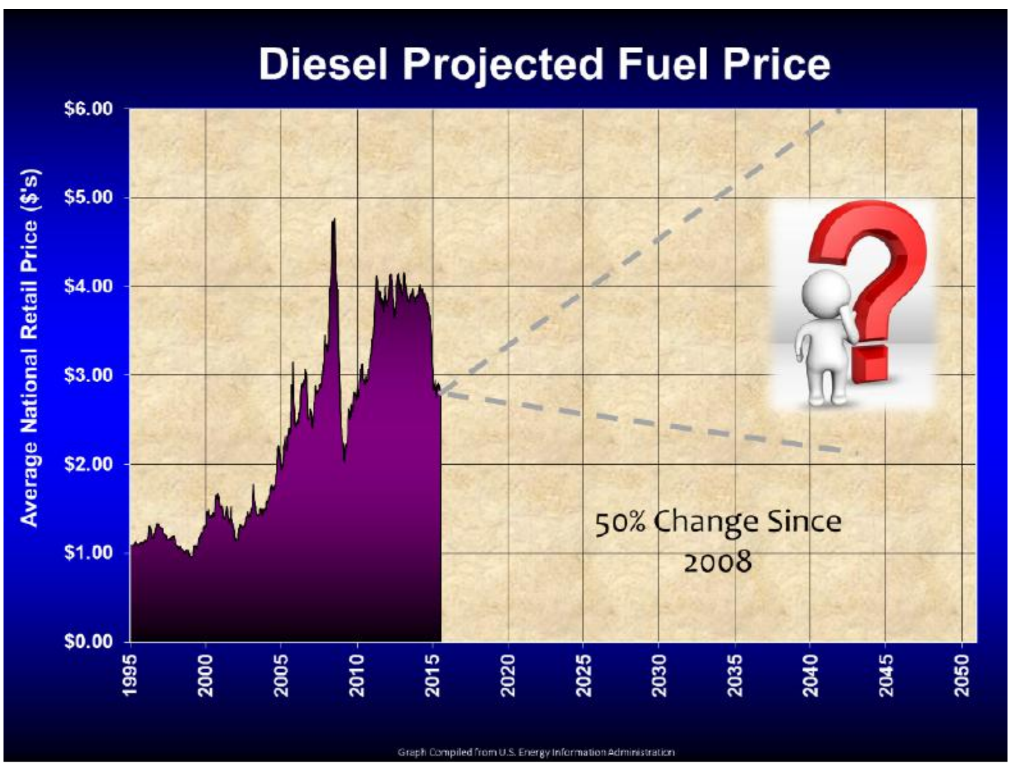


Figure 1: U.S. Diesel Fuel Prices

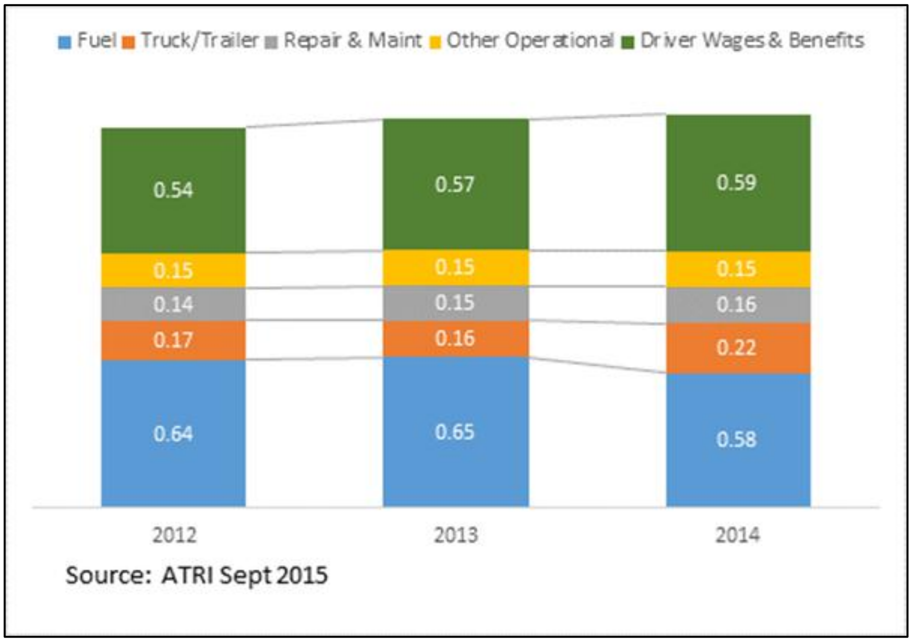


Figure 2: Trucking Operational Costs per Mile

Investment in proven technologies and practices that allow a truck or fleet to increase its fuel efficiency – meaning that it can do the same amount of business while spending less on fuel – is a hugely promising option for the industry in light of this trend of fuel-price volatility.

To understand, and thereby better facilitate, the uptake of such technologies, NACFE conducts an annual review, the "Fleet Fuel Study," of the industry-wide adoption rates of nearly 70 fuel efficiency technologies currently available for Class 8 tractors and trailers. This work, available on the www.nacfe.org website, has been called "the most comprehensive study of Class 8 fuel efficiency adoption ever conducted." (Truck News, 2012)

Figure 3: Fleet Study Participants

The overriding take-away from the most recent Fleet Fuel Study, completed in 2016, is that fleets are enjoying dramatic improvements in their fuel efficiency by adopting combinations of the various technologies surveyed — in 2015, the 17 fleets improved their fleet-wide fuel economy by 3%. The study found that the trucks put into service in 2015 were 16% better than the ones being replaced. The fleet-wide fuel economy improved to 7.06 mpg, while the U.S. average, for the approximately 1.7 million tractors in over-the-road goods movement, is 5.83 mpg. This finding was drawn from research into the use of fuel efficiency products and practices by 17 of the largest, most data-driven fleets (Figure 3). Those fleets represent both regional and long-haul tractors and trailers, in both dry goods and refrigerated cargo movement, and boast a combined inventory of 62,000 tractors and 217,000 trailers. The 2016 study reviewed 13 years of adoption decisions by these fleets, and describes their specific experience with the nearly 70 technologies. The fleets shared the percentage of their new purchases of tractors and trailers that included any of the technologies. They also shared 13 years' worth of annual fuel economy data for the trucks in their fleet. With these two pieces of information, which will be updated every year, NACFE is able to generate insights into the following aspects of the industry:

- Adoption curves for each of the technologies indicate which technologies have the steepest adoption rates, which are being adopted steadily but slowly, and which are not being purchased at all. These curves also show how uniformly (or not) fleets are acting in their adoption patterns.
- Identification among the various fleets of the innovators, early-majority, late-majority, and even laggards, in new technology adoption.
- Comparison of technology adoption rates to overall fuel efficiency.

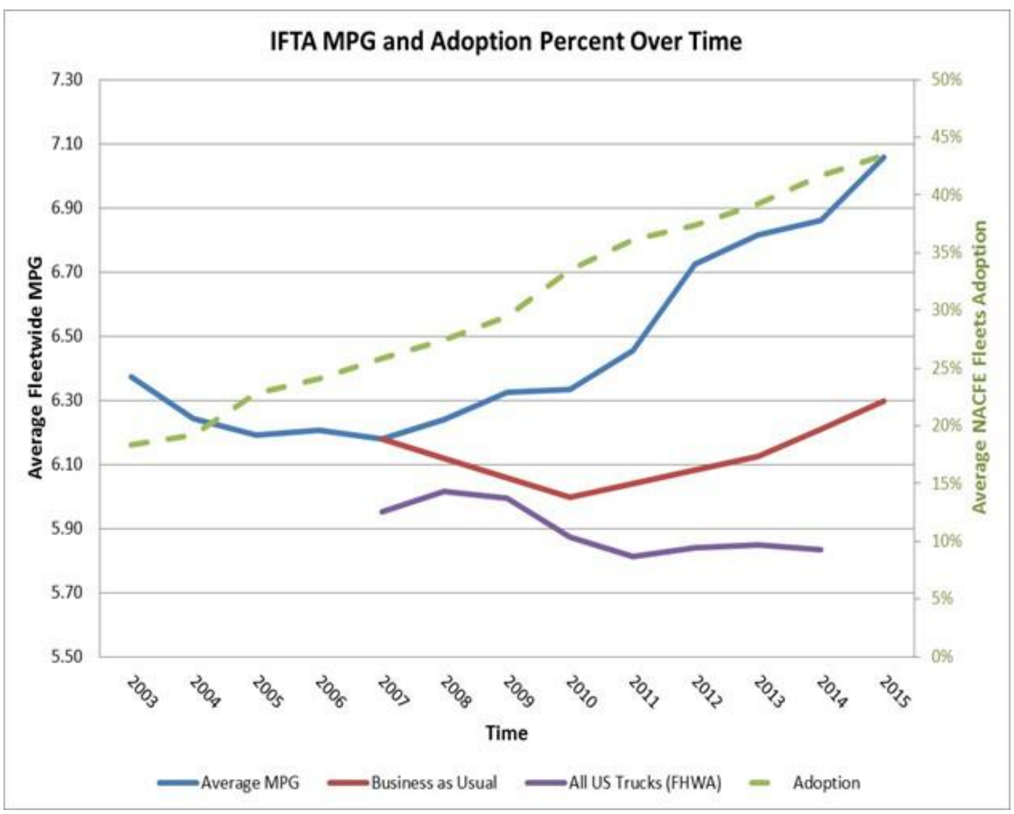


Figure 4: MPG per Truck – Blue line represents fleets surveyed by the Fleet Fuel Study

1.1. Trucking Efficiency's Confidence Reports

NACFE's Fleet Fuel Studies provide useful insights into adoption trends in the industry, as well as into the specific practices of different major fleets. NACFE hopes that this information alone could spur additional investment, particularly by fleets that may be lagging behind the overall industry when it comes to certain widely-adopted technologies. However, in the course of conducting the studies, it became clear that some technologies are still only adopted by the most progressive or innovative fleets in spite of their strong potential for achieving cost-effective gains in fuel efficiency. In order to facilitate the wider industry's trust in and adoption of such technologies, NACFE and CWR formed Trucking Efficiency and began this series of reports, called "Confidence Reports," which take an in-depth look at those most-promising but least-adopted technologies one-by-one.

Confidence Reports provide a concise introduction to a promising category of fuel efficiency technologies, covering key details of their applications, benefits, and variables. The reports are produced via a data mining process that combs public information and collects otherwise-private information (which is shared with Trucking Efficiency for the purpose of the reports), in order to centralize an unparalleled range of testing data and case studies on a given technology set.

Two-truck platooning represents one such technology set as it is emerging as a fuel-saving strategy for long- and regional-haul fleets.

The goals of this Confidence Report are: (a) to give the industry a foundational understanding of two-truck platooning; (b) to put it in context with the longer-term autonomous trucking initiative; (c) to provide an unbiased overview of the benefits and challenges related to platooning; and (d) to help fleets rationalize their investment in two-truck platooning.

This NACFE Confidence Report on two-truck platooning is one in a series of NACFE-focused reports on configuring vehicles and operations to improve their fuel efficiency. Visit www.truckingefficiency.org to view this and other completed reports on tire pressure systems, 6x2 axles, idle reduction, electronically controlled transmissions, electronic engine parameters, low rolling resistance tires, lightweighting, downspeeding, preventive maintenance, trailer and tractor aerodynamic devices, low-viscosity lubricants, and efficiency testing methods.

1.2. About this Report

The scope of this report is limited to the operation of two tractor-trailers following each other closely to form a small platoon. The short following distance is enabled by various currently available and emerging technologies. The report will put two-truck platooning into context of the continued automation of Class 8 tractors, however, higher levels of automation other than longitudinal control of the vehicles for two-truck platooning is not a focus of this effort. It also should be noted that all of the technologies previously studied by NACFE are available from truck builders or upfit centers today. This is the first technology studied by the group that is not readily available, but rather is in early stages of demonstration and deployment by industry suppliers and truck original equipment makers (OEMs). NACFE will continue its work by updating previous confidence reports on available technologies and studying the most interesting emerging ones. For example, in late 2016, the group plans to publish a Confidence Report on Variable Engine Accessories, where most of the technologies are still emerging.

NACFE's focus with this report is on the potential for fuel economy improvement with near term two-truck platooning that makes use of current production driver assistance systems and emerging vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication systems. These are real world systems that fleets will be encountering in the next five years rather than futuristic visions.

These initial platooning steps are technology building blocks toward an eventual fully autonomous vehicle, which could be decades away. This report includes background on where these technologies are headed to add perspective. However, NACFE's goal is to stay grounded in reality with near-term platooning opportunities where human drivers have their hands on the wheel and the technology is assisting the driver in getting better fuel economy by reducing aerodynamic drag through safely following another vehicle at shorter distances than an unassisted driver could safely maintain.

NACFE's and other industry surveys indicate that the opportunity to save significant fuel while increasing the adoption of collision avoidance technologies is a clear opportunity for the industry. However, in many ways, two-truck platooning has proven to be the most controversial of all new vehicle control systems emerging in the commercial vehicle market today. Interestingly, confidence in the capability of two-truck platooning technology and the viability of the concept is high among both fleet managers and OEMs and technology providers that were interviewed by this study team.

Many North American fleet managers, however, have concerns about the safety aspects of truck platooning in general and the psychological impact the system has on drivers in trailing vehicles, who will be driving or monitoring trucks that are essentially electronically tail-gating for hours on end with extremely limited fields of view and severely curtailed reaction times.

2. Two-Truck Platooning Explained

Truck platooning is an emerging transportation technology designed to boost fuel economy performance for tractor-trailers engaged in long- and regional-haul highway applications. Platooning combines existing commercial vehicle safety technology with emerging vehicle-to-vehicle communications and autonomous vehicle control technology to electronically "tether" tractor-trailers together in a convoy formation at highway speeds. Once a platoon of trucks is established, the vehicles' safety systems work in unison to draw the trucks together at significantly reduced following distances to overcome each vehicle's inherent aerodynamic drag.

The concept — familiar to fans of NASCAR auto racing — is called "drafting." Once the trucks have moved into close following distances, all of the engaged vehicles receive a significant fuel economy boost thanks to increased aerodynamic efficiencies. The lead vehicle, which bears the brunt of the aerodynamic load, typically sees only a modest fuel economy boost. But trailing trucks in a platoon, which are now operating in a low air pressure aerodynamic "sweet spot" can see significant increases in fuel economy performance at highway speeds.

When a group of trucks equipped with platooning technology is heading in the same direction, an electronic "invitation" to platoon is initiated and broadcast over the normal operating range of the vehicle's wireless control system. At this point, individual drivers can either opt to accept, or decline, the platooning invitation.

Once all interested drivers have accepted the platooning invitation, the trucks begin a high-speed, electronic "dialogue." The vehicles compare a whole host of operating parameters, including engine horsepower and torque, available braking force, vehicle weight, and payload. Additionally, the system checks and confirms that all safety and control systems required for platooning are in place and functioning properly.

In less than a minute, this vehicle dialogue is completed and the system assigns specific vehicles to specific locations in the platoon. Contrary to popular belief in the industry today, truck positions in a platoon are not optional or negotiable. Essentially, each truck platoon is a unique entity that exists only as long as those specific trucks operating in those specific conditions are in place. It is entirely possible that the platooning control system determine that a new truck, joining an established convoy an hour or two after it has formed, take the lead position.

That's because safety is the overriding control parameter of the platooning system, which positions trucks in a platoon based on their specific performance strengths and weaknesses: Trucks with stronger, faster reacting brakes will typically be positioned in trailing positions, for example. Likewise, in mountainous terrain, trucks with higher torque and horsepower will be placed in trailing positions since they will be better able to maintain proper following intervals in constantly changing (up-and-down) highway grades. Should drivers attempt to ignore predetermined vehicle placement in a platoon, the system will not electronically "confirm" and "form" the convoy.

2.1. Platooning Technology Path

The sophistication of platooning is evolving in stages. Two vehicles following each other to achieve better fuel economy has been in use manually for decades. One could argue that two drivers communicating through CB to arrange a two-truck platoon constitutes an early iteration of V2V communication technology, with the control systems being the drivers' brains and sensors being the drivers' senses.

The recommendation on a starting point for platooning requires reviewing braking capabilities and reaction times. The "2015 ATA TMC Automated Driving & Platooning: Issues and Opportunities" (TMC IR 2015-2) shows the differences between braking times for humans, automated individual vehicles, and coordinated pairs of vehicles. The collision avoidance and electronic brake systems when combined can reduce brake application times significantly versus an unassisted driver. The report suggests that typical separation distances for platooning may be in the 40 to 50-foot range depending on conditions.

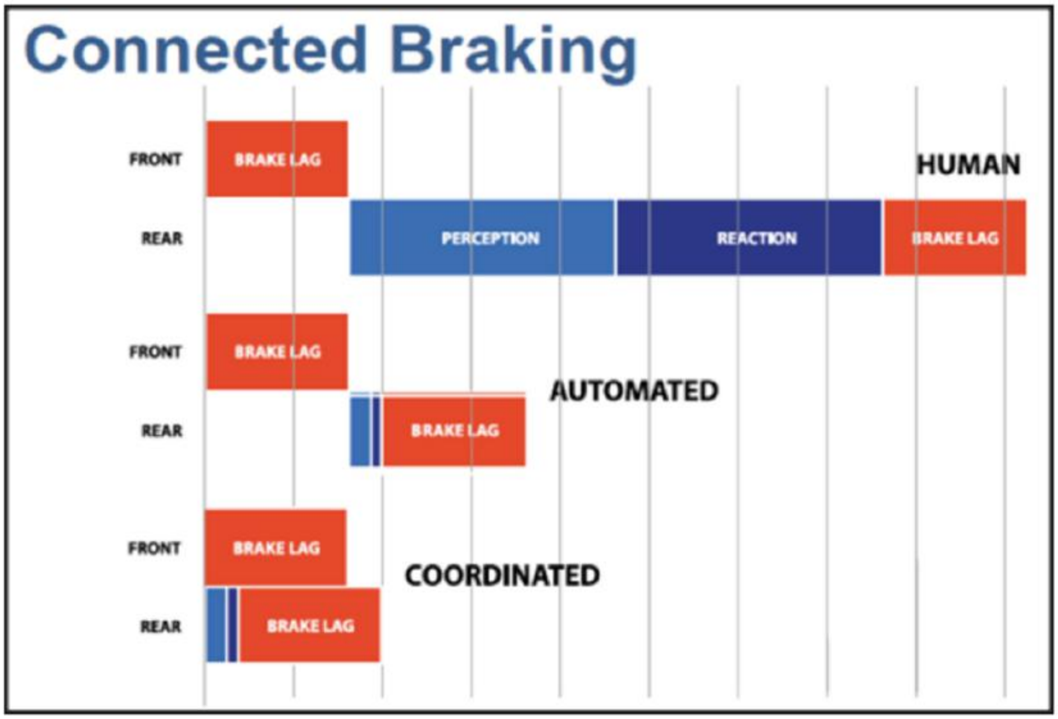


Figure 5. Brake Application Timing (ATA/TMC)

The potential fuel consumption savings versus an isolated single vehicle for 40 to 50-foot platooning separation distance could on average range between 8% and 19% for the following vehicle while the lead vehicle might see 3 to 5% fuel consumption reductions. Real-world factors will reduce these savings, as will be discussed in more detail later in the report. Comparisons against isolated baselines are for ideal conditions, where traffic conditions mean that vehicles already benefit to some extent from surrounding traffic. Those traffic conditions also may cause significant dithering of throttles and use of brakes that will reduce the fuel savings benefits. Additionally, studies show that engine cooling for current designed vehicles may cause the engine fans to engage more frequently during platooning, reducing fuel benefits. The German KONVOI testing, which will be explained later in more detail, showed fuel savings on a track that disappeared in on-highway testing with real traffic conditions. The NACFE research suggests that the opportunity for platooning on any route will be less than 100%. Some routes may be 50% or less. This still represents significant potential improvement in fuel use for the following vehicle in a platoon.

2.2. Platooning in Context with Automated Driving

Electronically assisted platooning is developing as the various technology building blocks are maturing. The Federal Highway Administration (FHWA) outlines levels of vehicle cooperation and automation in a chart presented in a 2012 report *Literature Review on Recent International Activity in Cooperative Vehicle–Highway Automation Systems* (FHWA-HRT-13-025).

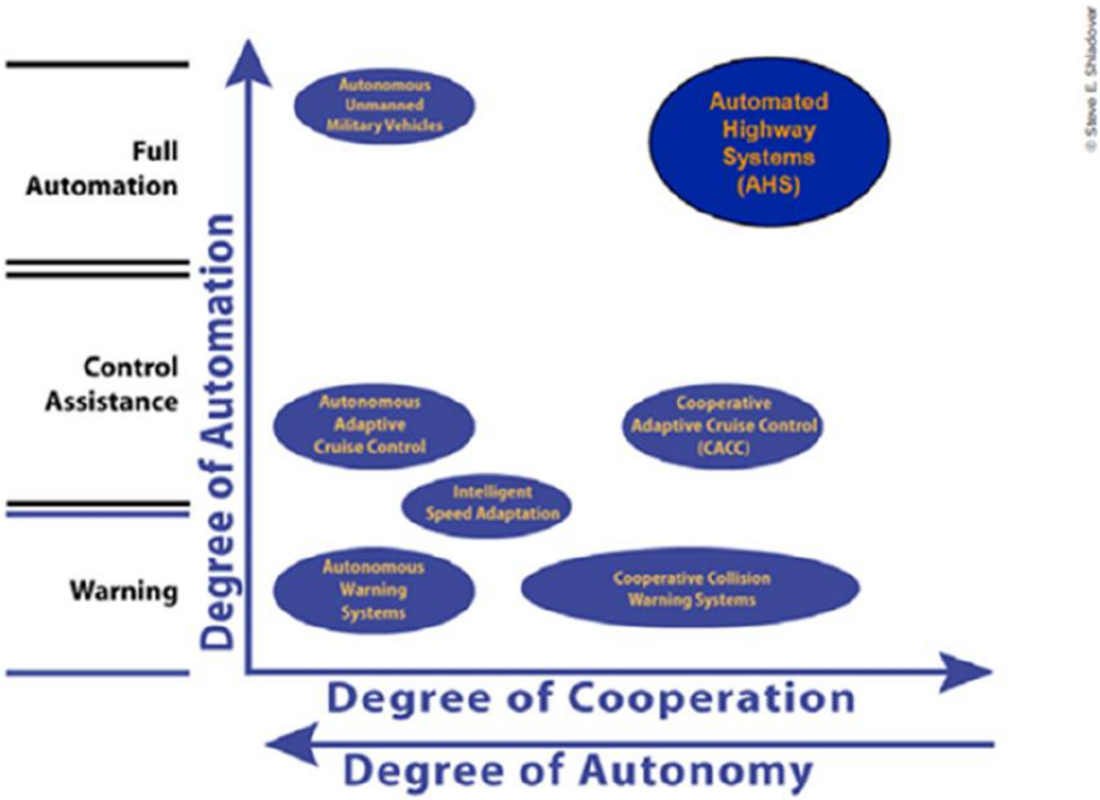


Figure 6: Levels of Vehicle Automation (FHWA)

Chen and Kavathekar described the elements of automated highway technology in a 2011 ASME paper, *Vehicle Platooning: A Brief Survey and Categorization* (ASMEDETC2011/MESA-47861). They outlined levels of automated highway system technology.

- Free Agent Concept
- Cooperative Concept
- Infrastructure Supported Concept
- Infrastructure Assisted Concept
- Adaptive Concept

According to the report,

- Free Agent Concept puts all smart technology into the vehicle and lets it act individually as a free agent, or a one-vehicle platoon. Since there was no infrastructure support needed, this vehicle could use this technology on any existing highways.
- This is followed by the Cooperative Concept, which added inter-vehicle communication to the Individual Vehicle Concept hence allowing for coordination of the vehicle's driving operation.
- The next progression is the Infrastructure Supported Concept. This improved upon the Cooperative Concept by providing dedicated lanes for the operation of smart vehicles. Global system information needed for the vehicle decision making and operation was provided by smart infrastructure embedded into these lanes.

- A further step is the Infrastructure Assisted Concept, which had the automated roadside system providing inter-vehicle communication at the entry, exit, and merging maneuvers.
- Finally arriving at the Adaptive Concept, which accounted for the different requirements of each location, thus creating standards leaving the decisions and solutions open to the localities.

These automated highway terms coexist with definitions of levels of vehicle automated driving presented in 2014's "SAE standard J3016, Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. "

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 7: Levels of Automation (SAE)

The "2015 ATA TMC Automated Driving & Platooning: Issues and Opportunities" (TMC IR 2015-2) divides the electronically assisted platooning modes as either Independent Operation or Cooperative Operation. Independent Operation is similar to the Free Agent concept, while Cooperative Operation encompasses modes with various degrees of V2V communication and control. TMC provides a number of examples beyond platooning, such as traffic jam assist, automated trailer backing, and others. NACFE's focus in this paper is the near-term driver hands-on-wheel platooning with driver assistance — the Independent or Free Agent operation — because this is the most production-ready technology fleets are encountering. As automation technology advances, though, aspects of cooperative platooning are near. The TMC projected automation enablers in its report (Figure 8).

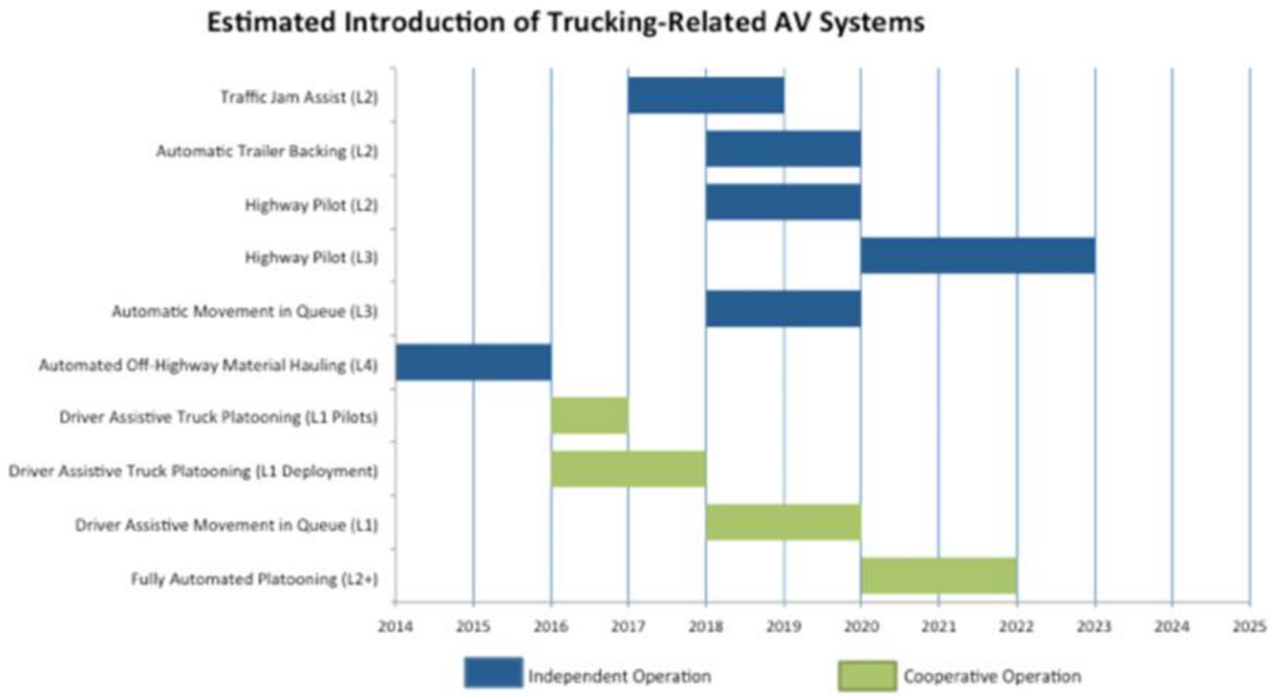


Figure 8: Automation Technology Timing (ATA/TMC)

Driver Assisted Truck Platooning Level 1 per TMC has the automation providing only longitudinal control on highway. This is the near-term form of platooning that NACFE focuses on in this report.

Highway Pilot Level 2 is defined by TMC as hands-off, feet-off, eyes-on highway use across the full speed range. This could include longitudinal and lateral lane control, and possible evasive maneuvering to avoid obstacles. Level 3 is then hands-off, feet-off, eyes-off operation, but retains the driver to engage when needed.

Automatic Movement in Queue and Driver Assistive Movement in Queue is intended for warehouse and yard operations where the vehicle is in a queue, releasing the driver from monotonous inching forward to enter or exit a facility per TMC. These are not platooning for fuel economy.

An approach to viewing the evolution of platooning is to discuss the required steps in technology to enable platooning. Some of these are occurring in parallel, others are required before subsequent functions can be implemented.

Platooning Technology Element 1: Collision Avoidance System — Includes the ability to safely brake the vehicle faster than human reaction times, the ability to sense surrounding traffic conditions, and a vehicle's own relationship to other vehicles and highway infrastructure and obstacles. This technology is in production use by fleets.

Platooning Technology Element 2: Adaptive Cruise Control — The ability to maintain a set distance between your vehicle and the one in front by variously decelerating or accelerating. Decelerating may involve multiple methods including coasting, mild braking, engine braking, or emergency braking. This technology is in production use by fleets.

Platooning Technology Element 3: MPG Optimization Systems — Software, sensors, and hardware that can optimize individual vehicle fuel economy performance based on surrounding traffic and environmental conditions. The engine and brakes need to know they are in traffic as a trailing vehicle and adjust their parameters so as not to defeat aerodynamic benefits of the platooning (i.e., minimize constant braking by coasting where possible, minimize fan on because the engine is not cooling properly possibly through modification of grille shutter systems to allow more ram air in when in following position so fans do not engage). This requires multiple systems by multiple manufacturers to work in concert.

Platooning Technology Element 4: Vehicle Transmission of Sensor Data — Each vehicle needs to be transmitting its collision avoidance and adaptive cruise information for other vehicles to use. This is the first stage of V2V communication needs. This first step is a one-way sending of data that other vehicles can intercept and make use of. This has security ramifications, but if it is sending only, it means there are no issues with someone taking control of a vehicle remotely.

Platooning Technology Element 5: Vehicle Reception of Sensor Data from Other Vehicles — A parallel step to Element 4 is that vehicles need to be able to receive and process the sensor data from other vehicles. This has security ramification as it opens up the possibility that someone could take control of a vehicle remotely. Prevention of misuse is very critical.

Platooning Technology Element 6: Platooning Software — Software that makes use of the other vehicle's sensor data to adjust performance of your vehicle – making use of the data received in Element 5.

Elements 1 through 6 create vehicles that are "smart-enough" to safely operate independently with driver supervision but improve their performance based on inputs from other vehicles and their own situational awareness. Vehicles are not controlling each other.

Platooning Technology Element 7: Platoon MPG Optimization Software — Software that allows two vehicles to perform even better by concurrently optimizing their individual performance knowing they are in a group. This requires two-way V2V communication.

Platooning Technology Element 8. Enhanced Platoon MPG Optimization Software — Software that allows a group of vehicles to optimize performance as a group – multi-vehicle (more than two) V2V communication.

Elements 6, 7 and 8 are natural progressions of complexity for more benefit.

On-board aerodynamic sensing is needed to facilitate mpg optimization. The engine needs to respond to all the environmental conditions, and should adjust performance to optimize mpg. The platooning improvement potential focuses on aerodynamics so some way of isolating aerodynamic performance as input to the engine control is needed. No sensors exist at present to reliably provide this data.

NACFE asserts that the near-term opportunities for fleet use of platooning lies with Elements 3 and 4. Farther downstream are systems that will enable V2V communication and integration of multiple subsystems to optimize fuel economy through augmenting electronic braking systems in concert with adaptive cruise control following technology and collision avoidance systems to reduce vehicle following distances and safely achieve fuel economy improvements. These systems may include driver assistance technologies such as automated lane keeping and driver behavior monitoring to ensure safety.

2.3. Platooning and the Greenhouse Gas Phase 2 Rule

The United States Environmental Protection Agency (EPA) and National Highway Transportation Safety Administration (NHTSA) released their final rule for Phase 2 of the Greenhouse Gas rule on August 16, 2016. Platooning is not mentioned in the Final Rule itself or the Regulatory Impact Analysis, as it uses enabling technologies in a freight efficiency practice. The rule will be driving increased adoption of many freight/fuel efficiency technologies such as aerodynamics, lower rolling resistance tires, powertrain, etc. to meet the stringency in the rule which will improve fuel efficiency of sleeper tractors by 25% in 2027. With respect to platooning, developers and integrators will be considering platoons with trucks varying substantially in their aerodynamic drag, tire rolling resistance, etc. This difference in fuel efficiency will need to be considered in the design of these platooning systems.

2.4. Current Adaptive Cruise Systems

Figures 9 and 10 show a typical 300-foot separation distance implied or required in many states as a prudent following distance. The current production adaptive cruise control (ACC) systems each have default trailing times that range from 2.8 seconds to 3.6 seconds. A 2.8 second gap corresponds to approximately 270 feet at 65 mph. The ACC systems also have a cone of forward visibility that ranges by manufacturer between 22 degrees and 45 degrees. The final image shows a 50-foot separation distance corresponding to approximately 0.5 second. An example car has been included for scale.

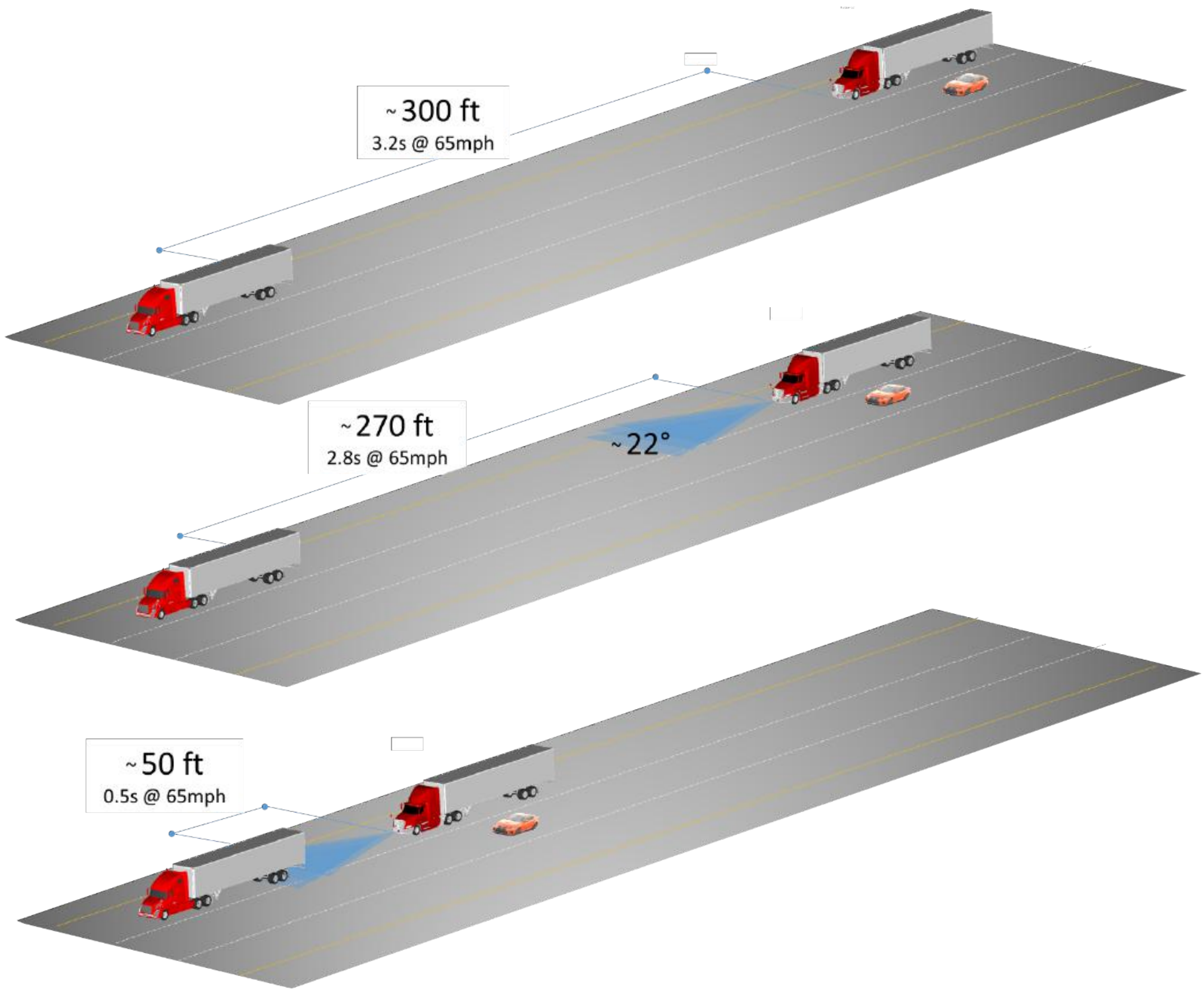


Figure 9: Vehicle Separation Distance Examples

In normal operation, the ACC systems maintain the separation time set in the device. When a stray car cuts in between the two vehicles, the ACC will disengage, and the driver must re-establish a proper gap to then re-engage the system. If the cut-in is close enough, the collision avoidance system (CAS) will also engage and brake the vehicle to prevent an impact.

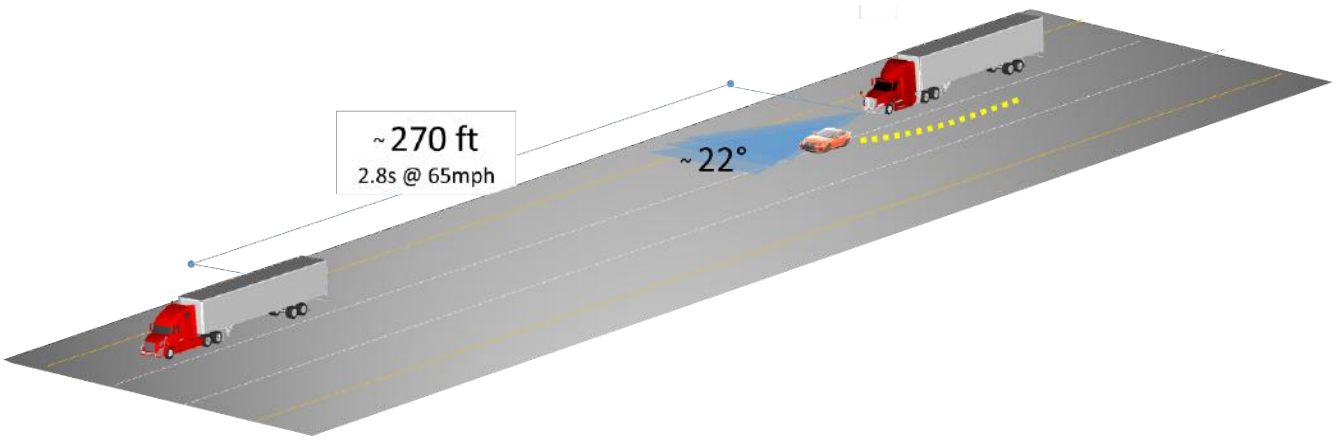


Figure 10: Vehicle Cut-In Event

The determination of fuel economy effectiveness of a platooning system will depend in part on how frequently other traffic interferes with operation. At the shorter distances, it becomes less likely that a car can cut in to the narrow space between the trucks. This is what the KONVOI research in Germany determined in the on-highway testing (to be detailed later).

What ultimately limits the gap is not the ACC system, but the ability of the trucks to safely brake in the permissible distances. The braking systems on each vehicle perform within some normal range depending on many factors such as temperature, load, tread depth, alignment, pavement roughness, weather, aerodynamics, etc. Each truck can have a range of stopping distances just within normal operation that could be ±30 feet for these factors. The current state of vehicle sensing does not have a way of reliably predicting the actual stopping distance in each situation for each vehicle, it can only assume some maximum stopping distance for a given speed as determined in testing for a range of vehicles.

In platooning, the trailing vehicle takes cues from the lead vehicle on how to brake. But neither vehicle at present knows exactly how well the other vehicle actually brakes in each situation, so safety likely presumes a worst case stopping distance for each. What the CAS and ACC systems combined can do is to apply the brakes at much faster speeds than a normal human could react.

Zheng, et al explains braking in the “2014 IEEE report Study on Emergency-Avoidance Braking for the Automatic Platooning of Trucks” as shown in Figure 11. (*IEEE Transactions on Intelligent Transportation Systems*, Volume: 15, Issue: 4, Mar. 2014).

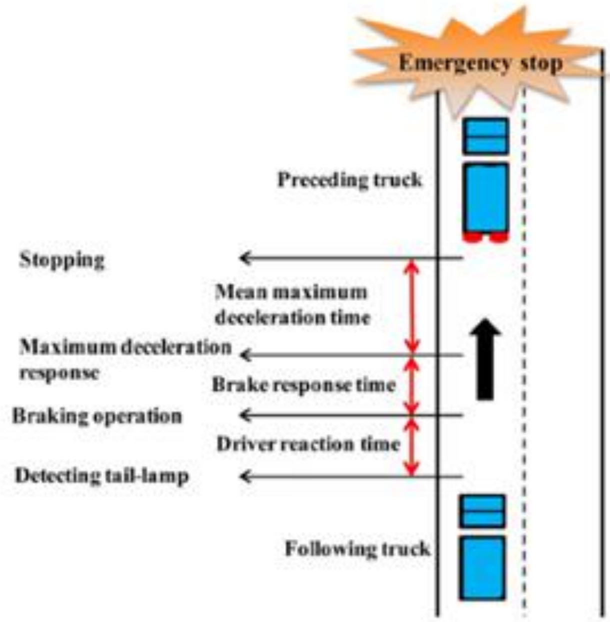


Figure 10: Collision Avoidance Stopping Event Sequence (Zheng, et al)

While the ACC and CAS systems can reduce the reaction time and provide the most responsive input to the brake system, the physics of stopping the vehicle with brakes is still governed by Federal Motor Vehicle Safety Standards (FMVSS) 121 standards. Those standards per National Highway Traffic Safety Administration (NHTSA) illustrated in Figure 11 require stopping in less than 250 feet at 60 mph for a typical tractor and van trailer. These distances were implemented in 2013, highlighting that different vintage trucks may have different minimum braking requirements, so in a platoon, older vehicles likely need to be in lead positions.

Phase	Axle Configuration	GVWR	New Requirement	Old Requirement	Compliance Date
1	Standard 6x4 tractors	Less than or equal to 59,600 lbs.	250 feet	355 feet	Aug. 1, 2011
2	2-axle	All	250 feet	355 feet	Aug. 1, 2013
	6x4 Severe Service Tractors	Above 59,600 lbs. and less than or equal to 70,000 lbs.	250 feet		
	6x4 Severe Service Tractors	Above 70,000 lbs.	310 feet		
	Tractors with 4 or more axles	Less than or equal to 85,000 lbs.	250 feet		
	Tractors with 4 or more axles	Above 85,000 lbs.	310 feet		

Source: National Highway Traffic Safety Administration

Figure 11: Required FMVSS 121 Stopping Distance (NHTSA)

The FMVSS 121 stopping distances highlight that two platooning trucks separated at, for example, 50 feet traveling at 60 mph, still require a considerable distance to physically stop once the brakes are applied. In the event the lead vehicle impacts an immovable object like a bridge abutment or pylon, the trailing vehicle will likely not have sufficient room to stop. One new technology being investigated by ZF that may address this issue is evasive maneuvering in the suite of future automated functionality (Transport Topics, ZF Unveils Evasive Maneuvering, Automated Highway Driving Systems, July 1, 2016).

2.5. Growing Use of Vehicle Safety Systems

As platooning technology develops, it is important to remember that many of the vehicle safety systems that form the building blocks of coordinated truck movements on the road are growing in their adoption by fleets, and some are already mandated by the federal government, or likely will be in the near future.

Experts cited in the July 2016 issue of *Heavy Duty Trucking* magazine, in a story titled, "Why you should consider advanced safety systems," say the next evolution of vehicle safety systems will be even more impressive than systems in use today, while noting that the "take rate" for safety systems on heavy-duty trucks today is already at the 30% rate on all new vehicles sold.

In the very near future, rapidly evolving V2V communication systems will allow similarly equipped cars and trucks to all react in a coordinated fashion to highway emergencies and work together faster and more accurately than any group of humans ever could, to mitigate or avoid injury and property damage when accidents occur. There is no reason to think the results of this leap forward will be anything short of amazing once the technology finds its way into commercial vehicle production.

And there is this: As safety systems become increasingly effective and commonplace in both passenger cars and commercial vehicles, government regulations mandating the use of these systems is only going to increase in the future, making a powerful argument that fleets should get ahead of the adoption curve today. "We anticipate that some of these safety systems will eventually be required by regulation," notes Wade Long, director of product marketing for Volvo Trucks. "Forward collision warning systems and automated emergency braking systems are likely to be among the first systems mandated, although it is difficult at the moment to say when, exactly, that will happen."

Here, the statistics are clear, says Jon Morrison, WABCO President for the Americas. His company carefully tracks safety figures compiled by the NHTSA, which prove out the effectiveness of fleet investments in safety. "NHTSA is projecting that the new fully-on mandated electronic stability control systems will prevent as many as 1,759 crashes, 649 injuries, and 49 fatalities each year," Morrison says. "And WABCO's own research confirms this. In terms of collision mitigation systems, heavy-duty truck fleets using our OnGuard collision mitigation system have reported a 65 to 87% reduction in accidents, resulting in an up to 89% reduction in accident costs compared to vehicles without OnGuard, with a payback in just two years."

According to Kelly Gedert, powertrain and components marketing manager for Daimler Trucks North America, Daimler is already moving toward total safety system integration. Gedert notes that the Detroit Assurance suite of safety systems is fully integrated with Detroit engines and transmission, as well as the truck's braking system and dashboard, to enhance driver safety by mitigating collisions. The full integration results in smoother and more fuel-efficient speed and braking transitions.

"Wider acceptance and adoption of safety systems is going to continue as a trend in the industry," Gedert says. "We will continue to see additional active safety system features rolled out each year; pedestrian recognition, cross-traffic recognition and blind spot recognition are a few examples that are in the future roadmap for safety technology. We are in an exciting time in the industry as today's safety technology sets the groundwork for tomorrow's autonomous vehicle."

Jeff Walker, product director for Eaton, says V2V systems have the potential to improve safety technology by knitting together individual vehicle safety measures into a more connected universe. While this will increase the onboard technical complexity, and require additional data processing assets as well as definition and adoption of standards, he thinks that overall, V2V can help the industry maintain and even increase safety even as it implements measures to increase efficiency and reduce costs, such as platooning. It is important to understand that these advanced systems are designed to 'assist' the driver, not 'replace' the driver, Walker says. "As these integrated systems become more prevalent, their ability to support drivers with such things as automated transmissions, adaptive cruise control, automatic braking and, other integrated solutions will lead to safer vehicles in the future."

These safety system trends are likely to continue and accelerate in the near future. Which means that in the next decade, it is likely that any new Class 8 tractor will be equipped with platooning technology and capability "right out of the box."

3. Benefits and Challenges

As with most technologies, there are both benefits and challenges entailed in adopting the practice of two-truck platooning. Benefits include fuel savings and accelerating the adoption of safety technologies, while the challenges are many and difficult to predict as there is virtually no experience with platooning at fleets.

3.1. Benefit: Saves Fuel

The combined performance of two or more vehicles driving efficiently as a group can exceed the sum performance of the individual vehicles driving alone. This has been analyzed, tested, and demonstrated since the 1950's, and experienced truck drivers are aware there are fuel economy benefits from following other vehicles. The key question is how much of a gain? A seemingly simple question that requires a more involved answer.

A mid-size fleet shared, "I'm hearing 3 to 5% fuel economy boost from platooning. The fuel economy benefits are pretty strong. That's a lot at any fuel price per gallon!"

3.1.1. Platooning Fuel Efficiency Testing

Platooning testing has measured potential improvement in a number of ways. One key experiment was reported in 2004 by Fred Browand, et al, of the University of Southern California (USC) as part of the California Partners for Advanced Transportation (PATH) program (UCB-ITS-PRR-2004-20 Fuel Saving Achieved in the Field Test of Two Tandem Trucks). He found that compared to trucks operating in isolation, that "In the spacing range of 3–10 m (10–33 ft.), fuel consumption savings lie in the range of 10–12% for the trail truck and 5–10% for the lead truck — with the larger values of saving occurring at the shorter spacings," as shown in Figure 12. The 2001 year trucks shown in this test were not equipped with roof fairings, the trailers were not equipped with skirts or other aerodynamic devices, testing was not in traffic conditions, speeds were 50–55 mph, trailers were lightly loaded or empty, and tests were done on an airport runway in variable wind conditions. The savings potential decreases as the vehicle-to-vehicle gap grows, with the lead vehicle benefits decreasing faster than the trailing one. The study describes a number of factors contributing to variation in the results including ambient wind, temperature, and road grade. The variability increases with longer gaps.

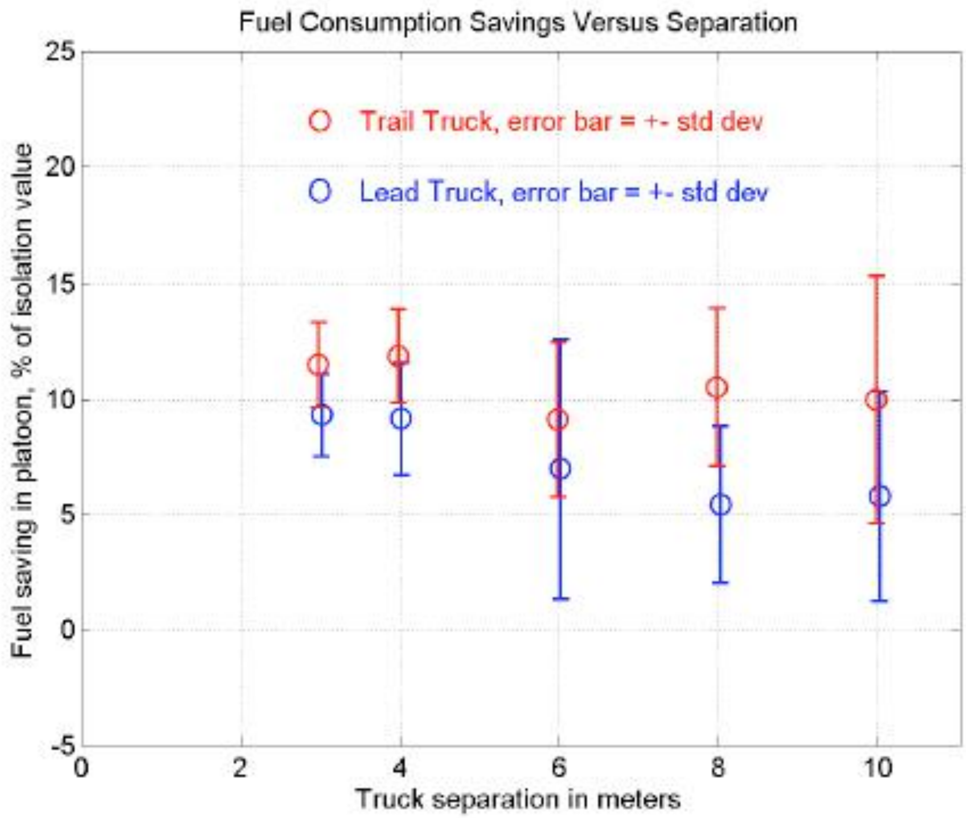


Figure 12: PATH Platooning Test Fuel Savings (Browand, et al)

Browand also plotted the actual fuel consumption versus separation distance seen in the testing in a 2005 Stanford presentation Workshop on Advanced Transportation, "Reducing Aerodynamic Drag and Fuel Consumption."

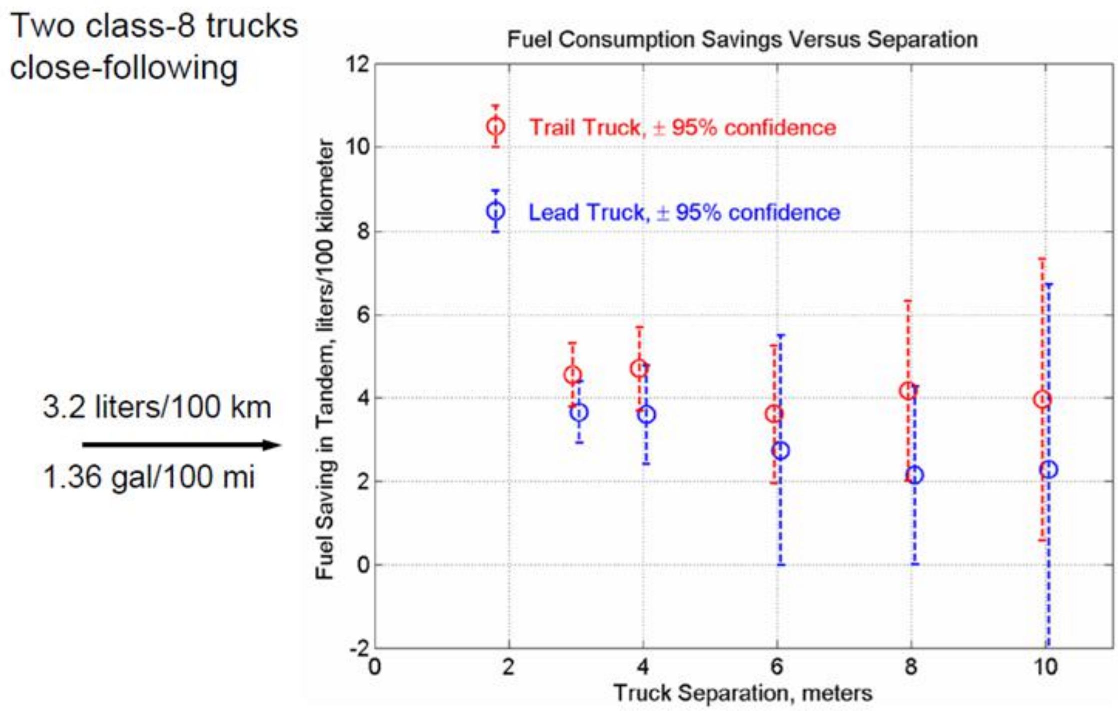


Figure 13: PATH Platooning Test Fuel Consumption Savings (Browand, et al)

Figure 14: PATH Platooning Test Vehicles (Browand, et al)

A fleet test conducted by Peloton on actual Utah highway routes was reported in 2013 by NACFE's Mike Roeth (Peloton Technology Platooning Test Nov 2013). The testing of a two tractor-trailer platoon shown in Figure 15 found the lead vehicle saved 4.5% on fuel consumption versus a baseline single vehicle. The trailing vehicle had a 10.0% fuel consumption reduction versus the single baseline vehicle. The testing used two identical 2011 model year aerodynamic tractors and trailers equipped with skirts and loaded to an operational weight. Testing was conducted using modified SAE J1321 procedures. The lone control baseline was a different model and make truck. Tests were conducted at 64 mph with separation distances of 36 feet, maintained by Peloton's platooning technology, with 99% or better on time during tests.

Figure 15: Peloton Platooning On-Highway Test (NACFE)

A 2015 Daimler SAE Connected Vehicles presentation by Derek Rotz highlighted fuel use improvement for a two-vehicle unit as 3% for the lead vehicle and 7% for the trailing one. The presentation also estimates net average fuel savings for a three-truck platoon with 25-foot separation as 5.3% while a five-truck platoon could average 6% net savings versus individual trucks operating alone.

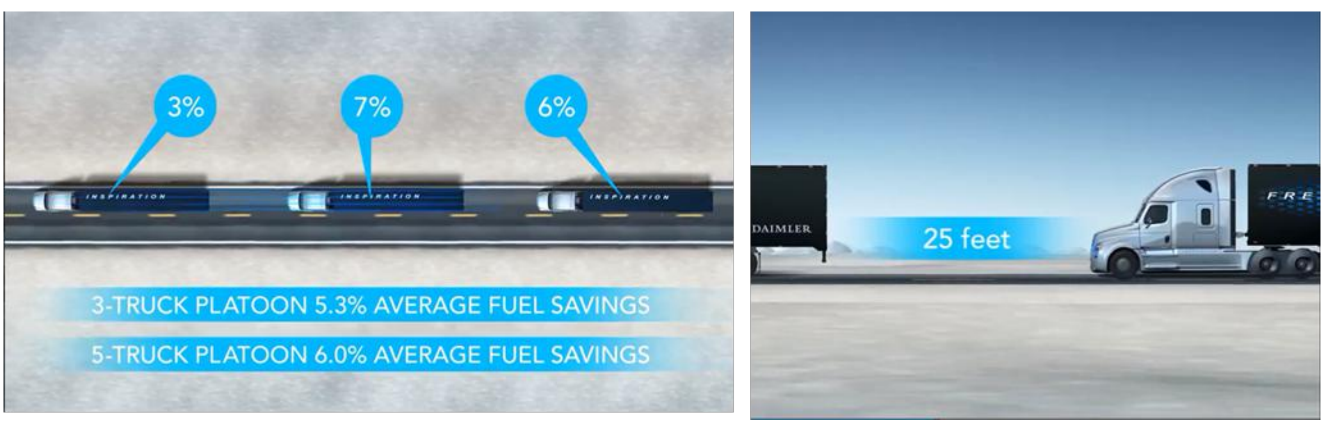


Figure 16: Daimler Platooning Savings (Rotz)

A 2014 SAE Paper (2014-01-2438) presented by the National Renewable Energy Laboratory's (NREL) Lammert et al reported test results from a two tractor-trailer platoon tested at speeds ranging from 55 mph to 70 mph and separation distances varying from 20 ft. to 75 ft. Trailers were loaded at 65,000 and 80,000 lb. GVWR. The testing also used a lone comparison vehicle and SAE J1321 test procedures.

Figure 17: NREL Platooning Test Vehicles (Lammert, et al)

The results showed that the platooning pair improved fuel use by 3.5% to 6.4%, with the best combined result occurring at 55 mph with a 30 ft. gap and 65,000 GVWR. The lead truck again saw improvement for shorter gap lengths and the trailing truck saw fuel savings that ranged up to 10%. This testing was on a relatively flat large oval track in Texas. Testing also included varying speed per a modified Heavy Heavy Duty Diesel Truck (HHDDT) cycle between 55 and 70 mph with a 50-foot separation distance showing lead truck fuel use savings of 2.7% and follower reductions of 4.2%. Tests were also run at 80,000 GVW at 65 mph and 50-foot separation with lead improving fuel consumption by 0.6% and follower reducing by 6.7%. Figure 18 shows the trend in reduction versus gap.

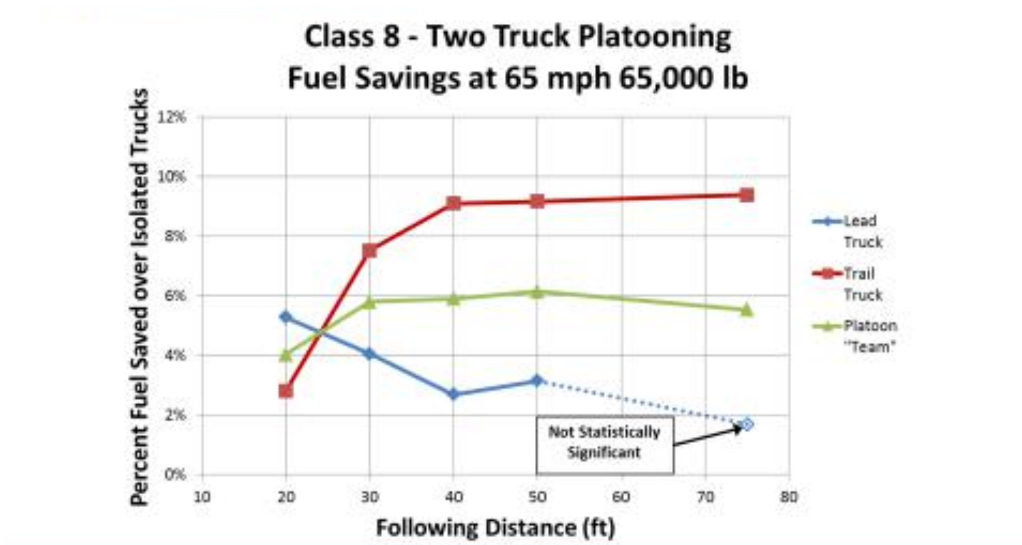


Figure 18: NREL Platooning Test Fuel Consumption Savings (Lammert, et al)

Similar trends in fuel use improvement by platooning have been documented in European and Japanese testing. Gotz and Mayr report in the 1998 book "Aerodynamics of Road Vehicles 4th Edition" that "even at vehicle intervals of 20 m (66 ft.) to 80 m (262 ft.), fuel savings remain substantial, at roughly 9%" for a 40-tonne (88,000 lb.) European tractor-trailer rig following another truck in a convoy.

A 2000 DaimlerChrysler SAE report by Bonnet and Fritz (SAE 2000-01-3056) documented a 21% fuel consumption reduction for the trailing truck at 28 tonnes (62,000 lb.), 80 km/hr (50 mph) and 10 m (33 ft.) spacing from the European Commission PROMOTE-CHAUFFEUR project. The lead truck at 10 m (33 ft.) spacing saw a 6% reduction in fuel consumption. The CHAUFFEUR project expected dedicated freight highway lanes.

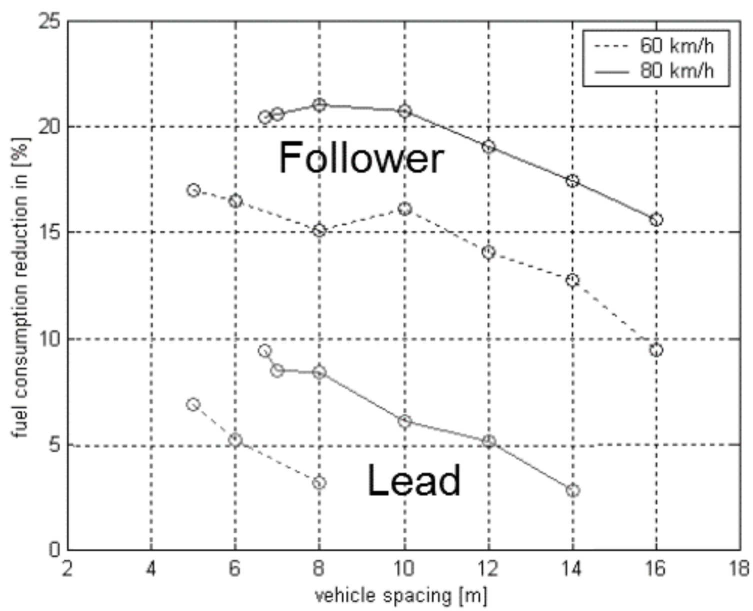


Figure 19: PROMOTE-CHAFFEUR Platooning Test Fuel Consumption Savings (adapted from Bonnet and Fritz)

Figure 20: PROMOTE-CHAFFEUR Platooning Test Vehicles (Bonnet and Fritz)

A 2011 KTH Swedish Royal Institute of Technology study by Alam with Scania (*Fuel-Efficient Distributed Control for Heavy Duty Vehicle Platooning*) reports a maximum fuel reduction of 4.7 to 7.7% depending on the inter-vehicle time gap, at a set speed of 70 km/h (43 mph). The vehicles were tested on a Swedish highway with trucks at 39 tonnes (86,000 lb. GVW) with speeds of 90 km/h (56 mph). This report also suggests that placing the lightest vehicle in the lead position provides better net group fuel economy because the ACC on the following vehicle provides some moderation of follower vehicle speed adjustment. The Scania/KTH researchers also participated in the 2011 Grand Cooperative Driving Challenge in Holland where the team demonstrated a mixed platoon group that included both trucks and cars.

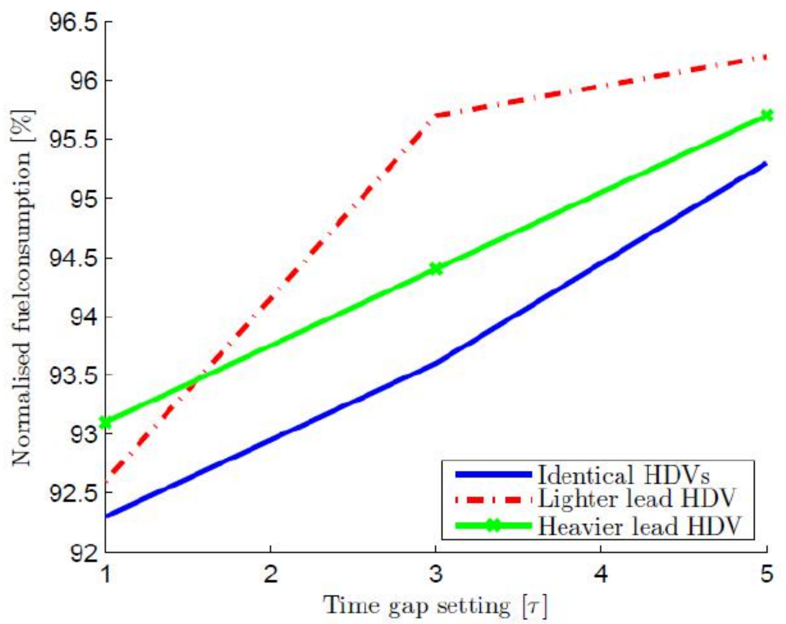


Figure 21: KTH/Scania Platooning Test Fuel Consumption Savings (Alam, et al)

Figure 22: KTH/Scania Platooning Test Vehicles (Alam, et al)

The European Commission sponsored the SARTRE project (Safe Road Trains for the Environment) with industry partners at Volvo. SARTRE fielded an automated platoon led by a truck driven manually, with a mixture of trucks and cars at 4 m (13.2 ft.) gaps. Evaluations included both track and European highway use between 2010 and 2012. Fuel consumption tests were done on a high speed track at 90 km/h (56 mph) and results were published by Davila, et al, in a 2012 SAE paper (SAE 2013-01-0767) showing fuel savings for all the vehicle types up to 15 m (49 ft.). The results highlight that performance gains are possible irrespective of the type of following vehicle.

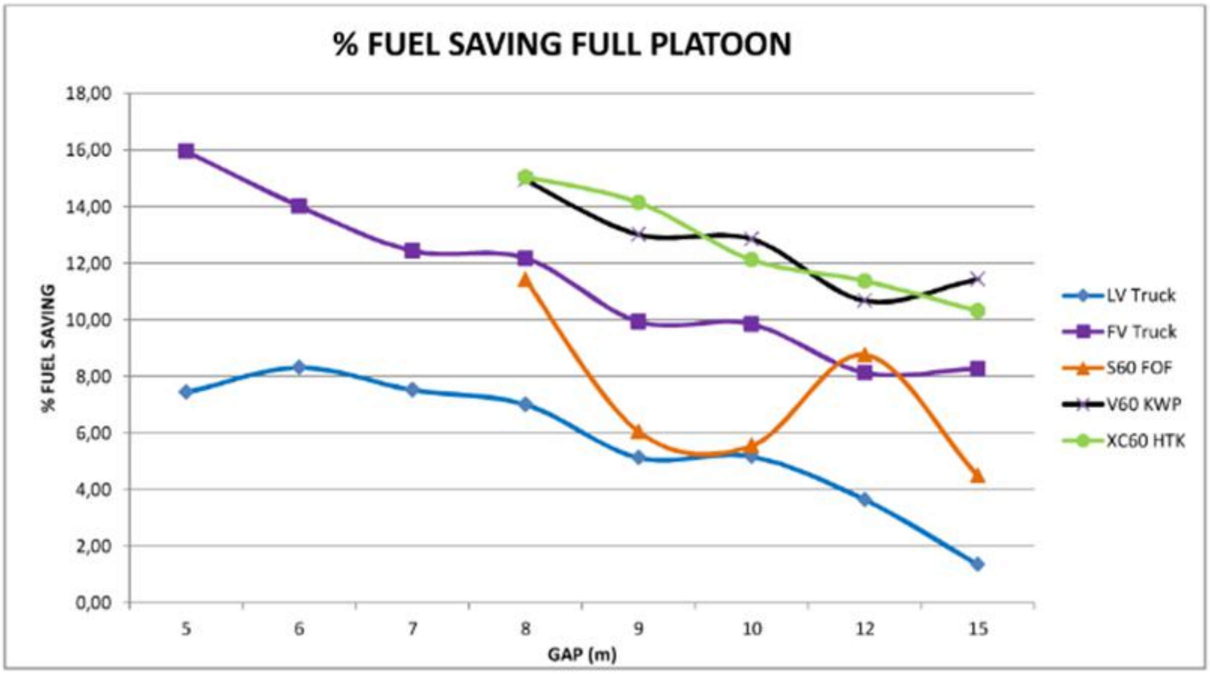


Figure 23: SARTRE Platooning Test Fuel Consumption Savings (Davila, et al)

Figure 24: SARTRE Platooning Test Vehicles (Davila, et al)

Japan under the Energy ITS project has conducted extensive testing on truck platooning, including three and four truck platoon track tests with no freight at 80 km/h showing 10% net fuel savings at 20 m (65 ft.) gaps. Tests on a flat road with three empty trucks and 10 m (32 ft.) gaps were reported by Tsugawa in 2013 as 13.7% improvement on fuel consumption, and 15.9% improvement with 4.7m (15 ft.) gaps.

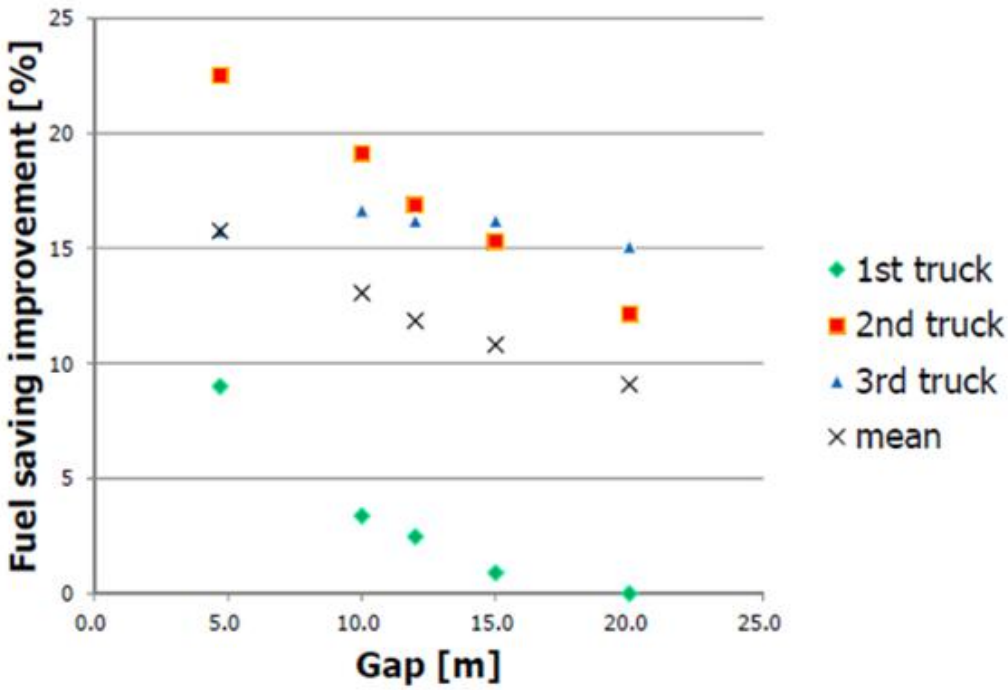


Figure 25: Japanese ITS Platooning Test Fuel Consumption Savings (Tsugawa, et al)

Figure 26: Japanese ITS Platooning Test Vehicles (Tsugawa, et al)

3.1.2. Summarizing Known Platooning Fuel Tests

Platooning truck investigations have been going on for decades. A review of publicly available platooning test information is summarized in the following table.

Investigation	Image	Following Distance	% Fuel Consumption Change vs. Alone		Conditions
			Lead	Follower	
Browand: USC PATH Testing 2003		3m (10ft) 4m (13ft) 6m (20ft) 8m (26ft) 10m (33ft)	9.2% 9.1% 7.1% 5.6% 6.0%	11.6% 12.2% 9.2% 10.8% 10.0%	Airport Runway No traffic 50-55mph Unladed Trailers MY 2001 Non-Aero Tractors Non-Aero Trailers Variable Winds
Roeth: Peloton Fleet Test 2013		(11m) 36ft	4.5%	10.0%	On highway Minimal Traffic 64 mph Laden Trailers MY 2011 Aero Tractors Skirted Trailers Variable Winds
Rotz: Daimler 3-Truck Platoon SAE Presentation 2015		(8m) 25ft	3%	7%	No Details
Lammert: NREL SAE Paper 2014	 Lead Follower	(6m) 20ft (9m) 30ft (9m) 30ft (9m) 30ft (12m) 40ft (15m) 50ft (15m) 50ft (23m) 75ft	5.3% 65mph 4.3% 55mph 4.1% 65mph 4.4% 70 mph 2.7% 65mph 2.2% 55mph 3.1% 65mph 1.7% 65mph	2.8% 8.4% 7.5% 4.6% 9.1% 9.7% 9.2% 9.4%	Oval Track No Traffic Varied Speeds 55-70 mph Laden Trailers 65k MY 2011 Aero Tractors Skirted Trailers Variable Winds
Bonnet: Daimler-Chrysler PROMOTE-CHAUFFEUR European Project 2000		6.7m (22ft) 7m (23ft) 8m (26ft) 10m (33ft) 12m (39ft) 14m (46ft) 16m (53ft)	9.5% 8.5% 8.5% 6% 5% 3% -	20.4% 20.6% 21% 20.8% 19% 17.3% 15.7%	Oval Track No Traffic Speed 50 mph Lead Truck Unladen 14.5t Following Truck Laden 28t Straight Trucks No Aero Treatments Constant Winds
Alam: Scania KTH Grand Cooperative Challenge Project		Not Specified – controlled time gap	4.7%-7.7% Identical Trucks 3.8%-7.4% Lead 10t Lighter 4.3%-6.9% lead 10t Heavier		On Highway Minimal Traffic Speed 43 mph 39t GVW COE Aero Variable Winds

Investigation	Image	Following Distance	% Fuel Consumption Change vs. Alone		Conditions
			Lead	Follower	
KONVOI German Platooning in Traffic Study 4 Truck Platoon 2005-2009		10-15m (33-49 ft)	None	None	On Highway With Traffic Varying Speeds COE Non-Aero Variable Winds
European Commission SARTRE Project Mixed Platoon 2010-2012		5m (16ft) 6m (20ft) 7m (23ft) 8m (26ft) 9m (29ft) 10m (33ft) 12m (39ft) 15m (49ft)	7.5% 8.4% 7.5% 7.0% 5.4% 5.2% 3.7% 1.1%	16% 14% 12.5% 12.1% 10% 9.9% 8.1% 8.1%	Oval Track No Traffic 56 mph Unspecified weights Straight Truck Aero Variable Winds
Japan Energy ITS Project 3 & 4 Truck Platoon 2013		5m (16ft) 10m (33ft) 12m (39ft) 15m (49ft) 20m (66ft)	9.0% 3.3% 2.5% 1.0% 0%.0	22.5% 19.0% 17.0% 15.1% 12.0%	Oval Track No Traffic 50 mph Unspecified weights Straight Truck Aero Variable Winds

These results can be graphed to show a consistent trend for the lead vehicle fuel consumption reduction as the separation distance increases.

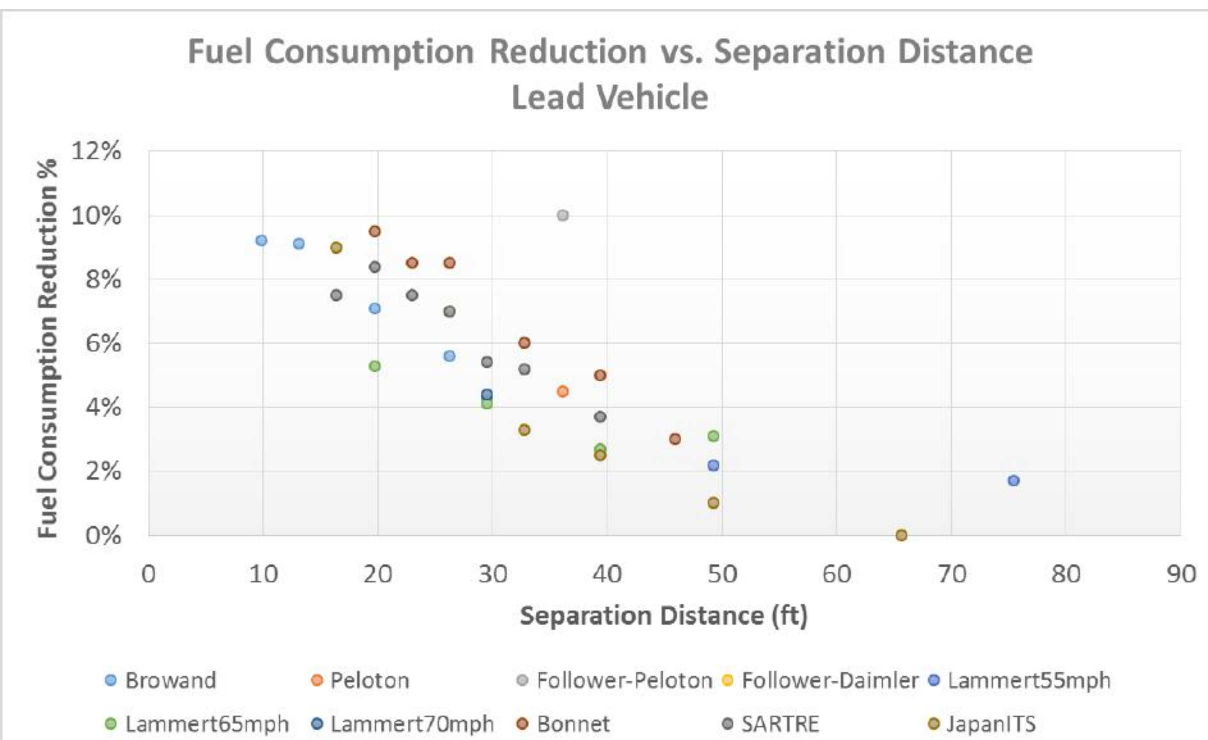


Figure 27: Summary Of Lead Vehicle Platooning Test Fuel Consumption Savings (Mihelic)

The same graph for the following vehicle is less well defined showing considerably more spread in the data reflecting the accumulation of the effects of other variables such as ambient winds, grades, weights, vehicle type, speed, etc. The trend again shows the fuel consumption reduction falls off at greater separations, but fuel consumption benefits continue out beyond a typical tractor-trailer vehicle length. The most significant gains are at the shorter following distances.

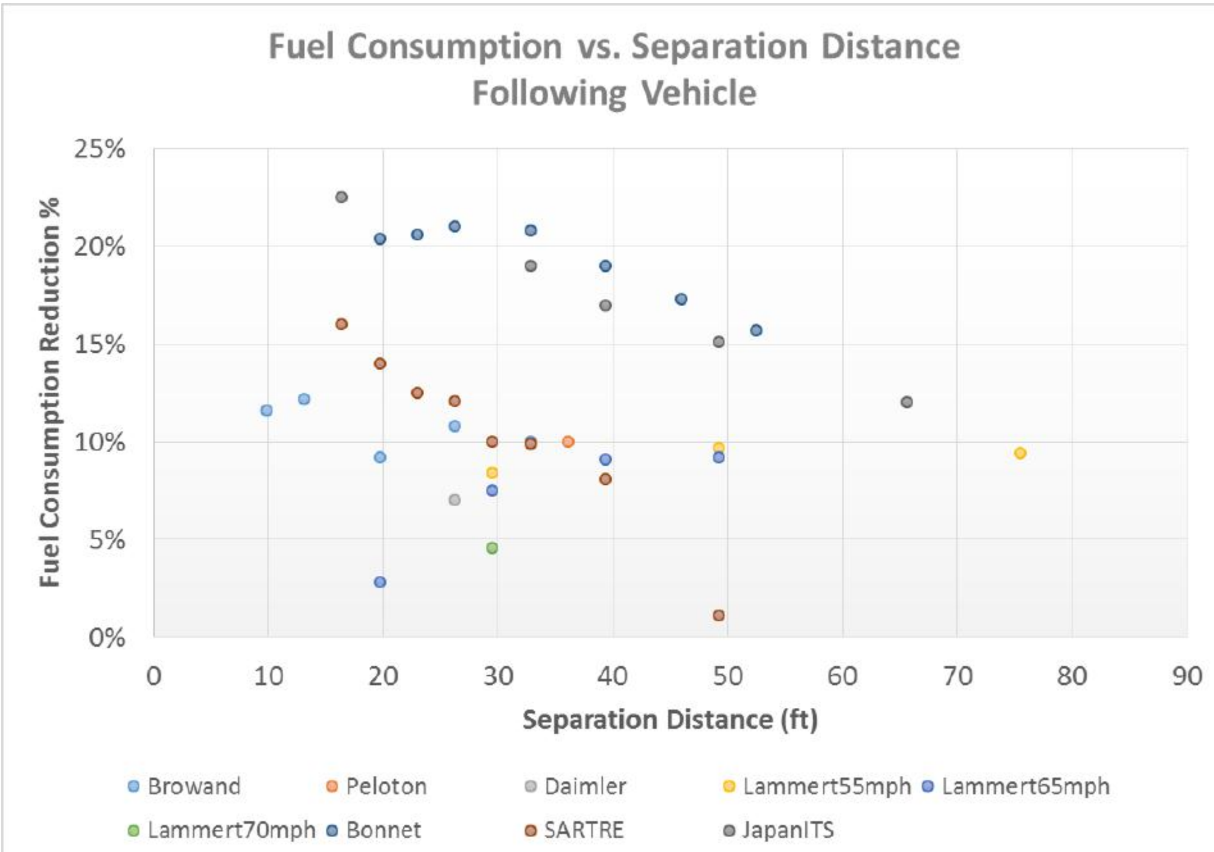


Figure 28: Summary Of Follower Vehicle Platooning Test Fuel Consumption Savings (Mihelic)

Focusing in on the 40 to 50 ft. following distance and about 60 mph speeds, NACFE estimates the savings to be approximately 4% for the lead truck and 10% for the following one when trucks are operated on a closed track in a consistent two-truck platooning arrangement. This equates to a 7.0% fuel efficiency improvement on average between the two trucks versus a truck operating in isolation.

3.1.3. Real-world Fuel Performance from Platooning

These platooning results are representative examples of the many studies that support beneficial gains from platooning. They universally compare the results to single vehicles operating alone. While this is a common method of reporting platooning benefits, it is a somewhat idealistic comparison. The method does not reflect that real world trucks travel in traffic perhaps 50% or more of their time. What are the potential fuel economy savings from platooning in normal real world conditions?

3.1.4. Platoon Disruptions

Looking at a typical highway as shown Figure 29, a truck's highway travel involves other vehicles in close proximity at least some percentage of the time. At other times the nearest traffic is far enough away that it has no aerodynamic effect on the truck.

Figure 29: Typical Highway Traffic (Virginia DOT)

Peterbilt reported in a 2014 SAE paper (2014-01-2436) that on-highway testing of its SuperTruck in Texas, depending on the route, showed that other vehicles aerodynamically affected the SuperTruck between 37% and 53% of the miles.

Route	Irving To Laredo	Denton to Vernon
In Wake Effects	37%	53%
In Free Stream	63%	47%

Figure 30: In-Traffic vs. Open Highway (Smith, et al)

Another reality of real world traffic is that tractor-trailers share the highway with other types of vehicles, each under their own driver's non-steady-state control. The vehicles do not all operate at the same speeds, nor do they stay at constant speeds. The nature of traffic tends to cause cruise control disengagement to adjust for differing vehicle speeds, random traffic densities, and safe operations. The cruise controls vary in capability and sensitivity. They are individually controlled so unlikely to all be set at the same highway speeds. Add in that commercial vehicles operate with varying speed limiter settings. A platooning vehicle group must maneuver in and around these other vehicles, which can introduce braking and acceleration events that waste fuel versus ideal test conditions.

The 2016 NHTSA Field Study of Heavy-Vehicle Crash Avoidance Systems (DOT HS 812 280) completed by Virginia Tech Transportation Institute collected CAS data from a total of 169 drivers operating 150 CAS-equipped trucks over a one-year period involving seven fleets and three million miles. It found that drivers, when in traffic, averaged between 2.4 to 2.8 seconds of headway (gap to next vehicle) at highway speeds. Measurements were recorded every 15 minutes and averaged by week. Those gaps translate to separation distances at 55 mph of 194 to 226 feet, or about three truck lengths. At 75 mph that translates to 282 to 308 feet, or about four truck lengths, close enough to have some aerodynamic benefit from lead vehicles.

The study determined that drivers from two companies activated their ACC system at an average rate between 13 times per hour and 38 times per hour. The study quantified that CAS following distance alerts (FDA) occurred at a rate between 4.3 and 7.2 times per hour for two study companies. This highlights that the amount of time a platooning group is operating in a steady state conditions varies, possibly considerably, from controlled track test results.

The NHTSA study concluded that, "CAS activations generated prior to a safety critical event (SCE) were most likely a result of lead vehicle actions, such as braking, turning, switching lanes, or merging. This finding is corroborated by research that found 78% of light-vehicle and heavy-vehicle conflicts are instigated by light vehicles around the heavy vehicle (Hanowski, Hickman, Wierwille, & Keisler, 2007). In contrast, advisory forward CAS activations were most likely to be a result of subject vehicle (SV) actions, such as passing, changing lanes, or following too closely." This NHTSA finding indicates that vehicles outside of the platooning group may significantly interfere with steady state platooning.

The benefit of platooning must be viewed in context of this real world traffic. Assessing the potential for platooning to improve fuel economy requires establishing a basis for comparison. One way to do this is by using data loggers to collect tractor operating details on actual duty cycles. Analyzing a vehicle's time under cruise control and time at speed over a period of weeks will provide valuable data for determining to what degree platooning might improve fuel economy.

3.1.5. Traffic Congestion Effects on Fuel Economy

Evaluating how often cars and other trucks are already providing some level of aerodynamic improvement requires additional data collection not readily available to production truck owners. It is technically feasible that collision avoidance systems can record the presence of nearby vehicles as seen in the NHTSA report. The NHTSA study used a specially designed miniature data acquisition system (MiniDAS) to acquire data for analyses. Adaptive cruise control systems could be logging data on how consistent the speeds are maintained on a route. Forward-looking on-board camera systems could collect the frequency of nearby vehicles. The pieces of technology needed for individual vehicles to log traffic conditions exist, but have not been deployed yet in a way owners can reliably access this traffic history.

Peterbilt's 2014 SAE Paper (2014-01-2436) highlights that two vehicles will affect each other's aerodynamic performance even as the gap increases, similar to Browand's USC testing. The wake field behind the lead tractor disturbs air for the following vehicle for many truck lengths. To put this in perspective, consider how the Federal Aviation Administration (FAA) sets minimum airplane separation distances for landing at between two and four miles to avoid the following plane experiencing turbulence. Peterbilt estimated through computational fluid dynamics analyses for a two-truck platoon with separation distances of 30 ft., 60 ft., 100 ft., 120 ft., and a mile that the trailing vehicle could see aerodynamic drag reductions for some distance from the lead as shown in Figure 31. The affects were captured on-road and indicated by changes in the free-wheeling engine fan rpm.

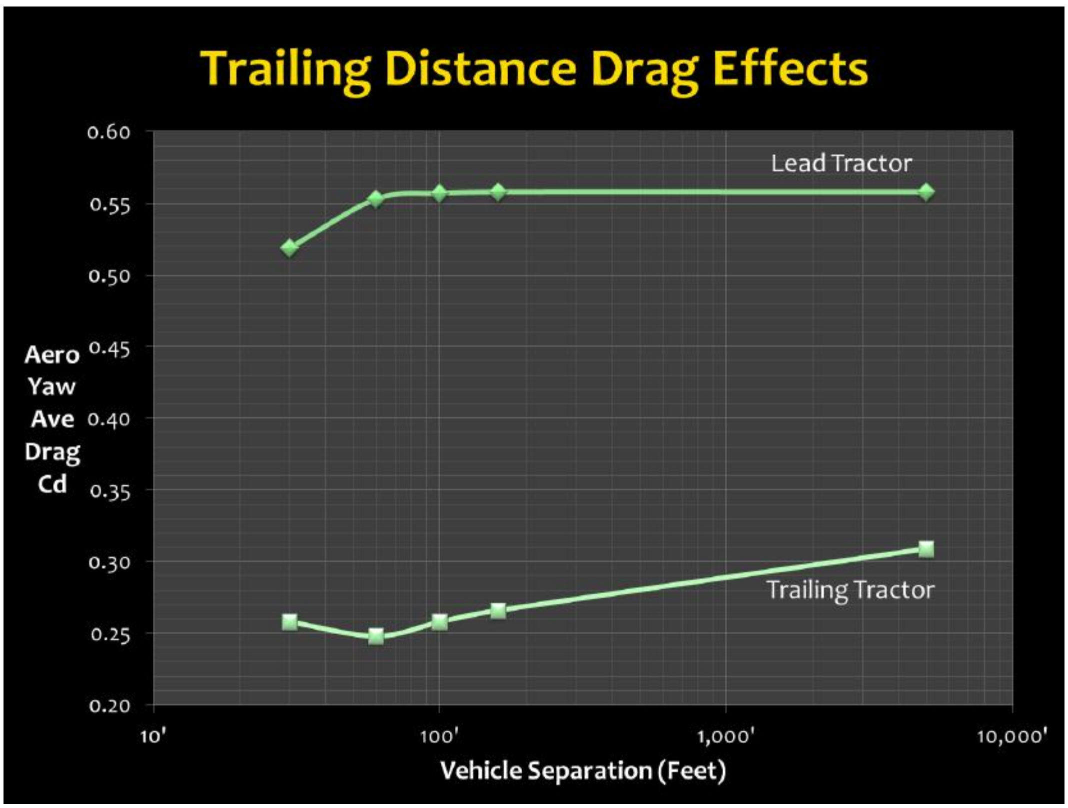


Figure 31: CFD Platooning Drag Reduction vs. Separation (Smith, et al)

The German government funded the KONVOI project from 2005-2009, which had a perspective that platooning trucks would need to share highways with other traffic. A four-truck platoon drove over 3,000 km (1,864 mi) with the first truck manually driven and the other three under automatic control, and police escort notifying traffic. According to the FHWA summary (Literature Review on Recent International Activity in Cooperative Vehicle–Highway Automation Systems FHWA-HRT-13-025) during this test, the platoon experienced 15 instances of cut-ins by car drivers, causing the platoon to separate. Six of these cut-ins occurred when the trucks were only 10–15 m (33-49 ft.) apart, about half a truck length or less. The FHWA reports that, "Researchers claimed that the trucks on the test track achieved some fuel-consumption savings even when they were driving at the 10-m (33-ft.) gap between trucks; however, there was no fuel-consumption savings in the tests on the public highway because the trucks had to vary their speeds to respond to traffic conditions and other vehicles on the road." Fuel consumption reduction was not a focus of the KONVOI project, rather the goal was understanding traffic and platooning. The project reported "positive [platooning configuration maintenance] results for constant driving at a velocity of 80 km/h (50 mph) with 10 m (33 ft.) distances." The FHWA also summarized that to maintain accurate separation distances, "it was necessary to design the systems with a high bandwidth, which means that it makes frequent corrections and tends to be 'busy,' which increases fuel consumption. This is a fundamental trade–off in the design of such systems and indicates the difficulty of saving energy and reducing greenhouse gas emissions when the equipped vehicles have to share the road with unequipped vehicles that do unpredictable things."

Figure 32: German KONVOI Platooning Test Vehicles (KONVOI)

3.1.6. Platooning and Adaptive Cruise Control

A key element of platooning is adaptive cruise control technology, a system for maintaining a set distance (or time) to a lead vehicle using a variety of methods such as laser and radar systems. Changes in the lead vehicle's velocity in a platoon result in the following vehicle automatically adjusting speed so that the separation distances remain constant.

The fuel economy ramifications of ACC operation are described in the 2011 KTH Swedish Royal Institute of Technology study by Alam with Scania (*Fuel-Efficient Distributed Control for Heavy Duty Vehicle Platooning*): "Any deviations in the form of acceleration and deceleration result in an increased fuel consumption. A heavy duty vehicle platoon control strategy generally receives information regarding the relative velocity and distance to the vehicles in the platoon and thereby maintains the relative distance by adjusting its speed accordingly. The increased control effort that the strategy creates, in the sense of additional transient engine actions and brake events, produces an increased fuel consumption."

There are a number of reasons the lead vehicle might alter speed. If the lead vehicle is equipped with a traditional cruise control with a set speed, grade changes and wind conditions can cause it to vary speed within its permitted tolerances. If the lead vehicle is equipped with ACC, the lead vehicle may need to react to traffic, vehicle cut-ins, obstacles, etc. If the lead vehicle is equipped with predictive cruise control, it will adjust to grades and vary speed to optimize fuel economy based on grades and highway speeds.

A 2012 IEEE paper titled "Cooperative Driving with a Heavy Duty Truck in Mixed Traffic: Experimental Results" by Nieu Nieuwenhuijze, et al, stated from testing that, "The increased control effort that the ACC creates, in the sense of additional transient engine actions and brake events, produces an overall increased fuel consumption. Thus to the best of our knowledge, it is still unclear whether the increased control effort produced by the ACC possibly cancels the reduction in fuel consumption achieved by decreasing the air drag."

3.1.7. Engine Fan On-Time

Recent studies have found that the improved aerodynamics of platooning vehicles brings with them a reduction in engine ram air cooling such that engine fans have more required on-time. The NREL study by Lammert, et al, (SAE Paper 2014-01-2438) stated, "The trailing vehicle achieved fuel consumption savings ranging from 2.8% to 9.7%; tests during which the engine cooling fan did not operate achieved savings of 8.4% to 9.7%." The authors stated in their 2014 SAE COMVEC presentation, "Closer following distances caused the engine fan on the trailing truck to engage, negatively impacting fuel savings."

According to a 2015 SAE paper by Exa and Volvo by Ellis, et al, (SAE 2015-01-2896), "Unlike similar investigations on platooning that solely focused on the potential fuel economy gain via aerodynamic drag reduction, this paper also highlights the adverse impact of platooning on the engine cooling performance in trailing vehicles, due to the reduction in ram air cooling caused by wake of the upstream vehicle." In computational fluid dynamics (CFD) analyses, the study evaluated a three and four tractor-trailer platoon at 65 mph with gap distances varied from 5 m to 9 m or about 16 to 30 feet. The paper concludes, "The incremental benefit of moving to a 5-meter (16 ft.) gap comes at a significant cost by further reducing engine cooling flow from the ram air cooling performance to levels that would most likely require fan engagement for all but the leading vehicle, thereby mitigating the potential fuel economy improvement." Figures 33 and 34 show temperature maps along the center of the under-hood region for the lead truck in clean air and the following truck at 5 m (16 ft.) separation, at 65 mph with zero-degree yaw wind angle conditions. The increased red at the front of the engine in the temperature map of the middle truck highlights increased heating that would initiate a fan-on response.

Figure 33: CFD/Thermal Study on Platooning Effects on Engine Cooling (Ellis, et al)

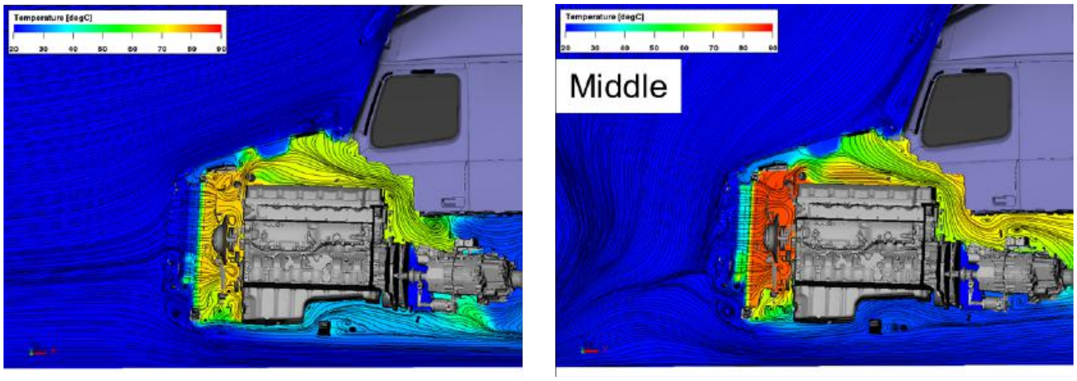


Figure 34: CFD/Thermal Study on Platooning Effects on Engine Cooling (Ellis, et al)

3.1.8. Real World Fuel Economy Summary

Given these real-world conditions, NACFE believes that fleets should expect lower fuel efficiency than reported in tests that have the platooning trucks operating on a test track or other location without traffic congestion. Each fleet will have to estimate this reduction depending upon the routes they plan to operate the trucks, but a reasonable estimate would be a reduction of about a quarter of the savings. This lowers the aforementioned savings of 10% for the following vehicle and 4% for the lead to 7.5% and 3%, respectively.

Finally, a fleet must apply its percentage of operating time that the truck equipped with platooning will actually be involved in a platoon. If that were 75%, then the real-world, expected savings would be on the order of 4%, average between the two vehicles.

3.2. Benefit: Accelerate the Adoption of Safety Equipment

As stated earlier, the adoption of technologies such as Collision Avoidance Systems, Adaptive Cruise Control, In-Cab Cameras, etc. are growing as their value is being studied and tested by fleets. And, by incorporating vehicle-to-vehicle communications to the technologies mentioned above, the following distances of two trucks can be reduced enabling platooning and saving fuel. This savings in fuel expense can help fleets accelerate the adoption of these technologies on their trucks. See Payback Calculator later.

4. Challenges

This Two-Truck Platooning Confidence Report is the first time NACFE has reported on an emerging technology. As such, there are several concerns and possible misconceptions about platooning commonly held in the industry today that must be addressed.

Interestingly, the confidence level among fleet managers that platooning technology, as well as the concept of platooning and the projected fuel economy gains it can yield, is very high across the board.

There is at the moment, however, a tremendous lag in the confidence that platooning can work in the "real world," most notably in heavy traffic or mountainous terrain. Fleet managers are also doubtful that drivers will be willing to engage in platooning operations, and are concerned about various safety issues and the security of the electronic systems used to connect and tether the vehicles together in a platoon.

Additional concerns include cost, system reliability, and questions about intra-fleet operations – notably how fuel credits will be accrued and shared.

NACFE found that the biggest concern among fleet managers focuses on the safety and the physiological well-being of platooning drivers – most notably drivers who are assigned to trailing vehicles in a platoon. It should be noted that the bulk of this concern comes from fleet managers with somewhat limited information as to how platooning works. These concerns are noted and are being addressed by vehicle manufacturers, platooning technology producers, and component suppliers. Equally noteworthy, drivers actually engaged in platooning validation and testing report that these concerns are exaggerated and that platooning does not noticeably increase driver stress levels or fatigue.

From a major for-hire fleet, "A lot of it looks spectacular. And I think it's do-able. But I have doubts. Not from a technology standpoint. I think that part of the puzzle is there. I'm skeptical about everything else around it: The regulations, return on investment, driver acceptance, insurability, convincing everyone that it is safe... There are a lot of challenges out there."

4.1. Challenge: Payback

The payback for platooning will be driven by many factors including the upfront cost for the equipment, any subscription costs for platooning, the savings in fuel, the costs to mitigate any of the challenges and the level to which the fleet is already investing in safety technologies. A payback calculator is provided with this study package in order to help purchasers evaluate the financial costs and benefits.

4.2. Challenge: Driver Acceptance

Two goals of vehicle automation are improvement in safety and vehicle efficiency. The range of vehicle efficiency potential has been described from testing. Benefits from application of selected automation that is in production show promise, such as documented in the "2016 NHTSA Field Study of Heavy-Vehicle Crash Avoidance Systems" (DOT HS 812 280) completed by Virginia Tech Transportation Institute which found "In over 3 million miles of data, no rear-end crashes of the type CASs are designed to prevent were identified." The study concluded, "While the CAS user experience can be improved, and some activation types were found to be less reliable than others, the results from this study suggest that the overall systems work as intended."

Other automation technology elements are also in production and have a field history in the real world. These include the three levels of cruise control – original cruise control (CC), adaptive cruise control (ACC) that adjusts vehicle speeds to follow a vehicle at a distance, and predictive cruise control (PCC) that adjusts vehicle speed to terrain, infrastructure, and other conditions.

Platooning systems, have not yet accumulated significant production field use, so predictions of safety benefits are more theoretical. The near-term focus of the technology relies on having a driver in the vehicle. This requirement stems from risk reduction and the reality that various situations will require drivers to intervene in some aspects of the autonomous operations. While truck platooning has not accumulated significant production mileage, a parallel can be drawn to decades of experience with aircraft pilots and the introduction of automation to cockpits.

Significant automation in jet liners began perhaps with the Boeing 757 introduced in the 1980s. An August 1989 *Aviation Week & Space Technology* (AWST) article outlined an Air Transport Association study of pilots, regulators, and manufactures that identified several issues associated with automating pilot functions, including:

- A potential for substantially increased “head-down” time
- Difficulty in recovering from automation failure
- Reluctance of flight crews to take over a malfunctioning system
- Deterioration of pilot/controller basic skills
- Complacency, lack of vigilance, and boredom of workers
- Introduction of unanticipated failure modes
- Difficulty in detecting system errors
- Incompatibility between advanced automated aircraft, existing air traffic control capability, and the rest of the fleet

These same categories of issues exist with respect to automating truck driving functions. In a 2016 article “Plans for self-driving cars have pitfall: the human brain” by Joan Lowy, (AP July 19, 2016) NHTSA’s Chief Highway Accident investigator, Rob Molloy, stated “Operators – an airline pilot, a train engineer or a car driver – can lose awareness of their environment when they turn control over to automation.” Further, he commented, “planes and trains have had automation for 20, 30 years, and there are still times when they’re like, ‘Wow, we didn’t expect that to happen.” Transportation Secretary Anthony Foxx, in the same AP article, was quoted as warning automakers they should realize that drivers will be tempted to use the technology in irresponsible ways and take that into account as they build their robotic systems. He said, “People are getting distracted by the coolness of the technology….In many cases, they are going beyond what the technology is capable of doing.”

A 1996 AWST article (AWST Mar. 4, 1996) sites a U.K. Civil Aviation Authority official, Terry Newman, saying, “Most designers hold the view that while modern automated equipment reduces pilot workload, his training and experience are essential in dealing with unexpected occurrences or system malfunctions. But at the same time, the skill levels of the baseline pilots are changing. Pilots are being encouraged to make use of automation at every possible opportunity, particularly autopilot, because it can do a better job than you. At the same time, there is need for additional knowledge on the part of the crew to become acquainted with these new features.” Newman stated, “There is a countervailing argument that the increased ease of operation as a result of automation allows reduced training time.” The AWST article highlights that “crews (may) complete training with a bare knowledge of basic automation functions.”

A 1999 NASA study (reported by David Hughes, AWST July 26, 1999) of commercial pilot training recommended that “Companies should formulate a policy on maintaining ‘hand flying’ skills for pilots to follow during transition training, including some portion of simulator training.” The AWST article states observations by David Woods, Ohio State human factors researcher, that training is needed “that shows pilots how breakdowns can occur during interactions with automation,” suggesting simulator training.

Figure 35: Driving Simulator (Sunheart)

In “No Easy Answers – Honing in on degradation of piloting skills” (AWST Dec. 9, 2013), Sean Broderick, reflecting on an FAA Working Group investigating the 2013 airliner crash at SFO airport, summarized “As aircraft and airspace management systems become more capable, pilots do less hand-flying and more system management. One result, in the working group’s words: ‘Concern has been expressed that pilot skill degradation occurs because the use of automated systems results in lack of practice or over-confidence in those systems.’”

The Department of Transportation issued a 2014 report *Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts: Past Research, State of Automation Technology, and Emerging Concepts* (DOT HS 812 043). The report includes a discussion of parallel connections between automotive and rail and airplane experience with automation. It concludes that “further research into shared authority and transitions between the driver and automation could provide significant benefit towards understanding and accounting for these risks.” The report also highlights the potential for skill degradation from overreliance on automation, stating, “Over time, this can possibly lead to a degradation in driver skill, as the reinforcement coming from constant engagement in the driving task is now lacking.”

There are airliner pilot automation experiences to be applied to truck driver automation. Automated vehicles have potential to improve safety and efficiency, but decades of airline experience have shown that the operator must remain skilled and that technology and the real world do not always work as expected requiring the driver to remain vigilant.

4.2.1. Drivers’ Experience with Platooning

Given the shorter following distances tractor-trailers maintain while platooning, there is currently widespread concern among fleet managers as to how drivers will cope with limited situational awareness (i.e., a severely restricted field of view, particularly to the front of the vehicle).

To compensate for this situation, it’s been suggested that platoon-capable trucks come with cameras and video screens to give all drivers, regardless of their position in a platoon, access to real-time information of dynamic road conditions around them.

When a lead truck is positioned in a platoon, its bumper-mounted camera begins transmitting video to trailing trucks in the platoon. This video is broadcast on the main display screen in the trailing tractors, usually located on the center section of the dashboard. This allows trailing drivers to see exactly what the lead driver sees as the platoon moves down the road. Likewise, the rear truck’s rearward facing camera, mounted in the bumper of its trailer, transmits video to the lead truck, so that driver can be aware of traffic conditions immediately behind the truck platoon.

Additional cameras give side- and blind-spot video as well, which drivers can view on secondary in-cab screens. However, rearview mirrors and radar-dependent active safety systems (such as blind spot and lane departure warning systems) remain the driver's primary source of information and safety concerning lateral traffic flow.

In spite of these measures, many fleet managers currently feel platoon drivers – particularly drivers in trailing vehicles – will not have sufficient fields of view and information to anticipate and react to threats while platooning. Fleet manager concerns about driver reaction times are closely linked to similar concerns regarding following distances and situational awareness.

Currently, many fleet managers feel drivers will either be too distracted or too bored to react quickly when a threatening road condition arises. Or, even if the driver is fully engaged in operating the vehicle, many feel the driver simply will lack the reaction time required to react safely in a crisis, similar to experiences most of us have had as tailgating drivers.

To assess actual driver experiences with platooning technology, NACFE interviewed four test drivers with a leading platooning technology developer in order to gauge their experiences thus far.

It should be noted that while their responses cannot be considered unbiased, their thoughts and experiences did shed light on several important aspects of platooning from a driver's perspective.

First off, the drivers were all older—averaging approximately 55 years old—maybe dispelling the notion that younger drivers will naturally feel more comfortable with platooning. The drivers then discussed their experiences with specific aspects of platooning called into question by industry skeptics:

The drivers, most of whom had 20-plus years of experience, noted that many truck drivers today already unofficially platoon to one degree or another, especially out west on sparsely populated highways. Using platooning technology, they noted, vastly increased the safety aspects of reduced following distances and noted that their individual comfort levels with platooning rose very quickly as they became familiar with it. In fact, it was the consensus among the interviewed drivers that the main reason the trucking industry at large is currently so skeptical regarding platooning is because people do not understand how quickly and effectively the integrated safety systems work. Another point the drivers stressed was that the system they test uses real-time road data from vehicles ahead, which the system processes, tracks, and reacts to.

Driver 1 noted that before he actually participated in a platooning drive, he felt he would have to "stand on the brakes" in an emergency situation. Instead, he found that the system reacted far faster than he could apply the brakes; so fast in fact, that he found his trailing truck only gained "about a foot or two" on the lead truck before the vehicles began slowing at a simultaneous rate.

Driver 2, (the most junior driver in the interview) said, "One of my earliest jobs was to test the system's ability to deal with hard-braking events. And it surprised me how effectively the safety system applied the brakes. I wasn't told when to hit the brakes, so each event was a surprise. The first few times, I kept my foot hovering over the pedal waiting to hit it hard when the lead truck's brake lights came on. But I never had to. The system handled the event before my foot could get to the pedal. Even at 50 mph, the response was immediate and backed my truck off by 50 to 60 feet each time."

Driver 3, who had spent several years as a driver/instructor for the National Highway Traffic Safety Administration, cited the organization's textbook section on truck braking, which notes that a fully loaded tractor-trailer traveling at 55 mph takes approximately 657 feet to come to a complete stop. But, he says, the safety systems used in platooning can bring a similarly spec'd and loaded tractor-trailer to a full halt in less than 200 feet safely.

Drivers also reported that pre-platooning anxiety about passenger cars breaking into a truck platoon had fallen off to the point that it was a "non-event" when it occurred to them now. Driver 4 explained that the system was so quick to respond to an intruding vehicle that it was "not a problem at all."

"Most of those cars transit in and out of the platoon rapidly," he said. "The system detects them coming in, taps the brakes and backs off – usually only about 50 or 60 feet. Once the car is gone, you hit the 'resume' button and the platoon closes back up quickly."

On a similar note, Driver 4 noted that the system works so smoothly, that drivers can feel how quickly both brakes and throttle are applied by the platooning safety systems. "It works very smoothly," he noted. "There's not a lot of a 'yo-yo' effect between the trucks as they establish and maintain position."

All interviewed drivers were adamant that platooning – even in a trail truck position – did not increase anxiety levels at all. Nor did they feel they were disengaged from driving the truck or unable to process and track road and track conditions around them.

"The driver is still the driver," Driver 1 explained. "And the information displays we use are constantly improving. We're adding more cameras and working on augmented reality systems that allow us to see everything around the truck. And I don't think people in the industry don't understand how far our display technology has already come, and how much more it is going to improve in the near future."

"The view is a little different from a trailing truck," Driver 3 noted. "But you can see just fine. It's not like the entire world is blocked out. It's a different mode of driving, yes. But it's not going to drive you crazy. You have plenty to keep you occupied."

Driver 4 added, "We understand that a lot of people feel this is a major problem. But we don't see it that way. We are communicating much of the time and you still have to be alert. I don't believe you'd ever get so bored that you'd fall asleep or run off the road. If you have those issues, you shouldn't be driving a truck, anyway."

"If you get tired, you can always leave the platoon," Driver 3 noted. "You're not obligated to stay there. If you feel fatigued, you can take a break."

"I drove 1,000 miles across Utah and Nevada recently, all of it in a trailing position," Driver 2 added. "And it wasn't a problem. There's not a lot to see out there, anyway. I'll be blunt: I've been [doing this] for more than 20 years. And driving can get pretty boring sometimes. So there's not a whole lot of difference when you're platooning. I may get tired when I've been in a trailing truck in a platoon all day. But I'm not any more tired than I can be if I'm driving a solo truck all by myself all day."

4.3. Challenge: Platoon Integrity

Another commonly cited safety concern is the overall integrity of the platoon as it moves down the road. Fleet managers wonder how the system as a whole, and the individual driver, specifically will react if – and when – passenger cars move into the gaps between platooning trucks to get out of a passing lane, for example, or get to a highway exit ramp. A smaller number of fleet managers expressed concerns that law enforcement officers would mistake platoons for now-illegal truck convoys and attempt to cite participating drivers. Most fleet managers expressing these concerns rightly noted that at the moment, awareness of truck platooning among both the motoring public and the law enforcement community is limited.

In a two-truck platooning system, each vehicle's active safety systems would react to a passenger car breaking into a platoon exactly as they would if a vehicle cut a single truck off in traffic today: The brakes would immediately engage and slow the truck until a safe following distance behind the intruder vehicle was achieved. Likewise, any trucks behind the threatened truck would react accordingly. Once the intruder vehicle left the platoon, the drivers would accelerate back up to the lead truck and the platoon would once again establish itself.

Once truck-platooning technology becomes market-ready, the trucking industry as a whole will have to embark on an educational campaign targeting legislators, law enforcement, and the general public. In the meantime, test convoys in Europe, as well as Daimler's platooning system showcased in Germany in 2016, all use a system of highly visible, flashing strobe lights to alert surrounding cars that a platoon has been established and is moving down the highway in unison.

A chief engineer at a truck OEM believes, "People, the public, will get used to seeing the trucks in close formation and know what platooning is, in pretty short order."

4.4. Challenge: System Security

In July of 2015, hackers working with *Wired* magazine were able to successfully gain access to a Jeep Cherokee's onboard electronic control system and shut the vehicle down at highway speeds. Known as "hacking," the ability to break into supposedly secure data systems is a serious problem and one that truck platoons and V2V systems are especially threatened by.

There has been recent news (Can Big Trucks Be Hacked, *Heavy Duty Trucking*, August 8, 2016) about a trio of researchers from the University of Michigan who hacked into the J1939 databus on a 2006 model year truck. It is important to note, the article said, that "While researchers did manage to seize control of the truck's throttle and engine brake controls, they used a laptop computer connected directly to the truck's dataport (OBD) to pull off their experiment."

OEMs, Tier 1 suppliers, and platooning technology developers all stress that system security will be paramount as development continues. Primary concerns will be to develop encryption that will protect platooning communication systems from hackers looking to obtain proprietary information about a specific vehicle or fleet specifications as well as preventing the ability to disable safety systems or assume control of autonomous vehicle systems with the intent to deliberately crash or divert a vehicle.

As with any autonomous vehicle system today, fleet managers invariably question the overall security of the technology used in platooning. Questions concerning the security of platooning communication protocols were common during interviews conducted for this Confidence Report. Usually these questions centered on system hacks and concerns that criminals could take control of an autonomous vehicle. With regard to platooning, most concerns seem to center on the security of any proprietary data that would have to be exchanged with trucks from rival fleets during the initial dialog phase of establishing a platoon.

"In the real world, I think fleets will pursue platooning cautiously. But we need to develop a secure electronic 'handshake' between two trucks and a way to determine who will lead and follow, and how speeds and maneuvers will be matched," said a truck OEM chief engineer.

4.5. Challenge: Amount of Viable Platooning Time

Another open question asked by several fleet executives interviewed for this report was the amount of time actual platooning would be possible given the nature of real-world trucking operations. In other words, would fleets invest in platooning technology only to discover they were able to use said technology only a small portion of the time when trucks were running routes.

Cited barriers to platooning included:

- Locating another platoon-capable truck
- Weather
- Traffic/road conditions
- Geography
- Platoon system glitches/maintenance or calibration issues
- Driver participation

Concerns with this line of thinking were that in practice, platooning might be a viable option only a small percentage of the time and any fuel-savings would not justify the outlay in acquisition and operational costs.

As noted, this currently is an open question that cannot be answered until more information concerning platooning's durability, flexibility, and ease-of-use in day-to-day fleet operations has been gathered.

Here is what a large for-hire fleet manager had to say on the subject: "I figure it would cost at a minimum, $1,500 to $2,000 per truck, but my concern is, we'd have to pay 100% for the technology, but only get to use it say, 25% of the time."

4.6. Challenge: Legislative Efforts and Public Awareness

As autonomous vehicles gain acceptance, changes to traffic laws that reflect the impact this new technology will have on our highway transportation are under consideration on both the state and federal level. This holds true for truck platooning as well, with several states, notably Nevada and Texas, passing legislation that allows limited use of public roadways for real-world testing of autonomous trucks and truck platooning technology.

On the other hand, in early July of 2016, Missouri governor Jay Nixon vetoed a bill that would have legalized truck platooning in his state, citing his belief that platooning is "unproven technology."

There are currently no federal laws prohibiting truck platooning in the United States. Most opposition to platooning from a legislative standpoint is currently centered at state-level laws dictating following distances between trucks and outlawing truck convoys.

OEMs and platooning technology developers are working with the American Trucking Association, which, in turn, is working with state-level trucking associations to raise awareness about truck platooning and its potential fuel-saving benefits with lawmakers at both the state and federal level.

Additionally, while NHTSA has not specifically commented on emerging truck-platooning technology as yet, the agency has sent strong signals that it will be issuing guidelines for mandatory V2V systems in passenger cars soon. Broadly speaking, that is an indication that the agency has confidence in V2V technology, and believes it will enhance highway safety. It is reasonable to assume that once V2V standards are set in automobiles, similar standards for commercial vehicles will follow soon after.

On September 20, 2016, the US Department of Transportation issued their Federal Automated Vehicle policy that will facilitate technology research, testing and implementation that will include aspects of two-truck platooning. (https://transportation.gov/briefing-room/federal-automated-vehicles-policy-septemeber-2016)

4.7. Challenge: Sharing Fuel Savings

Several fleet owners expressed concern over a new aspect of platooning technology: how would competing fleets compensate each other to maximize the benefits of fuel economy credits.

A specific scenario cited goes like this: Your truck is slotted into the lead position of a platoon, whereas two of your competitor's trucks take up the trailing positions. Your truck is only receiving a 3% fuel economy boost, while the second truck is getting 7% and any trucks behind that one is getting 9% or more.

Clearly, the first and second truck, while not exactly being penalized for platooning participation, are not getting as much of a benefit as the trucks farther back in the platoon.

Peloton has proposed a cloud-based "banking" system that would record overall platooning participation and allocate credits so that participating fleets would be properly rewarded for using platooning technology.

On the other hand, there is a line of thought that the law of averages would simply come into play and over time even out penalties and benefits for fleets that regularly engage in platooning operations.

4.8. Challenge: Reliability

Reliability of platooning technology systems remains a critical unknown as there is little field history on these systems.

The reliability of sensors, electronic controllers, software, communications, etc. become increasingly critical as platooning separation distances decrease, because reaction times required for safe operation become too short for the human driver to be a viable back-up system. There are published standards such as ISO 26262, Road Vehicles – Functional Safety, that outline the approach to ensuring reliable system designs.

Failures are classified by type. Each has an expected frequency of occurrence. Each has a severity level. Engineers perform a risk assessment to quantify the probability of each failure and can estimate the probability of failure of whole systems.

This probabilistic nature of reliability acknowledges that failures can and do happen. The goal is to minimize the frequency and severity of potential catastrophic events.

Many factors affect reliability. Some are well defined, others are only theorized, and still others are unknown. To some degree, product development requires trial and error field experience, a process of continuous improvement. There is a learning curve with all products and their designers.

There is a theme in platooning discussions that computer-controlled systems are flawless compared to human-controlled ones. This fails to recognize that humans design and build the computer controls. Aircraft designers are still finding new, unforeseen events in automated flight systems that cause failures. It is naïve to assume absolute omniscience on the part of designers and manufacturers. Factor in also that economics is involved in decision making on product system designs such that tradeoffs are necessary between cost, performance, and reliability. Algorithms may be able to choose the best solution to a situation from a table of options, but that table will not be all inclusive because it originates from experience. What has not been experienced yet may not be represented by good choices in the table. System designers are challenged to design for all the real world combinations of failures in new systems that have limited field experience and unknown failure modes.

The chicken-and-egg nature of platooning technology requires experience with on-highway systems in order to improve the knowledge base and reliability. As some of the key component elements have been in production use, such as collision avoidance, automated braking systems, adaptive cruise control, and others, designers are not starting from zero experience. On-highway platooning research demonstrations will evolve into production systems and reliability will improve based on feedback from actual use.

4.9. Challenge: Litigation

The intent of this report is to discuss fuel economy improvement potential from platooning technologies for cost reduction to fleet operations. Imbedded in operating costs is a need to address the potential impact of litigation. A detailed discussion is beyond the scope of this document, however NACFE has identified key operating cost questions needing clarification for platooning to progress.

Who is liable in an accident? Legal costs invariably affect the bottom line of any company. A commercial product developer can offset these costs by building them into the product price. A service provider, such as a fleet, can build legal costs into rates and surcharges. Insurance providers can build them into premiums. One theory is that the OEM or its supplier is responsible for automation technology, implying that liability costs would need to be built into product pricing. Another perspective is that the fleet is responsible for both the vehicle and driver, so liability costs might need to be built into freight rates or surcharges. The driver, in the evolving automation world, seems less accountable than the technology such as in an emergency braking situation where the tractor automation recognizes the need to apply brakes and bring the vehicle to a stop in much shorter reaction times than the driver could attain. For a legal overview of the topic of automation, see Bryan Smith's "Automated Vehicles are Probably Legal in the United States," (Texas A&M Law Review 411 - 2014).

Will automation technologies reduce the cost of ownership? The general consensus is that collision avoidance and automated braking systems will, and already have reduced the number of accidents. The NHTSA 2016 study supports this conclusion with a year's worth of fleet on-highway data. However, cost of ownership is more than just the accident rate. Maintenance and training are also factors, as is severity of events. As there are no production platooning systems in large fleet operations at present, there is scant actual data. As sensors become more sophisticated and software becomes more complex, correct maintenance becomes more critical to safe operations. Integration between multiple systems produced by multiple companies becomes more crucial. Updating equipment and software may be a regular necessity. This could increase costs of troubleshooting equipment, software, training, skilled personnel, and perhaps increased vehicle down time. Systems with high reliability may still encounter unexpected failure modes as observed through the years of commercial aircraft incidents and more recently automated car incidents. Also, while overall accident rates may go down with automation technology, accidents that do occur may be more severe. Picture a pair of platooning vehicles separated by 50 ft. where the lead vehicle unexpectedly impacts a bridge pylon because a false reading from a sensor or due to a vehicle cut-in or animal strike. The trailing vehicle will also impact. So a one-vehicle accident before automation could by default become a two-vehicle accident in platooning. It remains to be seen if insurance costs will go down because of incorporation of automation systems. They may just transfer upstream to the OEMs, suppliers, and data service providers, who may subsequently raise their prices to maintain profit margins. One recent discussion on the topic is from the Insurance Information Institute titled "Self-Driving Cars and Insurance." Another is a 2016 RAND report, *Autonomous Vehicle Technology: A Guide for Policy Makers*, (ISBN: 978-0-8330-8398-2).

5. Insights from Interviews

In conducting the research for this Confidence Report the study team spoke with fleets, technology developers, component suppliers, tractor OEMs, and others about the fuel savings available from tractor-trailer platooning, and the challenges and benefits of adoption. The following quotes offer a sample of insights from these interviews:

- General Comments
    - A private fleet manager, "I'm not sure it will support our business. We're not going to redirect trucks just to take advantage of platooning. And I'm not sure how it would work combined with other fleets. All the details that have to be worked out. Who gets credit for the fuel savings? But, I have no doubt it's going to happen: The technology is here. So I know the industry can make it work."
- On the wide-range of beliefs on the timeline for platooning
    - A major truckload fleet manager, "I'm thinking 2028 to 2030 before we see platooning operations on the road. There are still way too many studies that have to be done on this — from the effects on safety, how the drivers will handle looking at the back end of another truck for hours on end. We just don't know yet."
    - A private carrier, "Realistically, I think the industry will be testing this year but general deployment may not occur until 2017. We are cautiously optimistic on the savings, but will validate in testing. But we are going to have to demonstrate a comparable level of safety."

- A truck OEM manager, "The safety systems will soon become mandatory, so why not let that technology pay for itself by platooning. We and the fleets will figure this out pretty quickly."
- On fuel savings
  - A private fleet manager, "Anything that delivers around a 5% fuel economy increase always has my attention."
  - A major for-hire fleet manager, "Typically, in my experience, test results are usually double what you can hope for in the real world. So, being realistic, I'm thinking it will probably work out to be 2.5% for the lead truck and 5% for the trailing truck while platooning."
- On following distances
  - A major component supplier, "There is a tremendous amount variation in braking. And other factors that come into play even if everything else is the same—the condition of tires, and for that matter the general maintenance of all systems."
  - A fleet executive, "It's pretty clear to me that 40–50 feet is a good place to start, with good fuel savings and appropriate distance."
- On equipment cost
  - A mid-size fleet manager, "Pricing on stuff like this is generally expensive. I have a feeling this is going to be very pricey and I'm concerned about that."
  - A technology developer, "We don't think the cost will be as high as some groups are forecasting. And the cost picture can change rapidly as economies of scale come into play. Fleets are already putting these systems on trucks. And, while the numbers aren't finalized, right now, based on what we're seeing, we're estimating from $1,500 to $2,000 cost for the equipment per truck."
- On driver acceptance
  - A mid-size fleet, "I'm just not sure how the drivers are going to handle being in that trailing truck. My sense at the moment is that any fuel economy gains will be outweighed by the impact on the drivers and their health."
  - A large for-hire fleet, "I cringe every time I hear the statement, 'All the driver has to do...' and fill in the blank. They're not going to do 'it' 100% of the time. Maybe they'll use something half the time if you're lucky. The platooning business model sounds great: All they have to do is link up. But what if the guy is going to be the trail truck and he just doesn't want to?"
  - A test truck driver, "Platooning hasn't been a ground-breaking experience for us. The driving experience is very similar to normal truck driving today. There is a very short period of apprehension at first, but it becomes normal in a few days. It's not a big deal and the driver stays very central what's going on."
- On driver pay
  - A major for-hire fleet manager, "What will we have to pay drivers to get them to do this? The guy in the lead truck? Not much changes for him in terms of the job. The difference is the guy in back. Seems like it would be very monotonous with high stress — a challenging position to fill. You'd have to pay someone a premium to sit back there, I think."
  - A mid-size fleet manager, "Driver pay will have to be adjusted. We'll see an evolution on that. We may have to come up with new names for what we call 'drivers' today. I think you're still going to have to pay people to sit in that seat. But the nature of that job is going to change. I think it will morph into more of team-type job opposed to the individualist job it is today."
  - A fleet manager "In all cases, we expect to pay an incentive to the drivers to platoon."
- On platooning with other fleets

  - A fleet manager, "We're not sure about this yet. It will be our position initially that we will not platoon with anyone else. This may change over time."
  - A mid-size fleet, "I think there will be a lack of cooperation between fleets on platooning, and rightly so. So that will limit how much you'll be able to platoon. When you look at the expense and how often it can be used, I don't see it as a viable option unless fuel prices shoot up again."
  - A major component supplier general manager, "I think within the same fleet is the only way platooning can start. At the outset, there aren't going to be many fleets that are equipped to platoon. So there won't be wide scale deployment. But the big fleets will experiment and, assuming the tests are good, they'll move forward and create contracts with smaller fleets to platoon."
- Litigation concerns
  - Another fleet, "My opinion is that while the technology may support platooning quite well, there will be few if any fleets that participate. I don't see fleets willing to take the risk in our current environment with litigation. The risks just outweigh the rewards. You get a few 10s of an mpg boost. And if you have a thousand truck fleet it could save you millions of dollars. But one damn accident could wipe out that monetary gain."

6. Business Case for Platooning – Payback Calculator

It is critical to evaluate the total cost of ownership of adopting a particular technology. Most fleets estimate the payback using various financial models. A simple payback calculator is included with this Confidence Report publication package and can be downloaded as a spreadsheet at truckingefficiency.org. The study team suggests monetizing all benefits and consequences of adoption in order to be as comprehensive with the financial impact of adoption.

A screenshot of the output of the calculator is provided on the next page under three scenarios:

- A fleet platoons 75% of the time and has not bought the enabling technologies
- A fleet platoons 75% of the time and has already invested in the enabling technologies
- A fleet planning to platoon 50% of the time and already purchasing the technologies

Many factors influence this calculation and the inputs provided by NACFE are estimates given limited discussions with manufacturers and end users. It is critical each fleet input their own specific data. Given the inputs presented here, payback periods for these three scenarios are 23, 13 and 24 months, respectively.

NACFE Study Payback Calculator: 2-Truck Platooning

Yellow boxes are for user inputs

	Scenario 1	Scenario 2	Scenario 3	Notes:
Miles per tractor per year	110,000	110,000	110,000	Input fleet data
% of the miles platooning	75%	75%	50%	Input %
Miles per tractor platooning	82,500	82,500	55,000	Calculated
Costs				
Total Installed Cost				
Collision Avoidance Technology	$ 1,500			Input $0 if already in tractor spec
Adaptive Cruise Control	$ 250			Input $0 if already in tractor spec
V2V Radios for Transmission	$ 250	$ 250	$ 250	Input your own data
In-Cab Cameras	$ 200	$ 200	$ 200	Input your own data
Other material or tech update during ownership	$ 400	$ 400	$ 400	Input your own data
Labor to install	$ 200	$ 200	$ 200	Input your own data
Total Installed Cost	**$ 2,800**	**$ 1,050**	**$ 1,050**	**Calculated**
Other Costs				
Any per truck cost (Annual subscription, etc.)	$ 200.00	$ 200.00	$ 200.00	Input cost per truck per year
Additional maintenance costs per truck per year	$ 50.00	$ 50.00	$ 50.00	Input cost per truck per year
Other ongoing costs?				
Driver and technician training	$ 50.00	$ 50.00	$ 50.00	Input cost per truck per year
Incentivize drivers to platooning ($/mile)	$ 0.0075	$ 0.0075	$ 0.0075	Incentive per mile if any
Annual Driver Incentive	$ 618.75	$ 618.75	$ 412.50	Calculates annual incentive
Total Annualized Costs	**$ 918.75**	**$ 918.75**	**$ 712.50**	**Calculated**
Benefits				
Fuel Savings				
Fuel miles per gallon	7.00	7.00	7.00	Input fleet data
Fuel $ per gallon	$ 3.00	$ 3.00	$ 3.00	Input fleet data
Fuel Expense per mile per truck	$ 0.43	$ 0.43	$ 0.43	Calculated
Total Fuel Expense per year per truck before platooning	$ 47,142.86	$ 47,142.86	$ 47,142.86	Calculated
% of platooning miles following	50%	50%	50%	Input fleet data
Estimated % fuel savings following	7.5%	7.5%	7.5%	Input fleet data
Fuel expense saved following	$ 1,325.89	$ 1,325.89	$ 883.93	Calculated
% of platooning miles in the lead	50%	50%	50%	Input fleet data
Estimated % fuel savings while in the lead	3%	3%	3%	Input fleet data
Fuel expense saved in the lead	$ 530.36	$ 530.36	$ 353.57	Calculated
Fuel savings per year per truck	**$ 1,856.25**	**$ 1,856.25**	**$ 1,237.50**	**Calculated**
Repair and insurance costs	**$ 500.00**			**Zero if already assumed with**
Other Benefits?				**safety equipment**
Total of one time costs	**$ 2,800.00**	**$ 1,050.00**	**$ 1,050.00**	**Calculated**
Total of annualized costs	**$ 918.75**	**$ 918.75**	**$ 712.50**	**Calculated**
Total of annualized savings	**$ 2,356.25**	**$ 1,856.25**	**$ 1,237.50**	**Calculated**
Payback in months	**23.4**	**13.4**	**24.0**	**Calculated**

Dated: September 22, 2016

Notes:

7. Future Perspectives on Platooning and Autonomous Trucks

Platooning is a catchall term for a broad range of possible implementations of fuel economy improvement through controlled operation of two or more trucks in tandem. The term may have different meanings to different people. One future vision is a fully autonomous vehicle with no driver that is operating in a road train, where the trailers are being pulled by drone tugs that may not even have an operator cab, such as these example concepts from Renault and Volvo seen in Figures 36 and 37.

Figure 36: Possible 70 Foot Aero Trailer with Drone? (Umea Institute of Design)

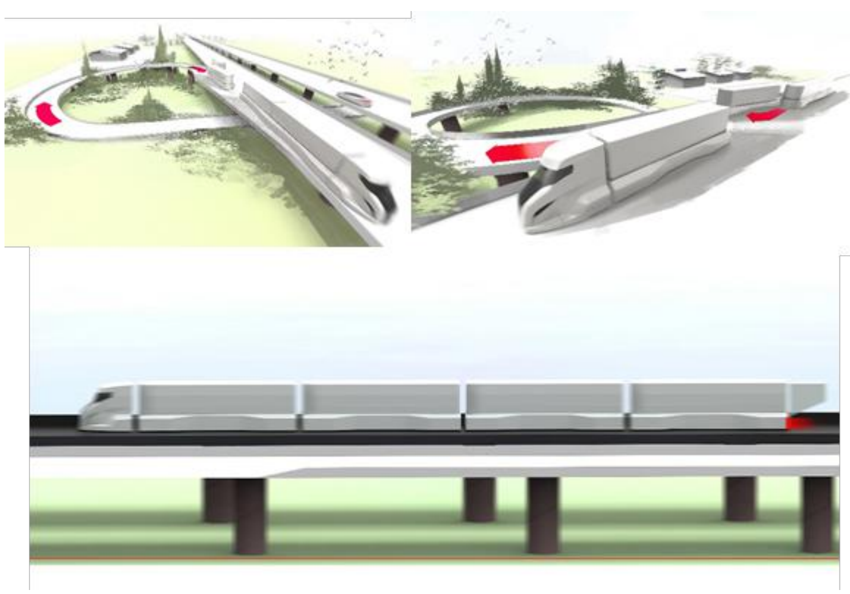


Figure 37: Volvo Slipstream Road Train (Volvo)

Others envision various levels of driver assistance technology where the driver remains principally responsible for directing the vehicle. These include variously longitudinal control, transverse control or lane maintenance, evasive maneuvering, electronically assisted collision avoidance braking, adaptive cruise control, etc., combining a collection of technologies into a viable system for some level of grouping vehicles to achieve better performance.

A fundamental question arises if two vehicles following very closely in a platoon makes economic and safety sense, then why not take it to its logical shortest gap and lower risk by eliminating the second tractor entirely and just using a double trailer? This was a question presented by Mihelic in a 2015 SAE Paper (SAE 2015-01-2897). The conclusion was that there were significant financial and safety reasons to consider doubles as the logical projection of a zero-gap platoon.

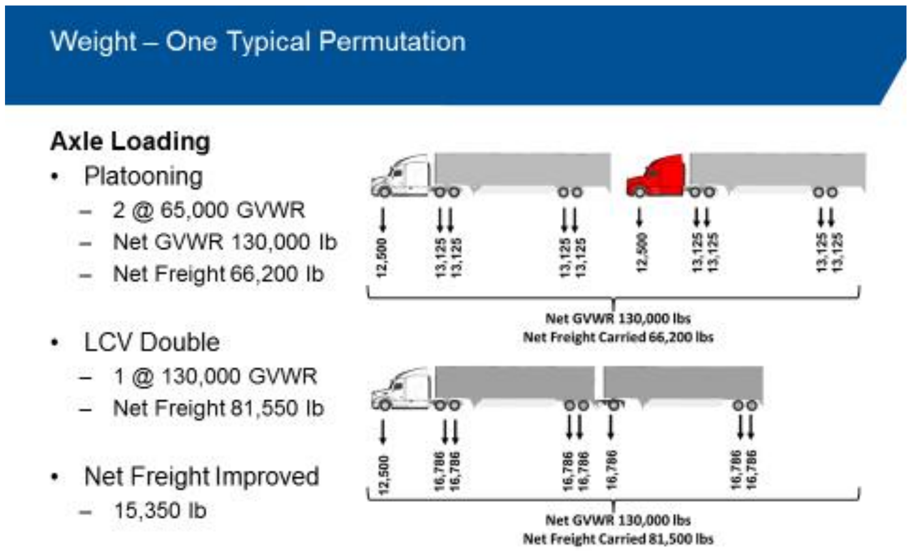


Figure 38: Platooning vs.Double (Mihelic)

Figure 39: Platooing vs. Doubles (Mihelic)

Projections for future on-highway freight demand is that it will increase significantly by 2050 and maintain its predominance over other freight transport modes. The freight industry has discussed driver shortages as a growing issue for some years, as well as a lack of newcomers to replace retirees. This is compounded by a seemingly perpetual high driver turnover rate reported as early as 2004.

Weight of Shipments by Transportation Mode

(Millions of tons)

	2007	2012	2040
Total	18,879	19,662	28,520
Truck	12,778	13,182	18,786
Rail	1,900	2,018	2,770
Water	950	975	1,070
Air, air & truck	13	15	53
Multiple modes & mail	1,429	1,588	3,575
Pipeline	1,493	1,546	1,740
Other & unknown	316	338	526

Figure 40: Projected Freight Demand By Mode (FHWA/BTS)

This underlies the fact that the future will likely involve moving more freight with fewer drivers, a conclusion that could significantly refocus capital investments and operating costs. A truly autonomous driverless drone is one potential solution. Transitioning to greater use of A-Train and B-Train doubles or triples as is occurring in Canada and the U.S. Northwestern states is another solution that is already feasible under permits or regional rules.

Platooning and long combination vehicles (LCVs) are not mutually exclusive concepts. Innovators in platooning technology, such as Scania's 2016 demonstration, also have demonstrated that platooning doubles is possible. Evolving safety technology applicable to single tractor-trailer operations is likely also relevant to LCVs.

Figure 41: 2016 Scania Platooning Doubles Demonstration (Scania)

The future solution for approving use of platooning technologies should also include use of LCVs.

Platooning has technical challenges with today's truck designs, such as cooling flow reduction seen in trailing vehicles that can cause fan engagement that reduces fuel economy savings. One OEM industry expert consulted by NACFE for this Confidence Report, said that future tractors and trailers may be redesigned to improve platooning and eliminate these technical challenges. Trailer rear ends and tractor hood systems may need to be optimized in context of platooning, where today's vehicles have not been designed with those additional needs.

The ultimate goal of near-term platooning is to reduce fuel expenses because of the aerodynamic benefits of the two vehicles operating as a system. A longer-term vision, expressed in a 2015 report by Janssen, et al, titled "Truck Platooning Driving the Future of Transportation," is to remove the driver from the system — "two trucks, one driver."

> *"The aim for truck platooning resides in the second big development: being able to let the second vehicle drive autonomously following the first truck without an actual driver in the cabin, that is: two trucks, one driver."*

Figure 42: Two Trucks – One Driver Automation Goal (Janseen, et al)

This vision stems primarily from recognition that the driver represents approximately one-third of the operating costs of a tractor-trailer, and is consistent with manufacturing and other industries' trends to replace human labor with robotics (i.e., replacing recurring operating expense with a one-time capital investment). Mihelic argued that even more savings are possible with one driver, one truck, and two trailers as it eliminates the capital and operating costs of the second tractor.

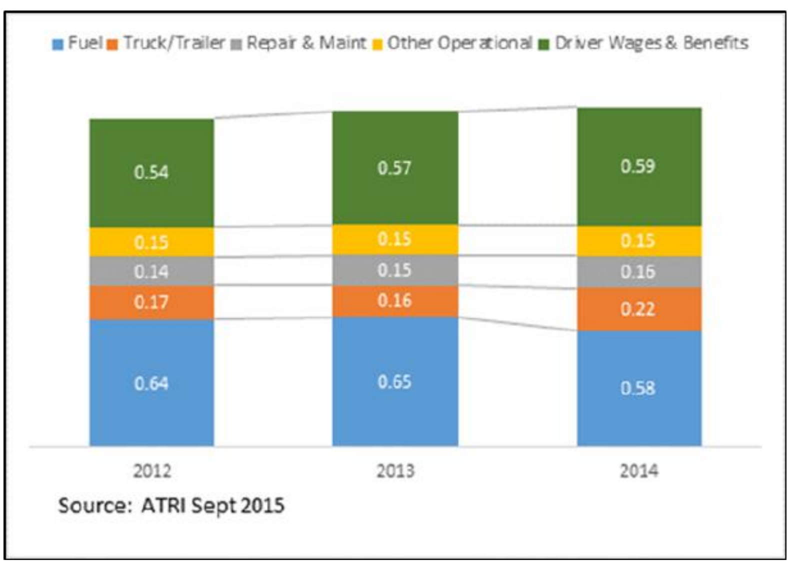


Figure 43: Trucking Operational Costs per Mile (ATRI)

The degree to which that replacement is feasible for heavy trucks may be similar to the degree that automation has influenced commercial aircraft operations, which still require human pilots some 50 years after initial introduction of automation technologies, while airplane capacity per crew has increased significantly.

While there are cases of self-aware drone aircraft operations, many are flown remotely by humans with computer assistance. This line of thought has not had much coverage in discussion of trucking operations, but seems a possible interim step between today's vehicles and fully autonomous ones by maintaining a human-in-loop. Imagine a driver sitting in an office at a driving simulator and safely maneuvering an actual truck with computer assistance in on–highway use miles away as is currently done with military drone aircraft.

One factor autonomous vehicles will need to address is obsolescence. The speed of innovation in computer systems often makes this year's cell phone obsolete within a year or two. Personal computers constantly are challenged with keeping up to date, often with industry refusing to update for long periods of time to maintain commonality as occurred with Windows XP's operating system which repeatedly persisted in industry through several attempts by Microsoft to move to new operating systems. Trucks tend to live productive lives of 10 to 25 years. One need only look at a 1996 phone versus a 2016 one to wonder how will truck autonomous systems be kept current? Software updates that exceed the capability of older hardware may necessitate new hardware purchases as occurred with Windows 10 replacing XP systems in offices. V2V communication systems will need to deal with a variety of vintages and capabilities in hardware and software in other vehicles.

Security is also a major area of future development as autonomy in vehicles raises many questions with respect to theft, violence, or malicious activities. Improvements in ensuring proper use of autonomous vehicles will be required.

The US Army has been involved in the development of autonomous trucks and platooning since the earliest self-driving vehicle research began, over two decades ago. It is easy to envision the benefits to the military of platooning, or leader-follower convoys. Fully autonomous vehicles follow the same technology development path and are also of interest to the military and are being developed in several different program paths, from trucks to UAVs to load carrying robots.

The Army has conducted several demonstrations of increasingly capable truck platooning technology. Most are led by the Tank Automotive Research and Development Engineering Center (TARDEC) in Warren, MI. In 2014 the AMAS Program (Autonomous Mobility Applique System) demonstrated a 3 truck platoon at up to 25mph, followed by a 7 truck platoon at up to 40mph. The AMAS program at TARDEC developed out of the Convoy Active Safety Technology system (CAST), which in turn had developed from the Autonomous Land Vehicle (ALV) project funded by DARPA in 1985.

Figure 44: Army TARDEC truck preparing to platoon on I-69 in Michigan (from US Army via Trucks.com)

AMAS envisions kits, or an "applique," that can be applied to any truck to enable platooning or -autonomous operation. The goal is a vehicle that can be manned or unmanned as the situation dictates. There would be two core component kits: a specific By-Wire Kit that would provide the electronically controlled subsystems and interface to the common Autonomy Kit. The Autonomy kit, along with the By-Wire kit, could provide capabilities such as Leader/Follower, waypoint navigation and advanced convoy behaviors as needed

The kits would include components such as Global Positioning System (GPS), Light Detecting Radar (LIDAR) systems, automotive Radio Detection and Ranging (RADAR) and commercially available automotive sensors in order to make the system affordable.

One example of that desire is the July 2016 demonstration at the Texas A&M TTI (Texas Transportation Institute). This two-truck platooning project successfully executed a number of new scenarios. The two Navistar tractor-trailers first traveled in a figure 8 at about 40 mph, followed by an increased gap distance, and ending with left and right lane changes in both directions. The TTI project was unique in that it examined combining lateral and longitudinal control through automated steering, acceleration and braking with no driver in the loop.

Also in July 2016, TARDEC conducted a demonstration on I-69 in Michigan, not far from their Warren headquarters. The Dedicated Short-Range Communications (DSRC) radios inside the 4-truck platoon where they key components of the project. The Michigan Department of Transportation has equipped a section of the I-69 with infrastructure to transmit and receive DSRC signals, enabling Vehicle-to-Infrastructure (V2I) communications. As a first test of platooning trucks using V2I on a public roadway, this demonstration of DSRC for vehicle to vehicle (V2V) and V2I communication was an important advance in truck platooning technology.

8. Conclusions

Given the current availability of information on two-truck platooning, the study team arrived at six conclusions:

- The fuel savings of two-truck platooning is valid and given all the real-world effects is likely around 4% average of both trucks, at a 40 to 50 ft. following distance over a typical long-haul duty cycle.
- The bulk of the required technology is currently available and being purchased by many fleets.
- Intervals of 40 to 50 ft. will likely have sufficient payback for early adopting fleets and then shorter distances, with their higher fuel savings, can be implemented with product improvements.
- Two-truck platooning is not fully autonomous/driverless trucking and it is actually being improperly grouped with that concept. This form of connected platooning gains most of the fuel efficiency opportunity of fully autonomous trucks.
- Driver stress will likely be less than perceived to date. There was stress with many automating functions, such as automatic transmissions and cruise control, that are now commonplace.
- Platooning will accelerate the adoption of other technologies such as collision avoidance and adaptive cruise control.

8.1 Recommendations

Given the work of this study team a few recommendations are being offered for the industry to focus on and expedite the speed with which platooning is introduced and adopted. These are not a complete list of the possible recommendations or needed items that must be addressed, but rather some key ones that emerged from the work on this study.

- Real-world fuel economy possible with platooning should be evaluated in a set of tests with real trucks on real routes with varying levels of truck and passenger car congestion.
- Standard communication protocols and security measures should be expedited within the groups already working on them.
- OEM and fleet testing should be expanded to ensure appropriate functionality and reliability of all system components.
- Driver education should be developed to increase the understanding and performance of driving trucks in platoons.
- Total cost of ownership and payback analyses should continue to be certain all costs and benefits are monetized and improved.

8.2 Confidence Rating

For each of the Confidence Reports completed by Trucking Efficiency, the various technologies assessed therein are plotted on a matrix in terms of their expected payback in years compared to the confidence that the study team has in the available data on the performance of that technology – that is, not only how quickly fleets should enjoy a payback on their investment, but how certain Trucking Efficiency is in the assessment of that payback time. Technologies in the top right of the matrix have a short payback, usually thanks to their low upfront cost, and moreover are found to have enough performance data that fleets can be highly confident in those short payback times, usually because the technology is more mature or otherwise has a more substantial track record of results.

Figure 45: Confidence Matrix Two-Truck Assisted Driver Platooning for Class 8 Trucks

Appendix A – References

First Occurrence	Reference	Source
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Figure 2: Trucking Operational Costs per Mile	Roeth, M., North American Council for Freight Efficiency (NACFE) graph from data from American Transportation Research Institute (ATRI), "An Analysis of the Operational Costs of Trucking: 2015 Update," Sep. 2015	http://atri-online.org/wp-content/uploads/2015/09/ATRI-Operational-Costs-of-Trucking-2015-FINAL-09-2015.pdf
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