FHWA Research and Technology Evaluation

Truck Platooning

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Foreword

The Federal Highway Administration's (FHWA) Research and Technology (R&T) Evaluation Program seeks to assess and communicate the benefits of FHWA's R&T efforts; ensure that the organization is expending public resources efficiently and effectively; and build evidence to shape and improve policymaking. FHWA partners with State transportation departments, local agencies, industries, and academia to conduct research on issues of national significance and accelerate adoption and deployment of promising research products.

This report examines how FHWA's investment in truck-platooning research affected truck-platooning knowledge, the availability and quality of such research, and the deployment of truck-platooning technology. The findings of this report should be of interest to engineers, practitioners, researchers, and decision makers involved in the research, design, performance, and deployment of truck-platooning technology.

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Director, Office of Corporate Research,
Technology, and Innovation Management

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16. Abstract
This report assesses how FHWA's investment in truck-platooning research affected truck platooning knowledge, the availability and quality of data, and the deployment of truck platooning technology. The research projects reviewed in this report are the "Partial Automation for Truck Platooning" (PATP) and "Driver-Assistive Truck Platooning" (DATP). The focus of the PATP and DATP projects was to decrease the costs of freight travel by improving fuel efficiency and highway mobility and allowing long-haul trucks to travel together as efficiently as possible. Although it was difficult to measure the effects of specific FHWA activities, the Research and Technology Evaluation project team found the research output from PATP and DATP addressed previously identified research gaps, influenced stakeholders' overall technology awareness and knowledge of truck-platooning technology, and led the way for follow-on research. All interviewees agreed the benefits outweighed the costs and all but one—who was unsure—had a positive impression of qualitative return on investment. Having project partners commit to cost sharing showed potential payback for project partners, while research output from the PATP and DATP projects showed that truck platooning was a viable option to help increase fuel efficiency among two- and three-truck platoons.

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APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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List of Abbreviations

Abbreviation	Definition
ATRI	American Transportation Research Institute
BAA	broad agency announcement
CACC	cooperative adaptive cruise control
Caltrans	California Department of Transportation
CHP	California Highway Patrol
DATP	Driver-Assistive Truck Platooning
DOE	U.S. Department of Energy
DOT	Department of Transportation
EAR	Exploratory Advanced Research
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FTC	Federal Trade Commission
ITS	Intelligent Transportation System
NRC	National Research Council of Canada
OEM	original equipment manufacturer
PATH	California Partners for Advanced Transportation Technology
PATP	Partial Automation for Truck Platooning
R&T	Research and Technology
ROI	return on investment
SARTRE	Safe Road Trains for the Environment
UC Berkeley	University of California at Berkeley
V2V	vehicle-to-vehicle

Executive Summary

Purpose of the Evaluation

This report assesses how the FHWA Office of Operations Research and Development's work on truck-platooning research affected truck-platooning knowledge, the availability and quality of data, and the deployment of truck-platooning technology.

Program Description

Truck platooning is the linking of two or more trucks in convoy, using connectivity technology and automated driving support systems. The project, "Assess the Feasibility of Deploying Partial Automation for Truck Platooning," funded through the Exploratory Advanced Research (EAR) program, researches truck platooning to help reduce the cost of hauling freight long distances and improve highway operations by allowing long-haul trucks to travel together more efficiently than unlinked trucks. Trucks travelling closer together at smoother speeds improves traffic flow and boosts the efficiency of delivering goods. The project consisted of two complementary subprojects: "Partial Automation for Truck Platooning" (PATP) and "Driver Assistive Truck Platooning" (DATP).

PATP was conducted under the University of California at Berkeley's (UC Berkeley's) Partners for Advanced Transportation Technology (PATH) Program (in partnership with Volvo Group North America and Cambridge Systematics). On the other hand, DATP was conducted under Auburn University's Global Positioning Satellite and Vehicle Dynamics Laboratory (in partnership with Peterbilt, American Transportation Research Institute, Peloton, and Meritor, Inc.). Researchers developed strategies and technology using advanced sensors and connected-vehicle technologies to allow two or three trucks to travel closely together in platoons to maximize efficiencies.

DATP is a wireless technology that links trucks together such that the following truck mirrors the lead truck's braking and acceleration, allowing for shorter following distances. The DATP project involved the adaptation of cooperative adaptive cruise control (CACC) for two-truck platoons. Researchers for the DATP project looked at the business factors of DATP operations and potential reductions in fuel consumption, as well as safety, system robustness, and transportation impacts. To advance market introduction of heavy-truck DATP, researchers identified and addressed key questions related to technical work, evaluation, and industry engagement. Phase One of the DATP project consisted of developing a DATP concept of operations and requirements document, and Phase Two consisted of business case studies with key fleet executives, traffic modeling, and system testing.(1,2)

Researchers for the PATP project developed and refined the control system enabling trucks to maintain shorter following distances and increased the number of trucks in a platoon from two to three. Researchers identified market needs for a CACC-based truck-platooning system by building, demonstrating (Route 87 in San Jose, CA; the Motor Vehicle Test Centre in Blainville, Québec; I–110 in Los Angeles, CA; and I–66 in northern Virginia), modeling and simulation (I–710 from the Port of Long Beach to Los Angeles, CA) and evaluating the potential benefits. CACC was implemented on three Class-8 trucks to test control-system responses, energy saving potential, and usability by commercial truck drivers. The PATP project also included microsimulation computer modeling to estimate the traffic and energy consumption impacts in an urban freeway corridor where large numbers of heavy trucks use CACC. Researchers disseminated research findings to stakeholders (e.g., media, Government officials, private industry) through publications, presentations, and demonstrations.[2]

Methodology

To assess the impacts of FHWA truck-platooning research, the R&T evaluation program team used a logic model to identify questions pertaining to project inputs, activities, outputs, and short-term outcomes. FHWA and research partners were asked questions about truck-platooning project goals to determine the project's success in accomplishing those goals. The evaluation pertained to the following three areas:

- Evaluation Area 1: Inputs (i.e., prior state of truck-platooning technology, project selection, and partnerships).
- Evaluation Area 2: Activities and outputs (i.e., FHWA coordination, contribution to the state of truck-platooning knowledge, and research dissemination).
- Evaluation Area 3: Outcomes (i.e., future research, changes to public policy, and impacts on the deployment of truck-platooning technology).

The first set of questions related to establishing project inputs and the effectiveness of the PATP and DATP projects in coordinating with partners to provide findings and recommendations pertinent to FHWA stakeholders in the Office of Operations Research and Development and other R&T programs. These questions included the following:

- Research Question 1: What was the state of truck-platooning technology prior to truck-platooning research?
- Research Question 2: How did the EAR Program select truck platooning (specifically PATP and DATP) as a topic for research?
- Research Question 3: What were the roles of and how effective were the partnerships with academia and private industry in truck-platooning research?

The second set of questions related to project partner research activities, efforts to disseminate research findings, and FHWA's role. These questions included the following:

- Research Question 4: How did FHWA coordinate with research partners to demonstrate truck-platooning technology?
- Research Question 5a: How did truck-platooning research contribute to truck-platooning knowledge?
- Research Question 5b: How did demonstrations improve stakeholder and public understanding of the benefits and challenges of deploying truck-platooning technology?
- Research Question 6: How effective has FHWA been in disseminating research findings?

The final set of questions related to the various outcomes of research activities, including future research, changes to public policy, and impacts on the deployment of truck-platooning technology. These questions included the following:

- Research Question 7: How did truck-platooning research affect the development and deployment of truck-platooning technology (including Federal, State, local, and private sector)?
- Research Question 8: How did truck-platooning research affect Federal, State, or local policy or guidance on truck platooning?

- Research Question 9: How did truck-platooning research accelerate truck platooning in the United States?
- Research Question 10a: What FHWA resources were committed to truck-platooning research?
- Research Question 10b: What is the expected return on investment (ROI) from truck-platooning research?

To answer these questions, the evaluation team collected and analyzed documentary evidence and performed interviews. Each question required interviews with project stakeholders, primarily those involved with the PATP and DATP projects, research, and demonstrations. Interviewees provided qualitative information on project operations and effectiveness.

Findings

The following are summary findings from the three evaluation areas. For more detailed findings, please see the main report.

Evaluation Area 1: Inputs

- Finding 1: Research by PATH, as well as European and Japanese truck-platooning projects, demonstrated the aerodynamic and fuel efficiency benefits of truck platooning but were not demonstrated in an operational environment using U.S. equipment. FHWA identified gaps in technical knowledge, human factors, safety benefits, and expected market impacts prior to the PATP and DATP projects.
- Finding 2: Truck-platooning research received support from the FHWA leadership, and the associated positive benefits were a key factor in its inclusion in the EAR program.
- Finding 3: Previous work on truck platooning and/or partnerships on related projects played significant roles in shaping partnerships for truck-platooning research. Partnerships enabled the pooling of resources and expertise (e.g., technical, management, outreach) to achieve project objectives. The ability to leverage resources from in-kind partners contributed significantly to the overall research. The PATP and DATP project partnerships were effective; the only issues noted were project delays from the execution of agreements and unforeseen challenges from innovative collaboration with private sector startups. Specific to DATP, researchers turned the challenges of a partnership into benefits.
- Finding 4: Project teams coordinated PATP and DATP activities, with FHWA staff playing a key supporting role. The FHWA Program Office was involved with demonstrations at Intelligent Transportation System America 2016 in San Jose, CA; on I–110 near the Port of Los Angeles; and on I–66 in northern Virginia and played an active role in the Virginia demonstration.

Evaluation Area 2: Activities and Outputs

- Finding 5: PATP and DATP outputs addressed previously identified gaps in technical knowledge, human factors, safety benefits, and expected market impacts.
- Finding 6: FHWA focused efforts on disseminating findings internally for follow-on research. With support from FHWA, researchers disseminated findings internally and externally through publications, presentations, and demonstrations. The effectiveness of dissemination remained unclear, and the opinions were mixed.

Evaluation Area 3: Outcomes

- Finding 7: PATP and DATP directly influenced follow-on projects such as FHWA truck-platooning research on human factors, including projects outside EAR funding on commercial deployment and impacts on bridges. PATP and DATP encouraged additional research by Federal agencies, academia, and private industry. The impact PATP and DATP had on commercial development was mixed or limited.
- Finding 8: Several interviewees noted that, while policy implications were unclear, PATP and DATP impacted awareness and general knowledge of truck-platooning technology.
- Finding 9: Original equipment manufacturers noted concerns over the economic viability of deploying truck-platooning technology.
- Finding 10: Federal funding for the programs (i.e., PATP and DATP) was over $3.4 million. Project partners committed to cost matching up to 20 percent (approximately $340,000). Having partners commit some funding showed potential payback that could make truck-platooning research viable. All interviewees agreed the benefits outweighed the costs and all but one—who was unsure—had a positive impression of qualitative ROI.

Recommendations

Based on the evaluation of the two EAR-funded projects (i.e., PATP and DATP), the R&T Evaluation program team offered the following recommendations for FHWA research:

- Recommendation 1: Continue fostering partnerships and seeking future opportunities for collaboration with a range of partners, both within and outside the U.S. Department of Transportation.
- Recommendation 2: Conduct periodic market forecasting or industry needs assessments to determine whether a future deployment of truck-platooning technology would be economically viable.
- Recommendation 3: Consider ways to incentivize the speedy execution of agreements to avoid project delays.
- Recommendation 4: Continue disseminating FHWA knowledge and expertise when engaging stakeholders, particularly at public outreach events and technology demonstrations.
- Recommendation 5: Collect data on resources committed to project success, including those from FHWA, project partners, and other stakeholders.
- Recommendation 6: Ensure research findings are broadly disseminated.

1. Introduction

1.1 Evaluation Purpose

The Federal Highway Administration (FHWA) initiated the Research and Technology (R&T) Evaluation program to help FHWA leadership and program and project managers communicate the impacts of their research, ensure resources are being expended effectively, and build evidence to inform future projects and policymaking.

One of the projects identified for evaluation is the FHWA Office of Operations Research and Development's (R&D) project on Truck Platooning ("Assess the Feasibility of Deploying Partial Automation for Truck Platooning) funded through the Exploratory Advanced Research (EAR) Program. The project encompassed research on technology and strategies to allow two and three long-distance trucks to travel close together in platoons using vehicle-to-vehicle communications and sensors, such as cameras and radar.

This report assesses how FHWA's investment in truck-platooning research affected truck platooning knowledge, the availability and quality of data, and the deployment of truck platooning technology.

1.2 Program Background

Truck platooning is the linking of two or more trucks in convoy, using connectivity technology and automated driving support systems. The link enables all of the vehicles in the platoon to communicate with each other, allowing them to automatically accelerate together, brake together, and follow each other at a closer distance than is typically possible with unlinked trucks. "Assess the Feasibility of Deploying Partial Automation for Truck Platooning" consisted of two complementary subprojects ("Partial Automation for Truck Platooning" (PATP) and "Driver-Assistive Truck Platooning" (DATP)) to develop prototype trucks capable of platooning in a realistic setting outside the laboratory.(4) "Assess the Feasibility of Deploying Partial Automation for Truck Platooning" addressed several technical and operational challenges, including implementing cooperative adaptive cruise control (CACC) in trucks, following distance thresholds, maintaining platoons in an operational environment, and driver and stakeholder acceptance.(1)

PATP was conducted by California Partners for Advanced Transportation Technology (PATH) at University of California at Berkeley (UC Berkeley) with support from California Department of Transportation (Caltrans), Volvo Group North America, Cambridge Systematics, and Los Angeles Metro/Gateway Cities Council of Governments. UC Berkeley PATH developed a three-truck platooning system for extensive aerodynamic and fuel-efficiency testing as well as operational environment (i.e., highway) testing and demonstrations. PATP research demonstrated that adding CACC to trucks so they can travel in stable platoons has the potential to save fuel and reduce freeway congestion.(2) UC Berkeley PATH also publicly demonstrated truck-platooning technology as an outreach component of PATP in the following three instances:

- June 2016 at Intelligent Transportation System (ITS) America 2016 in San Jose, CA.
- March 2017 on I–110 near the Port of Los Angeles.
- September 2017 on I–66 in northern Virginia.

"Driver-Assistive Truck Platooning" (DATP) was conducted by Auburn University with support from Peterbilt, American Transportation Research Institute (ATRI), Peloton Technology, and Meritor, Inc. Auburn University examined the business case for truck-platooning technology in Phase One and conducted aerodynamic simulations, developed a prototype two-truck platoon, and tested fuel efficiency in Phase Two.(1,2) DATP project concluded that large, for-hire fleets and private fleets are best positioned as early adopters of DATP. Traffic modeling results showed that DATP caused no delays to the overall freeway traffic stream compared to existing conditions and can improve peak team fuel savings of two truck platoons by 7 to 10 percent.

Researchers for both PATP and DATP projects developed CACC systems for commercial trucks that used dedicated short-range communication systems for vehicle-to-vehicle (V2V) communication, which allowed the trucks to safely maintain a constant time gap (PATP) or constant following distance (DATP). When engaged, the following truck's acceleration and braking were controlled by the CACC system, while the vehicle operator—consistent with SAE Level 1 automation—maintained control of steering. Significant components of the PATP and DATP projects were developing a human–machine interface and analyzing driver responses to close following distances. Truck platooning requires active supervision and steering by each vehicle operator, as indicated in table 1.(6)

Table 1. SAE automation levels.

Automation Level	Driving Features
Level 0	The vehicle operator performs all necessary driving functions.
Level 1	An ADAS can control either steering or braking/accelerating, but not both simultaneously.
Level 2	An ADAS on can control both steering and braking/accelerating simultaneously in some circumstances. The vehicle operator must monitor the driving environment at all times and perform all other necessary driving functions.
Level 3	An ADS can control all driving functions in some circumstances, but the vehicle operator must be ready to take back control at any time. In all other circumstances, the vehicle operator performs all necessary driving functions.
Level 4	An ADS can control all driving functions and the vehicle operator need not pay attention in some circumstances. In all other circumstances, the vehicle operator performs all necessary driving functions.
Level 5	An ADS can control all driving functions in all circumstances. Vehicle occupants are just passengers and never need to perform any driving functions.

ADAS = advanced driver-assistance system; ADS = automated driving system.

While the development of CACC for commercial trucks began in Europe and Japan prior to 2013, EAR Program funding for the PATP and DATP projects began in 2013. UC Berkeley PATH and other organizations researched truck platooning in the 1990s using different technologies that required modifying roadways. Table 2 presents a timeline of domestic and international truck-platooning research. Except U.S. Army truck-platooning research, PATP and DATP represented the first major development of prototype commercial truck platooning using CACC in the United States.

Table 2. Timeline of truck-platooning research prior to the PATP and DATP projects.

Year	Domestic	International
1993	Platooning of Trucks/Buses (UC Berkeley PATH), 1993 to 2011[7]	—
1994	National Automated Highway Systems Consortium Program, 1994 to 1997[7]	—
1996	—	Chauffeur, 1996 to 1998[7]
2001	—	Chauffeur II, 2001 to 2005[7]
2002	—	Demonstration: Chauffeur, 2002[7]
2003	Demonstration: Early Bus Platoon Demo (UC Berkeley PATH), 2003[7]	—
2005	—	Konvoi, 2005 to 2009[7]
2007	*Increasing Highway Throughput: Communications and Control Technologies to Improve Traffic Flow* (UC Berkeley PATH), 2007 to 2011[8]	—
2008	U.S. Army Center for Agent–Soldier Teaming, 2008 to 2010[9]	Japan Energy ITS, 2008 to 2012[7]
2009	—	SARTRE, 2009 to 2012[7] Demonstration: Konvoi, 2009[7]
2011	—	Grand Cooperative Driving Challenge, 2011[7] Demonstration: SARTRE (Gothenberg), 2011[7]
2012	U.S. Army Autonomous Mobility Appliqué System, 2012 to 2014[10]	Demonstration: SARTRE (Hallered), 2012[7]
2013	DATP(Auburn University), 2013 to 2017[1] PATP (UC Berkeley PATH), 2013 to 2018[2]	Demonstration: Japan Energy ITS, 2013[7]

—Not applicable.
SARTRE = Safe Road Trains for the Environment.

Two reports were published from the DATP project: *Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near Term Deployment: Phase One Final Report*, and *Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near Term Deployment: Phase Two Final Report.*[1,2] *Cooperative Adaptive Cruise Control (CACC) For Partially Automated Truck Platooning: Final Report* was published from the PATP project in 2018 along with a number of additional materials available to the public.[2]

2. Evaluation Design

This evaluation of truck-platooning research was designed using a logic model framework to qualitatively and, where possible, quantitatively assess the activities, outputs, and short- and long-term outcomes of the PATP and DATP projects. The logic model framework, which relied on project and stakeholder goals and objectives, allowed evaluators to uncover findings and make recommendations to FHWA and other stakeholders.

2.1 Logic Model

A logic model links program components, such as inputs, activities, outputs, outcomes, and impacts, in a causal chain and establishes a framework for interpreting the relationship between program resources, planned activities, and expected results. While not a comprehensive description of all program processes and activities, a logic model is a tool for explaining how stakeholders expect activities to effect change. Not all components occur contemporaneously, so a logic model is not a linear framework. A logic model aids in explaining the theories of change that drive the design of a program and provides hypotheses (i.e., if the program does X, then Y will occur) that can be tested during an evaluation. Figure 1 lists the components of truck-platooning research.

2.2 Evaluation Approach

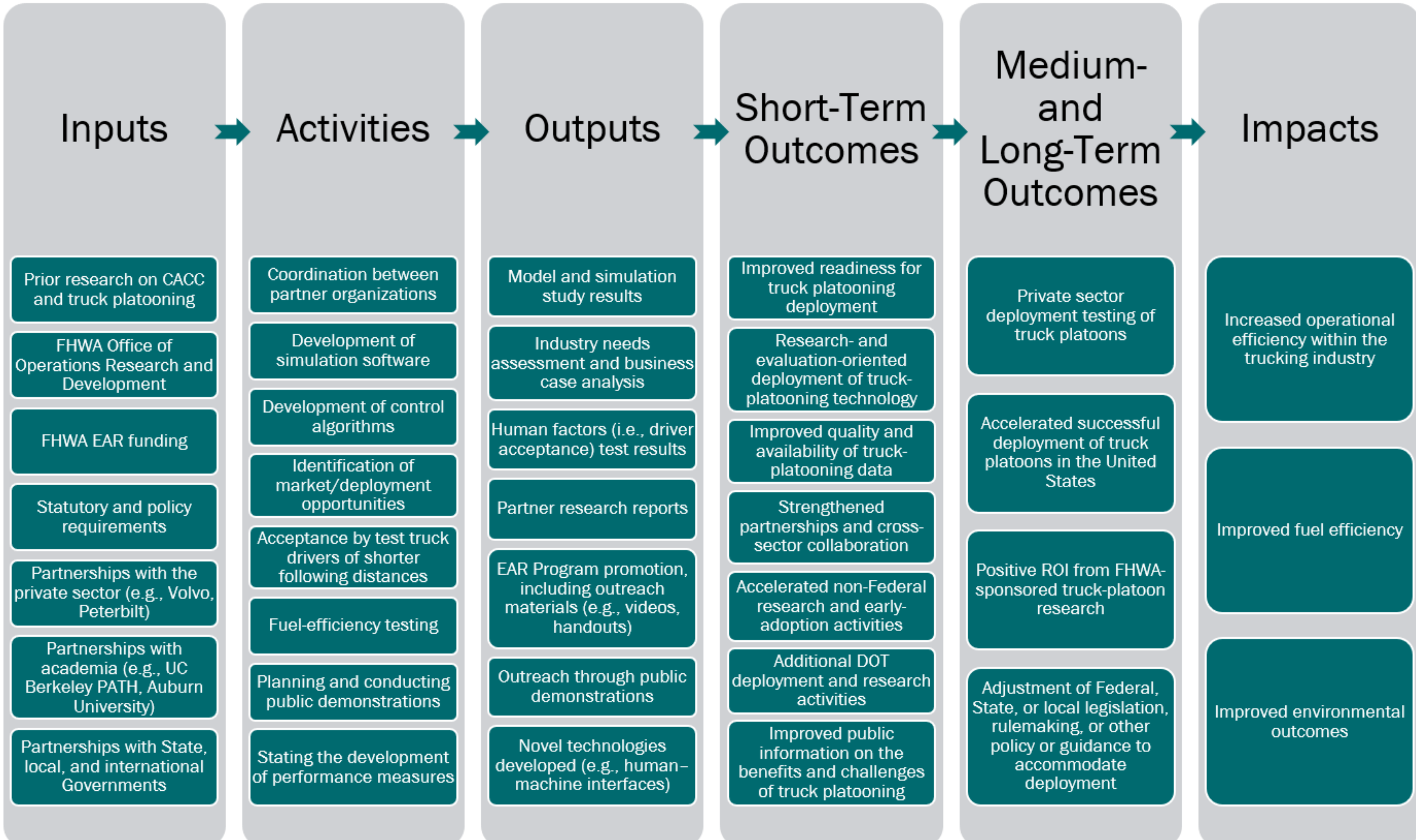
Using the logic model framework and discussions with FHWA staff, the R&T Evaluation program team asked interviewees questions in three broad categories: project inputs, activities and outputs, and outcomes and impacts.

Project Inputs

Specific aspects of project inputs, including the prior state of truck-platooning knowledge, project selection, and project teams and partnerships, were evaluated first.

Key data sources included literature preceding and contemporaneous with the PATP and DATP project launches, announcements and agreements for research projects, and background and context from researchers (e.g., UC Berkeley PATH, Auburn University, FHWA Office of Operations Research and Development).

Table 3 presents the topics, specific research questions asked, and the purpose of each question with regard to project inputs.



Source: FHWA.

DOT = Department of Transportation.

Figure 1. Truck-platooning logic model.

Table 3. Project input research questions.

Topic	Research Question	Purpose
Prior state of truck-platooning knowledge	Research Question 1: What was the prior state of truck-platooning knowledge?	Establish a baseline of knowledge. Given the absence of an observed counterfactual, the prior state of knowledge provided a point of comparison for changes in knowledge from truck-platooning research.
Project selection	Research Question 2: How was truck platooning selected as a research topic for the EAR Program?	Establish broad project objectives, as well as goals specific to PATP and DATP.
Project teams and partnerships	Research Question 3: What was the role of partnerships with academia and the private sector in truck-platooning research, and how effective were those partnerships?	Determine the roles and effectiveness of coordination between FHWA and project partners.

Activities and Outputs

Research activities and outputs, including questions exploring FHWA's role in coordinating with project partners and/or research activities, the contribution of these studies to the state of truck-platooning knowledge, and FHWA's dissemination of findings, were evaluated next.

Key data sources included documentation, public demonstrations and assessments, and insights from project partners, FHWA staff, and other stakeholders.

Table 4 presents the topics, specific research questions asked, and purpose of each question with regard to activities and outputs.

Table 4. Activities and output research questions.

Topic	Research Question	Purpose
FHWA coordination	Research Question 4: How did FHWA coordinate with partners and demonstrate truck-platooning technology?	Determine FHWA's role in primary research for the PATP and DATP projects and with public demonstrations.
Contribution to the state of knowledge	Research Question 5: How did research and demonstrations contribute to the state of truck-platooning knowledge and how did demonstrations improve stakeholder and public information regarding the benefits and challenges of deploying truck-platooning technology?	Assess the impact of truck-platooning research on the state of truck-platooning knowledge.
Research dissemination	Research Question 6: How effective has FHWA been in disseminating research findings?	Summarize FHWA's efforts to promote research findings and characterize the effectiveness of outreach.

Outcomes

Various outcomes of primary truck-platooning research activities, including future research; changes to legislation, rulemaking, or other policy or guidance; subsequent deployments of truck-platooning technology; and a qualitative assessment of ROI, were evaluated last.

Key data sources included research materials and literature referencing PATP and DATP and assessments and insights from project partners, FHWA staff, and other stakeholders.

Table 5 presents the topics, specific research questions asked, and the purpose of each question with regard to outcomes.

Table 5. Outcomes and impacts research questions.

Topic	Research Question	Purpose
Future research	Research Question 7: How has truck-platooning research affected future research on the Federal, State, or local level or that by the private sector?	Evaluate the effects of outcomes on continuing truck-platooning research.
Policy outcomes	Research Question 8: How has truck-platooning research affected legislation, rulemaking, or other policy or guidance at the Federal, State, or local level?	Establish plausible connections from project research, activities, and outreach to changes in legislation, rulemaking, or other policy or guidance.
Deployment	Research Question 9: Did truck-platooning research accelerate the deployment of truck-platooning technology?	Provide a qualitative assessment of how truck-platooning research, activities, and outreach affected commercial deployment of truck-platooning technology.
ROI	Research Question 10: What was the ROI and what FHWA resources were committed to truck-platooning research?	Establish FHWA resources committed to truck-platooning research and provide a qualitative benefit–cost assessment.

3. Evaluation Methodology

The following sections are an overview of the evaluation methodology used in this study. Data came from two primary sources: program documentation, including reports and other FHWA publications, and interviews with stakeholders. Instances in which additional supporting materials were needed are noted.

3.1 Truck-Platooning Documentation and Reports

The documentation and report review provided detailed information on the prior state of truck-platooning knowledge, insight into the work performed for the PATP and DATP projects and outputs, and information on the short-term outcomes of the projects. For the purpose of this evaluation, “report” refers to any published output from the PATP and DATP projects and other truck-platooning research efforts, while “document” refers to primary literature sources, including materials published by FHWA and others from academia and the private sector, on truck platooning.

Report Reviews

The R&T Evaluation program team interviewed FHWA staff, collected published reports, reviewed primary researchers’ websites for related materials, and requested copies of any additional reports discussed during interviews. In addition to published reports, FHWA staff provided the R&T Evaluation program team with some unpublished supporting materials that were reviewed but not used as sources for the findings and recommendations in the evaluation.

The R&T Evaluation program team collected and reviewed three research outputs from the PATP and DATP projects, as shown in table 6.

Table 6. Published research outputs.

Report	Associated Project	Summary
Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near Term Deployment: Phase One Final Report(2)	DATP	The Phase One report evaluated the business case for truck platooning using information from the ATRI-conducted survey of carriers and analyzed platoon formation and sensitivity to fuel efficiency on various factors, including lead and following vehicle speed adjustment. The phase one report also summarized initial work on human–machine interface development, vehicle preparation, simulation results, V2V communications, and aerodynamic research.
Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near Term Deployment: Phase Two Final Report(1)	DATP	The phase two report further analyzed the business case, incorporating ATRI interviews with major trucking fleet executives.
Cooperative Adaptive Cruise Control (CACC) For Partially Automated Truck Platooning: Final Report(2)	PATP	The final report summarized the research conducted under PATP. One area of research, developing and testing three-truck platoons, included fuel-efficiency tests under several time gaps and trials on California highways to collect driver gap-preference data. Researchers conducted microsimulations to assess truck platooning's impact on traffic flow and fuel efficiency in high-density urban highways with heavy truck traffic.

Legislative and Policy Timeline

The R&T Evaluation program team constructed a timeline of State legislative changes related to truck platooning. The timeline was primarily based on Scribner, with additional insight from interviewees.(11) Project outputs, including public demonstrations of truck platooning, publications, and outreach by researchers and FHWA staff (based on interviewee reporting), were integrated into the timeline as well. While no causal link was inferred, the timeline review was a point of reference when assessing stakeholder responses regarding policy and legislative changes from the PATP and DATP projects.

Qualitative Analysis of Benefits and Costs

During the interview process, the R&T Evaluation program team collected project cost information for both the PATP and DATP projects from FHWA documents and stakeholders. In addition to project funding, the R&T Evaluation program team collected all available information on Federal partner funding and in-kind contributions from project partners and other supporting organizations. Because truck platooning is an emerging technology, information on its benefits came primarily from stakeholder qualitative assessments.[1]

[1]The scale of potential fuel-efficiency benefits is dependent on how widespread truck-platooning systems are, thus introducing too much uncertainty into any estimate of future-efficiency benefits derived from research regarding fuel efficiency.

3.2 Stakeholder Interviews

The R&T Evaluation program team conducted interviews to answer questions from each evaluation topic. The R&T Evaluation program team worked with the FHWA Truck Platooning program manager to develop an initial interviewee list and gather contact information. The interviewee list included FHWA staff involved in the PATP and DATP projects, other Federal Department of Transportation (DOT) staff, and key PATP and DATP project team members.

The R&T Evaluation program team completed 13 interviews, including 5 with FHWA staff, 1 with Federal DOT staff, and 7 with members of the PATP and DATP project teams. The interviews were conducted by phone (except for one that was conducted in person) and generally lasted 60 min. One R&T Evaluation program team member led the interviews and two others took notes.

The R&T Evaluation program team developed a detailed interview guide consisting of 15 to 25 open-ended questions with detailed probes for each stakeholder group. (See appendix B for the full suite of questions.) The questions were specifically designed to address each of the following evaluation topics:

- Project background/context questions inquired about the interviewees' role in the project (PATP or DATP) and the length of time they have been involved in truck-platooning research.[2]
- Prior state of truck-platooning knowledge questions addressed the state of knowledge on truck platooning at the outset of the PATP and DATP projects, including known capabilities of truck-platooning technology and gaps in research.
- Project selection questions explored why truck-platooning research was selected for the EAR-funded projects.
- Project teams and partnerships questions explored the following:
    - How project teams and partnerships were formed (including FHWA's role in their formation).
    - The roles and activities of the different project team members and partners.
    - How project activities were coordinated.
    - The effectiveness of the teams (i.e., how well they worked together).
    - Challenges or issues faced, including whether and how teams overcame challenges.
    - Whether there were changes to project teams or partnerships, and if so, how the project was impacted.
- FHWA coordination questions assessed FHWA's role in coordinating with research partners on project activities, including background information on demonstrations, the goals of the demonstrations, whether the goals were met, challenges faced, and lessons learned.
- Contribution to the state of truck-platooning knowledge questions gathered information on the ways research projects and demonstrations contributed to the state of the knowledge on truck platooning.
- Dissemination questions explored the ways FHWA disseminated research findings from both the PATP and DATP projects and the effectiveness of FHWA's efforts.
- Future research questions assessed whether and how the two EAR-funded projects impacted follow-on research efforts related to truck platooning, including those sponsored by Federal agencies (e.g., FHWA, DOT, non-DOT modal partners) and non-Federal organizations (e.g., State or local agencies, academia, private sector).

[2]Project background/context is an interview topic area and not an evaluation area. Each interview started with a couple background questions that provided context for understanding the interviewees' responses.

- Policy outcomes questions addressed whether and how the PATP and DATP projects affected Federal, State, or local policy or guidance on truck platooning.
- Deployment questions addressed whether and how the PATP and DATP projects impacted the deployment of truck-platooning technology.
- ROI questions asked interviewees to qualitatively assess how the benefits of the two EAR-funded projects compared to the costs and provide their perspective on the ROI of the research.

The interview guides included questions relevant to each stakeholder group. For example, stakeholders involved in the PATP project were only asked questions in reference to the PATP project. Some FHWA staff had knowledge about both the PATP and DATP projects, so they were asked to consider both projects in their responses. In general, stakeholders received many of the same questions; however, other Federal DOT staff were not asked questions about project selection or project teams and partnerships because they were not responsible for these activities. Likewise, project team members were not asked about project selection since it was FHWA's responsibility. Table 7 illustrates the evaluation topics covered with each stakeholder group. In some cases, minor adjustments were made to the interview guides, as needed. For example, when the R&T Evaluation program team learned that the DATP research was ongoing, a question was added to the interview guide pertaining to the ongoing work.

Table 7. Interview topics by stakeholder group.

In-Depth Interview Topics	FHWA Staff	Other Federal DOT Staff	Project Partners
Background	X	X	X
Project selection	X	—	—
Prior state of truck-platooning technology	X	X	X
Project teams and partnerships	X	—	X
Stakeholder demonstrations	X	X	X
Research products	X	X	X
Impacts of the research	X	X	X
Future research efforts	X	X	X
ROI	X	X	X

X Topic covered.
—Topic not covered.

Interview Analysis

The interviews yielded detailed transcripts with examples and key quotes for each evaluation area covered. The R&T Evaluation program team entered responses to the questions, along with detailed examples and quotes, into a spreadsheet with each evaluation question as a separate tab. Within each tab, the interviewees comprised the columns and their responses comprised the rows. Similar responses were organized in the same row (i.e., in different columns based on the commenter), which enabled the R&T Evaluation program team to easily discern the extent to which opinions were widely held or unique to a specific stakeholder or group. The spreadsheets served as raw materials to inform the writeup of the evaluation questions. When necessary, the R&T Evaluation program team referred to the more detailed interview transcripts to ensure comments and findings were appropriately ascribed.

4. Evaluation Findings

The following sections discuss insights and findings gained by the R&T Evaluation program team from interviews and document reviews. Findings are grouped by evaluation area and topic.

4.1 Evaluation Area One: Inputs

The following findings relate to inputs into the PATP and DATP projects, as defined in the Evaluation Approach section.

Prior State of Truck-Platooning Knowledge

Research question 1: At the start of these EAR-funded projects (PATP and DATP), what was the state of knowledge on truck-platooning technology?

Finding 1a: Prior research by UC Berkeley PATH and European and Japanese truck-platooning projects demonstrated the aerodynamic and fuel efficiency benefits of truck platooning but were not demonstrated in an operational environment using U.S. equipment.

In the decade prior to the PATP and DATP projects, the level of activity in cooperative vehicle–highway automation systems increased significantly in Japan and Europe but remained relatively low in the United States.[1]

International

The European Chauffeur project developed V2V-based platoons, but Shladover noted the system "had no cooperation with the roadside."(12) The German Konvoi system was developed and tested between 2005 and 2009 on public roads with police escorts, completing more than 1,864 mi of travel in a four-truck platoon. The lead vehicle was manually controlled, while the following vehicles were under automatic control. Despite police escorts, 15 cut-ins occurred and the vehicles separated automatically. The Safe Road Trains for the Environment (SARTRE) project, a research consortium funded by the European Commission, also developed trucks capable of platooning with project partner Volvo Group North America, testing the technology by 2010 and demonstrating it on public highways by 2012.(7) Additional research on fuel efficiency was conducted as part of these projects and Japan's Energy ITS project. Notably, the Konvoi project noted reduced fuel efficiency when operating on public highways relative to earlier test track conditions.

Prior to the start of the PATP and DATP projects, truck-platooning technology, including V2V communication, platooning algorithms, sensors, and human–machine interfaces necessary to maintain a consistent and safe following distance with automated braking and lateral control, was demonstrated in several international projects, including prototype systems in the relevant operational environment (i.e., public highways). Although the Konvoi and SARTRE projects involved demonstrations in real-world conditions with frequent interactions with other highway users, the demonstrations were not done in a wide variety of facilities and weather conditions. Even though the

[1]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Matthew Keen, and Sarah Plotnick on September 12, 2019.

truck-platooning technology was demonstrated as a prototype in a relevant operational environment it does not suggest truck platooning was at a similar level of readiness in the United States. One interviewee noted that U.S. equipment, controls, and operations were substantially different from European or Japanese systems, so the technology was not as developed specifically for the United States.[2]

Within the United States

UC Berkeley PATH researchers, who had been developing an SAE Level 1 CACC truck system and its precursors for over a decade, developed and tested the system under study conditions prior to the initiation of the PATP project.[3(13)] Earlier work, including that by UC Berkeley PATH using other technologies and European and Japanese truck-platooning research using CACC technology, demonstrated the aerodynamic and fuel efficiency benefits of truck platoons. However, prior UC Berkeley PATH testing was on closed roads with no curvature using trucks with no loads instead of a real-world operational environment.[4]

This initial work by UC Berkeley PATH researchers emphasized the need to perform technical work prior to market introduction. Nearly all interviewees noted U.S. commercial trucks present different technical challenges than commercial trucks operated outside North America.

Finding 1b: FHWA identified gaps in technical knowledge, human factors, safety benefits, and expected market impacts prior to the PATP and DATP projects.

Researchers in the EAR Program gathered relevant information, spoke with experts, and determined the scope of the proposal, which helped in identifying heavy-truck platooning as one of a select number of topics to include in the 2013 EAR program broad agency announcement (BAA) No. DTFH61-13-R-00011.[(1)]

Researchers in the EAR Program theorized that truck platooning "would aid in potentially reducing fuel costs and could provide some capacity enhancements."[5] Technical challenges faced by researchers in the EAR program included signal loss and signal double tracking (i.e., double interference leading to questionable data), as well as "safety implications, operational, and human factors."[6] An FHWA staff member described this need as follows:

> *"At that point, there has been some work both in simulations of truck platooning and highly controlled environments but nothing that sort of looked at live traffic and all the things along the roadway—certain issues of curvature, loads, etc. Those were some of the things we felt were unexplored and would benefit from some research."*[7]

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[2]FHWA staff member; post-interview correspondence, comments on initial draft on January 27, 2020.

[3]Project partners; interviews conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

[4]FHWA staff member; post-interview correspondence, comments on initial draft on January 27, 2020.

[5]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

[6]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

[7]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

Project Selection

Research question 2: How was truck platooning selected as an area of research for the EAR Program?

Finding 2a: Truck platooning was identified through EAR Program project topic investigations and received support from the EAR Program Corporate Implementation Group, which represents offices across FHWA that conduct or fund research.

FHWA and the EAR Program identified PATP as an exploratory research topic and included it as a specific subcategory of research in BAA No. DTFH61-13-R-00011 as Topic 1D, Partial Automation for Truck Platooning.

Prior to the availability of EAR Program funding, FHWA completed a scan of potential opportunities related to automated highway systems. An FHWA interviewee described funding for truck platooning as follows:

> *"There was interest there, but not interested [no interest] in funding. Had to wait for EAR [program] funding of our work."*[8]

Truck platooning was a relatively new concept that "needed more research"[9] and funding support from the EAR program. An FHWA interviewee described the EAR program as an "opportunity to identify projects in areas of interest" to FHWA and a "terrific opportunity to continue research threads" that were not as established.[10]

Identifying topics for BAA No. DTFH61-13-R-00011 began with an initial investigation, or what an FHWA interviewee described as desk reviews, and speaking with a panel of experts from DOT and other Federal agencies, State DOTs, and nongovernment technology experts to help scope topics and program investments.[11] Desk reviews are an important part of initial project scoping—collecting, organizing, and synthesizing available information. Up to 20 different topics were considered for possible exploratory research, and the investigation process narrowed down the potential research topics to between 3 and 5. BAA No. DTFH61-13-R-00011 had "several elements relating to connected vehicles, with truck platooning being one of them."[12]

Additionally, FHWA leadership played a role in championing truck platooning. According to an FHWA interviewee, during the investigation, truck platooning received "strong interest from [the FHWA] Office Director [at the time]. He would attend most the major conferences, work with potential

[8]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

[9]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Sarah Plotnick, and Matthew Keen on September 12, 2019.

[10]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

[11]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

[12]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

partners, and his leadership was a major factor" for the inclusion of truck platooning in the EAR Program.[13]

Finding 2b: Associated positive benefits were key factors for the inclusion of truck platooning in the EAR Program.

In BAA No. DTFH61-13-R-00011, the ability of truck platooning to provide significant positive benefits was the first reason listed for the inclusion of truck platooning as a relevant research topic for the EAR Program.

Specific mentions of a recently completed UC Berkeley PATH truck platooning project funded by the EAR Program in a previous funding opportunity, a "recent international scan sponsored by the EAR Program, discussion during the TRB Workshop on the Future of Road Vehicle Automation, and information about related Defense Department research interests all suggest that truck platooning might lead to significant safety, mobility, emissions, and energy benefits in the highway system."(1,14)

FHWA drew attention to the potential improvements to truck travel and operational safety benefits from truck platooning research and made the inclusion of "safety at levels that equal or exceed current safety levels" a requirement for all proposed research projects.(1)

Exploring the potential benefits of safety, operations, mobility, emissions, and energy savings was of major importance to FHWA and the EAR Program, as addressing these benefits was a requirement for a project to receive funding.

Project Teams and Partnerships

This section provides findings related to the research question on how the DATP and PATP project teams and partnerships were formed, the role of partnerships in the EAR-funded truck-platooning research, and the effectiveness of the partnerships. Throughout this section, the project teams are referred to as partnerships; in some cases, distinctions are made between funded partners and unfunded partners.

Research question 3a: How were the partnerships with academia and the private sector chosen?

The project teams for both the DATP and PATP projects involved formal, funded research partnerships across multiple organizations. The DATP team, led by Auburn University, included the following partners:

- Peloton.
- Peterbuilt.
- ATRI.
- Meritor, Inc.

The PATP team, led by UC Berkeley PATH, included the following partners:

- Caltrans.
- Volvo Group North America.
- National Research Council of Canada (NRC) (unfunded research partner).

[13]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

- Cambridge Systematics.
- Los Angeles Metro/Gateway Cities Council of Governments.

Finding 3a: Previous work on truck platooning and/or previous partnerships on related projects played significant roles in shaping project partnerships.

The solicitation of funding for the DATP and PATP projects encouraged partnerships; however, FHWA did not play a role in the selection or the formation of the partnerships. Rather, interviewees described the significant role of previous work on the subject area and/or previous partnerships on related projects in shaping the DATP and PATP project partnerships.

The EAR Program funded the PATP and DATP projects in 2013, leveraging over a decade's experience working on precursor truck platooning and CACC technologies,[14] and private sector innovation developing truck-platooning algorithms.[15]

For the PATP project, the UC Berkeley PATH team learned of Volvo Group North America's interest in the subject area at a technical conference and discussed the possibility of working together; BAA No. DTFH61-13-R-00011 provided them with that opportunity. UC Berkeley PATH's history of research partnerships with Caltrans (who was providing funding to UC Berkeley PATH for the PATP project) led to the involvement of Los Angeles Metro/Gateway Cities Council of Governments, who supported stakeholder activities. Similarly, a history of research partnerships between members of the UC Berkeley PATH team and a Transport Canada senior researcher led to NRC's involvement in the PATP project. A number of interviewees explained that many relationships were forged through ongoing attendance at conferences and technical meetings as well as joint participation on working groups and committees.

For the DATP project, a previous partnership on a related project between Auburn University and Peloton contributed to their continued partnership. In addition, Peloton's history of research partnerships with Peterbilt and Meritor, Inc. played a role in bringing these industry partners onboard, as did Auburn University's history of research partnerships with ATRI.

Some interviewees commented that there was not a lot of time to form partnerships, and teams needed to be in place by the time a request for proposal was issued. As one interviewee described, "[UC] Berkeley PATH had their ear close to the ground for this grant[16]" and was able to quickly form its team of partners.

Finding 3b: Executing agreements among partners can result in project delays.

After FHWA funded Caltrans for the PATP project, Caltrans had to execute an agreement with UC Berkeley PATH for the execution of the research project. According to the FHWA interviewee, it took almost a year to execute the agreement, which resulted in delays since work could not be performed without the agreement. FHWA thought the agreement would be executed quickly because

[14] Project partners; interviews conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on June 18 and 24, 2019.

[15] Project partners; interviews conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on June 24 and July 24, 2019.

[16] Project partners; interviews conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on June 24 and July 2, 2019.

the two entities worked together on numerous projects, but the agreement process was time consuming and impacted the project schedule.

Research question 3b: What was the role of private sector, academic, and modal partnerships in the EAR-funded truck-platooning research?

Finding 3c: Partnerships enabled the pooling of resources and expertise (e.g., technical, management, outreach) to achieve project objectives.

The DATP and PATP project teams were intentional in their approach to forming partnerships, selecting partners to fill specific roles based on their expertise or the resources they could bring to the project. For example, Auburn University managed numerous government projects (including other EAR-funded projects outside the scope of this evaluation) and felt they were in a good position to manage the DATP project. However, Auburn University needed a private sector partner to provide technology, so they teamed with Peloton and began working on truck-platooning technology. In addition, Meritor, Inc. was one of two main companies with expertise in braking technology, which was key to making the truck-platooning technology work. The DATP project team knew they needed partners with ties to the trucking industry, so they reached out to Peterbilt. Similarly, ATRI was brought in because of their previous experience conducting outreach with the trucking industry, including surveys on driver acceptability, which was a component of the DATP project. ATRI also provided legitimacy to the study within the trucking industry.

For the PATP project, UC Berkeley PATH assumed the technical lead and relied on Volvo Group North America for their expertise in truck capabilities and systems integration. Cambridge Systematics provided stakeholder outreach support based on its previous work on the I–710 corridor. Transport Canada—and more specifically, NRC—which became involved in later phases of the research, contributed its test track, which was critical to testing the technology. In addition, Peloton was an unfunded collaborator on the PATP team, providing technical insight and guidance.

Research question 3c: How effective were the PATP and DATP partnerships?

Finding 3d: The PATP and DATP project partnerships were very effective with minimal issues noted.

All project partners agreed the partnerships were effective and team members worked well together. A Federal DOT interviewee described the situation as follows:

> *"UC Berkeley PATH and Auburn [University] put together a great list of partners…the partnerships were strong and enticing."*[17]

A PATP research partner stated the following:

> *"We definitely have a good working relationship with [academic partner]…we have talked over the years and worked really well in coordinating what we needed to do and making sure everyone got the information they needed from these projects."*[18]

[17]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20 and 21, 2019.

[18]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on July 9, 2019.

Another interviewee indicated they were "all pulling in the same direction trying to reach the same goals."[19]

One interviewee noted there were disagreements related to technical aspects of the work, but disagreements were always handled respectfully, and team members worked collaboratively to identify the best approach.

Some interviewees noted the commitment of Volvo Group North America, which sent a researcher from Sweden to live in California for a few weeks to ensure the preferred electrical system—which was designed for European trucks—worked when installed on American trucks, to the PATP project.

While there was consensus on the effectiveness of the partnerships, there were some challenges related to partnering with academia and the private sector. Some interviewees acknowledged administrative challenges, such as contracting delays, with one interviewee explaining that project extensions were required due to issues in moving funds from one institution to another. Along the same lines, another interviewee mentioned the following:

> *"I recall some administrative delays [i.e., trying to…make some payments]…that's the extent of frustrations I have heard about."*[20]

Another interviewee noted that staff turnover at UC Berkeley PATH led to some delays with the PATP driving simulator study. Likewise, staff turnover at Los Angeles Metro/Gateway Cities Council of Governments resulted in less involvement by that organization, as the new person was less engaged with the PATP project. Los Angeles Metro/Gateway Cities Council of Governments also had competing priorities that led to a shift in focus away from truck-platooning research to other work.[21]

The only other issue mentioned related to a nongovernment partner that conducted a survey of truck industry stakeholders, including drivers, owner-operators, and fleet managers. This survey was sent to a large, unspecified number of stakeholders and received 109 responses.(2) Following the survey, FHWA staff and other project partners noted the partner conducting the survey was unaware of the paperwork reduction act, a Federal law that limits government agencies from conducting or sponsoring onerous public data collection.[22] In this instance, it was determined that the survey occurred under an existing approval for ITS Joint Program Office,[23] though this determination was made after the survey was conducted.

Finding 3e: Partnering with private sector startups offered opportunities for innovation but also came with unique challenges.

The DATP project team indicated there were both benefits and challenges to collaborating with a private sector startup. The DATP project team benefitted from their private sector partner's accelerated timeline for technology development. However, due to the proprietary nature of the

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[19]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on June 24, 2019.

[20]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on July 9, 2019.

[21]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on June 24, 2019.

[22]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 30, 2019.

[23]Provided by David Kuehn, FHWA Office of Corporate Research, Technology, and Innovation Management Team Director/Program Manager.

technology, the startup was sensitive about the research and chose not to share detailed information about the technology. An interviewee explained the situation as follows:

> *"They were a startup and this was their first product, so they worried about what was being said and published and what could be reflected on them."*[24]

Another interviewee noted that coordinating the private sector partner's priorities with project priorities was a challenge, although details were not provided to clarify this point.[25]

Finding 3f: With the conclusion of a partnership, the DATP team turned a project challenge into a benefit.

A change in the partnerships for the DATP project initially presented a challenge but was ultimately beneficial to the project. When Peloton fulfilled its contractual obligations, they opted not to continue with the project and pursued commercial development rather than research and development. The DATP project team felt their work was incomplete and planned to conduct additional testing to expand upon initial results. With Peloton's departure, the DATP project team no longer had access to their proprietary truck-platooning technology and scrambled to redevelop the technology.

Nonetheless, Auburn University's work to date with Peloton gave them important insights into the technology. An interviewee noted the following:

> *"We learned a lot from seeing Peloton's system…The hardest part was the interfaces with the trucks and drivers, and seeing Peloton's system gave us a head start."*[26]

Despite the additional costs and impacts to schedules, Auburn University found it beneficial to have developed the technology and could now "see inside the black box"[27] whereas Peloton previously managed the technology. After developing the algorithm, Auburn University understood how it worked and could more easily make adjustments. A DATP partner felt having to develop the technology "opened up lots of opportunities."[28]

Finding 3g: Leveraging resources from in-kind partners contributed significantly to the overall research.

Both the PATP and DATP projects took advantage of in-kind resources offered by nonfunded project partners that resulted in significant contributions to the projects. The PATP project team searched for a location to test fuel efficiency but underestimated the costs to conduct such tests.[29] Transport Canada had a similar interest in researching the increased fuel efficiency associated with truck-platooning technology and contributed significant resources at no charge. Transport Canada

[24] Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on July 24, 2019.

[25] Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on June 24, 2019.

[26] Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on July 24, 2019.

[27] FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20 and 21, 2019.

[28] Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on July 24, 2019.

[29] Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on July 9, 2019.

allowed use of their Motor Vehicle Test Centre in Blainville, Québec, for 3 weeks of extensive testing and funded the NRC to provide engineering support, truck drivers for the test, and data analysis. A PATP partner explained the situation as follows:

> *"[Transport Canada] put out substantial funds to pay for testing on their test facility in Canada; it was a huge benefit to the project."*[30]

Another interviewee stated the following:

> *"Canada provided great support—rigorous and accurate."*[31]

Likewise, the FHWA project lead commented on the significant value of the in-kind contribution, including "an energy analysis that was never done at this level."[32]

In its follow-on fuel-efficiency testing, the DATP project team partnered with NRC and benefitted from free use of the Motor Vehicle Test Centre in Blainville, Québec. NRC provided support for 3 weeks of testing. Peterbilt contributed two trucks for use in the DATP project. Toward the end of the project, when the lease was expiring, Peterbilt gifted the trucks to FHWA so they could continue using them for additional testing planned in Canada.

Demonstrations of truck-platooning technology associated with the PATP project involved numerous unfunded partners whose contributions were key to success. The demonstration on I–66 in northern Virginia, which was conducted to showcase the technology to Congress and Federal DOT officials, required significant upfront planning. FHWA modal partners, Federal Motor Carrier Safety Administration (FMCSA) and National Highway Traffic Safety Administration, were involved, with FMCSA providing the trailers for the three tractor-trailer combinations. In addition, the Virginia DOT, Virginia Police, Virginia Governor's office, and Fairfax County Government played key roles. According to one interviewee, the planning partners held weekly conference calls for 4 to 5 mo as they worked through an "endless list of challenges"[33] related to selecting an appropriate route, determining where to store the vehicles and stage the attendees, and conducting outreach. These unfunded partners spent many hours planning the logistics and ensuring the safety of the demonstration.

Although the demonstration on I–110 near the Port of Los Angeles was smaller in scale than the demonstration on I–66 in northern Virginia, it still required significant planning and the involvement of many unfunded partners who contributed their time and resources. Interviewees cited the Port of Los Angeles—which hosted the demonstration—Los Angeles Police Department, Harbor Police, and California Highway Patrol (CHP) as key partners. For example, the Port of Los Angeles provided trailers for the demonstration and CHP was responsible for the safety aspects of the demonstration, including the setup for traffic control.[34]

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[30]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on June 24, 2019.

[31]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on July 2, 2019.

[32]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on September 12, 2019.

[33]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on June 24, 2019.

[34]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on July 2, 2019.

FHWA Coordination

Research question 4a: How did FHWA coordinate with research partners?

Finding 4a: Project teams coordinated DATP and PATP activities, with FHWA staff playing key supporting roles.

The PATP and DATP team leads coordinated their general project activities, while FHWA staff played an oversight role by providing guidance and technical input at quarterly meetings (or as needed), reviewing deliverables, and processing invoices (in their role as a Contracting Officer's Representative). For the PATP project, one interviewee indicated that FHWA was quite involved, noting the following:

> *"FHWA showed great interest and kept track of the details. They were ready to step in where needed[35]."*

While FHWA was less involved in the day-to-day activities of the PATP and DATP projects, it played a critical role in the organization and execution of the demonstration on I–66 in northern Virginia.

Research question 4b: How did FHWA determine how to demonstrate truck-platooning technology?

Finding 4b: The FHWA Program Office had very limited involvement in the two California demonstrations but contributed significantly to the demonstration on I–66 in northern Virginia.

PATP conducted an initial demonstration of truck platoons at ITS America 2016 in San Jose, CA. UC Berkeley PATH was the primary coordinator of activities, with the scope of the demonstration limited the conference attendees. FHWA staff attended and were actively engaged in the process. Although the ITS America 2016 demonstration was informal, it still required planning; FHWA was involved in selecting routes, developing scenarios, and messaging.[36]

PATP project partners, including Caltrans, UC Berkeley PATH, and Los Angeles Metro/Gateway Cities Council of Governments, coordinated for the March 2017 demonstration on I–110 near the Port of Los Angeles (see Project Teams and Partnerships section).[37] In addition to project partner coordination, CHP and other agencies were engaged in the process. Caltrans and PATP project partners advocated for a legislative change necessary to conduct onroad testing and demonstrations at close following distances (see Policy Outcomes section). FHWA staff attended the demonstration but had a limited role in coordination activities.

UC Berkeley PATH and FHWA staff coordinated the final public demonstration associated with the PATP project, conducted in September 2017 on I–66 in northern Virginia. FHWA was heavily engaged in managing the logistics of the demonstration, including site selection and stakeholder

[35]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on October 8, 2019.

[36]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on June 24, 2019.

[37]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on June 24, 2019.

engagement.[38] In addition to coordination activities, FHWA and PATP project partners promoted the second two public demonstrations. For the demonstration on I–66 in northern Virginia, FHWA created a press release promoting the innovative truck-platooning research.(13) Though causality could not be established, the demonstration on I–66 in northern Virginia had several press reports covering the event,[39] whereas the demonstration on I–110 near the Port of Los Angeles had limited coverage and the demonstration at ITS America 2016 in San Jose, CA, had no public press coverage.(15–19)

4.2 Evaluation Area Two: Activities and Outputs

The following findings relate to the activities engaged in for and outputs from the PATP and DATP projects, as defined in the Evaluation Approach section.

Contribution to the State of Truck-Platooning Knowledge

Research question 5a: How did these studies contribute to truck-platooning knowledge?

Finding 5a: PATP and DATP research outputs addressed previously identified research gaps.

DATP

Research products from the DATP project include the Phase One and Two reports.(1,2) The analysis spans several areas related to truck platooning, including aerodynamic modeling, business- and use-case analyzing, and two-truck platoon development for testing.

Business-Case Analysis

Phase One included an evaluation of the business case for truck platooning using data from an ATRI-conducted survey of carriers. The evaluation found larger over-the-road truck fleets have the greatest potential for adoption due to the density of freight movements on specific corridors and long travel times. Perception of driver acceptance was generally poor, with 62 percent of respondents "unlikely or not likely at all to use [truck-platooning technology]."(2) However, the evaluation found a relatively short expected payback period for owner-operators (10 mo) and fleets (18 mo).

Phase Two included interviews with executives with large truck fleets who identified stakeholder priorities, including fuel efficiency, low cost, compatibility with collision-avoidance systems, and availability as a retrofit.(1) Truck platooning was identified as most feasible with truckload over-the-road operators (i.e., long-haul operators). Interviewees indicated platoon formation would initially only be within a fleet, though there was some indication of multifleet formation provided some criteria were met.

Aerodynamic Simulations

Initial simulations in Phase One demonstrated a reduction in drag for following vehicles at large following distances (i.e., greater than 100 ft) and aerodynamic benefits for lead vehicles at closer

[38]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on June 24, 2019.

[39]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Matthew Keen, and Sarah Plotnick on September 12, 2019.

following distances. Increased fuel efficiency and reductions in drag were demonstrated at safe following distances.[40]

The Phase Two aerodynamic simulation confirmed that drag reduced with closer following distances, but with "additional negative aerodynamic effect" at distances closer than 50 ft, reducing the expected increase in fuel efficiency.

Two-Truck Platoon

Phase Two included installing a prototype CACC system in two trucks for fuel-efficiency testing at various following distances from 30 to 150 ft on a test track. The analysis found the greatest increase in fuel efficiency for the following vehicle at 50 ft, with a 10.24-percent reduction in fuel consumption. Lead vehicle fuel efficiency declined at closer following distances, with the closest observed distance, 30 ft, reducing the lead vehicle's fuel consumption by 5.27 percent.

Significant work developing V2V systems necessary for the two-truck platoon prototype was included in both phases of the DATP project.

Platoon Formation Analysis

Phase One used ATRI-provided truck-movement data that allowed the DATP project team to estimate the frequency of platooning formation. Analysis of a 300-mile roadway segment showed platoon formation of 30 to 45 percent, with platoons persisting for 55 to 75 percent of the length of the roadway segment. This demonstrated the feasibility of platoon formation as a necessary component for realizing real-world benefits from truck platooning technology. Additional analysis in Phase Two included consideration of variance in brake performance. Variance in brake performance impacted necessary reaction distances and therefore affected safe following distances; lower brake performance means trucks need a greater following distance.

PATP

UC Berkeley PATH has had numerous research products developed from their truck-platooning research, as well as presentations and video material.[(20)] The bulk of their research activities were summarized in their 2018 final report, *Cooperative Adaptive Cruise Control (CACC) for Partially Automated Truck Platooning*.[(2)] The analysis included testing three-truck platoons under various conditions to assess "potential impacts if introduced into public use." These activities included truck-platooning technology demonstrations showing trucks can maintain spacing with a smooth ride and safely respond to vehicle cut-ins.[(2)] Experiments on a test track conducted with and without other aerodynamic improvements (i.e., side skirts and boat tails), demonstrated closer gaps between trucks in a platoon increased fuel efficiency.

The PATP project team conducted onroad trials on California highways with nine test drivers and collected gap-preference data. In addition, researchers conducted microsimulations to assess the impacts of truck platooning on traffic flow and fuel efficiency on high-density urban highways with heavy truck traffic. The PATP project team found lead trucks experienced no significant reduction in fuel consumption, the first following (i.e., second) truck reduced fuel consumption by 6 to 7 percent, and the final (i.e., third) truck reduced fuel consumption by 9 to 11 percent.

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[40]Following truck drag reduction was noted for simulated following distances from 9 to 108 ft and from 9 to 54 ft for the lead truck. The implied safe following distance was 36 ft, though these simulations predate DATP on-road testing.

Other notable research outputs include UC Berkeley PATH research on truck driver preference and behavior when truck platooning (using CACC) is engaged.(21) This research provided more in-depth analysis of observed driver behavior when truck platooning in an operational environment (i.e., northern California highways). The analysis included behavioral responses to driver cut-ins (generally cars entering the gap between trucks), different road grades, and differing levels of traffic congestion. For their efforts, UC Berkeley PATH, Volvo Group North America, and FHWA staff authors were awarded the Transportation Research Board 2018 Patricia F. Waller award.

Dissemination

Research question 6: How effective has FHWA been in disseminating truck-platooning research findings?

Finding 6a: FHWA focused efforts on internal dissemination of project findings for follow-on research.

Auburn University's DATP and UC Berkeley PATH's PATP projects submitted individual technical reports and summary final reports to FHWA. An interviewee from FHWA explained that each deliverable had a corresponding technical report, stating, "We have about 13 or 14 reports that were heavily edited…but not published."[41] Another FHWA interviewee described one challenge to external dissemination and publishing the reports was the tight hold on some of the proprietary technical details of the research. Even so, the interviewee believed there was only a small audience of people external to DOT looking to replicate the work, at this point. There could be "universities out there who will be interested with the technical results," but publishing reports publicly "isn't necessarily going to help them. If there are some, we [FHWA] probably need to look at working with them."[42]

Additionally, there was a cost to publishing a final report. An FHWA interviewee noted that "some reports [were] not available to the public [because it] does cost money to complete [a] final report."[43] However, final reports were not the main objective for the truck-platooning research. Instead, external dissemination consisted of project summaries, high-level results, and fact sheets published on the FHWA and EAR program websites.

An interviewee from FHWA and the EAR program described how internal dissemination efforts were the focus for the truck-platooning research. FHWA was mostly concerned with "how do we [FHWA] transition the results of work" to other DOT research agencies because the truck-platooning research was mostly "identified for handoff…[and designed to be] rolled into the new work" at FHWA and research projects with ITS Joint Program Office and FMCSA as partners.[44] Completing a final report was not central to FHWA's goals for the truck-platooning research. Instead, the "purpose [was] almost to get the internal team to understand and move to [the] next step."[45]

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[41]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Matthew Keen, and Sarah Plotnick on September 12, 2019.

[42]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

[43]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

[44]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

[45]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

Finding 6b: External dissemination relied heavily on the actions of project team members with support from FHWA.

The efforts to disseminate the truck-platooning research findings were mainly led by the DATP and PATP project team members. As stated by an FHWA interviewee, "The external transition, because of many promotional partners, [was not] really an issue."[46] Additionally, another FHWA interviewee said the practice of "relying on the partners [to share] the results to the public" was one of the methods the EAR Program used to externally disseminate the project findings, especially when FHWA was "not always allowed to have contact with international community…[but] project partners [were] engaged with the international community."[47]

Both Auburn University and UC Berkeley PATH published final reports on their respective websites. Interviewees from UC Berkeley PATH said their website also contained videos made by UC Berkeley PATH and Transport Canada. These "videos came out pretty quickly" and, along with the summary report, helped with dissemination.[48]

Additionally, FHWA encouraged members of both the PATP and DATP project teams to submit research papers to different conferences and make presentations about the truck-platooning research. An FHWA interviewee described dissemination efforts, including presentations at the Transportation Research Board Annual Meeting and other technical conferences.[49] Another FHWA interviewee mentioned participating in "a number of webinars" as an additional dissemination method.[50]

An interviewee from the UC Berkeley PATH said the following:

> *"Every conference we attended, we had full support from DOT [FHWA] to go and present the project…[FHWA] made sure we pretty much had the right kind of visibility and helped us get into the right discussions."*[51]

An interviewee from the Auburn University had similar comments about how they were also "encouraged" by FHWA "to submit to the TRB [Transportation Research Board Annual Meeting] and other technical conferences."[52]

Finding 6c: The effectiveness of dissemination remains unclear and opinions mixed.

[46] FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.
[47] FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.
[48] Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 30, 2019.
[49] FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Matthew Keen, and Sarah Plotnick on August 20, 2019.
[50] Project partner; interview conducted by evaluation team members Margaret Petrella and Christina Foreman on July 9, 2019.
[51] Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on October 8, 2019.
[52] Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on June 24, 2019.

The opinions from interviewees on the dependence on project partners for external dissemination were mixed. The most positive opinion of the effectiveness of dissemination was from an FHWA interviewee who said the following:

> *"It was reasonably effective at letting people aware that the research is in place…and the high-level accomplishments."*[53]

Other FHWA interviewees stated the dissemination efforts were more "partially successful and we [FHWA] could have done better."[54] Others said it was still too early to say and that "we [FHWA] are still in the process of disseminating [and are] unsure" of the effectiveness.[55]

From the perspective of a project team member, the project partners had "not seen a plan from FHWA on how to disseminate findings…the effectiveness is hard to tell."[56]

4.3 Evaluation Area Three: Outcomes

The following finding areas relate to outcomes from the PATP and DATP projects, as defined in the Evaluation Approach section.

Future Research

Table 8 provides a roadmap of truck-platooning research interviewees identified as follow-on projects to PATP and DATP. The list of projects included Transport Canada's fuel-efficiency testing project and Department of Energy's (DOE's) project in parallel with U.S. Army and SAE Level 2 lane-keeping projects. Other FHWA-sponsored research projects, such as human factors research on driver engagement and the CARMA Platform℠, were also identified in the interviews as related to the PATP and DATP projects.

[53]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 30, 2019.

[54]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

[55]FHWA staff member; interview conducted by evaluation team members Margaret Petrella and Christina Foreman on July 9, 2019.

[56]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 30, 2019.

Table 8: Follow-on research.

Description of Follow-on Research Topics	Auburn University (DATP)	UC Berkeley PATH (PATP)
Transport Canada supported PATP fuel-efficiency testing, expanded the range of testing conditions, and supported on- and offroad operational environment testing for DATP.	X	X
The DATP team was given additional time and money from FHWA to conduct further fuel-efficiency testing based on the fuel performance anomaly.	X	—
DOE provided a grant and sponsored additional fuel-efficiency testing with partners from the DATP and PATP projects and tested driver behaviors entering and exiting highway traffic with DATP trucks.	X	X
U.S. Army Combat Capabilities Development Command Ground Vehicle System Center partnered with the DATP team to demonstrate commercial and military mixed platooning.	X	—
DATP resources were utilized in work with Texas A&M Transportation Institute to develop SAE level 2 lane keeping.	X	—
Forthcoming FHWA research on human factors, commercial deployment, and impacts on bridge structures.	X	X
FHWA Pilot Project Phase 1, Truck Platooning Early Deployment Assessment.	X	X
FHWA identified the need for future research on traffic and impacts on other drivers' behavior.	X	X
Forthcoming FHWA research on driver engagement based on the DATP project.	X	—
Forthcoming FMCSA research into safety based on the DATP and PATP projects, such as full high-speed truck braking tests and driver fatigue.	X	X

X Topic covered.
—Topic not covered.

Research question 7: How have the PATP and DATP projects affected future FHWA-supported research on truck-platooning technology? How have the PATP and DATP projects affected other Federal (i.e., non-FHWA) follow-on research efforts? How have the PATP and DATP projects affected other (i.e., State, local, or private sector) follow-on research efforts?

Finding 7a: The PATP and DATP projects justified further research in human factors and directly influenced truck-platooning research outside EAR on commercial deployment and impacts on bridges.

The PATP and DATP projects generated interest in truck platooning and demonstrated the feasibility of truck platooning using CACC on commercial vehicles. As a result, FHWA sponsored further research both during the course of the PATP and DATP projects and after the primary research activities were completed.

One FHWA interviewee drew a direct connection between EAR-funded research and several current or forthcoming research projects, including a human-factors study about driver reactions to truck platoons, the commercial pilot deployment of CACC, and a study of potential truck platoon impacts on bridge structures.[57] These new research efforts came out of the demonstration of truck-platooning technology from the PATP and DATP projects.

Another FHWA interviewee described forthcoming research on driver engagement, noting that research follows from the DATP project and focuses on topics that have not yet been addressed but need to be understood from a policy standpoint.[58] Another FHWA interviewee noted the DATP and PATP projects help them identify the need for research on the impacts of truck-platooning deployment on traffic and other drivers' behavior. The interviewee noted that two-truck platoons (not mediated by CACC but at close following distances) are not unusual. Most interviewees noted the pilot deployment project as an example of a follow-on project from the PATP and/or DATP projects.[59] Interviewees noted direct causality from one or either projects was not possible, but an FHWA staff member noted that if the PATP and DATP projects were not successful, FHWA was not going to continue with other research on truck-platooning technology.[60] One interviewee noted the PATP team was particularly interested in promoting their work.[61]

Other CACC research conducted under FHWA, including CARMA Platform, was noted by at least one interviewee, but no direct connection between the PATP or DATP projects was established.

[57]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

[58]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

[59] In March 2019, a Broad Agency Announcement Awarded Phase 1 Truck Platooning Early Deployment Assessment. The project goal is to assess various aspects of in-service truck platoons that are delivering commercial goods by a fleet operator on their common delivery routes over an extended time period. Three teams were awarded Phase 1 projects and developed detailed plans and proposals for a Phase 2 field operational test. In July 2020, the Phase 2 award was made to the California PATH team. Phase 2 includes implementation of the platooning systems and the evaluation components, readiness testing, 12 months of operational data collection, and evaluation.

[60]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Sarah Plotnick, and Matthew Keen on May 20, 2019.

[61]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20, 2019.

While not a new area of research, the DATP project contributed to its new cost extension of approximately 2 yr, allowing researchers to conduct further technology development and investigate inconsistencies between model results and empirical fuel-efficiency test results.[62]

Finding 7b: The PATP and DATP projects encouraged research by other Federal agencies, including DOE.

DOE began sponsoring research, including fuel-efficiency testing under a wider range of following distances (both shorter and wider gaps) than conducted under the original DATP research. DOE initiated this follow-on research with PATP and DATP partners, strongly suggesting DOE interest was sparked by the initial PATP and DATP findings on fuel efficiency.

DOE was interested in the fuel-efficiency anomaly discovered in the PATP project, so DOE partnered with the PATP team to repeat the fuel-efficiency tests under a wider range of following distances. Other DOE research using the trucks from the DATP project tested driver behavior entering and exiting highway traffic.[63] Additionally, the PATP project partners received an independent grant from DOE for a second round of fuel-efficiency testing that only occurred because of the original PATP fuel-efficiency testing.[64]

In addition to DOE, Auburn University used the trucks from the DATP project in work with the U.S. Army Combat Capabilities Development Command Ground Vehicle Systems Center.[65] This partnership included a demonstration in support of commercial and military mixed platooning and data-collection efforts.

Other DOT agencies, particularly FMSCA, have been more engaged in truck platooning following the PATP and DATP projects. Per interviews with FHWA staff, FMSCA appeared quite engaged with the demonstration on I–66 in northern Virginia.[66] FMCSA staff and other project partners stressed the need for further research into safety using data from the PATP and DATP projects to run trucks in parallel.[67] The interviewees indicated full high-speed truck and braking tests are needed to fully understand the safety performance thresholds, which are needed by the trucking industry. Driver fatigue, a risk in situations where drivers have minimal engagement in vehicle operations for extended periods, was also noted as an area requiring more research.

Finding 7c: The PATP and DATP projects encouraged research in academia and the private sector both domestically and internationally.

Resources developed under the DATP project were used in work with the Texas A&M Transportation Institute to develop SAE Level 2 longitudinal lane keeping.

[62]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on July 24, 2019.

[63]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on July 24, 2019.

[64]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on July 24, 2019.

[65]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on July 24, 2019.

[66]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Sarah Plotnick, and Matthew Keen on August 20, 2019.

[67] FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Sarah Plotnick, and Matthew Keen on August 20, 2019.

Transport Canada supported the PATP fuel-efficiency testing and committed significant resources to expand the range of conditions and following distances tested. Additionally, Transport Canada supported 3 d of onroad testing in an operational environment—as well as test-track testing—at their Motor Vehicle Test Centre in Blainville, Québec, using DATP resources.[68]

Finding 7d: The PATP and DATP projects' impact on commercial development was mixed or limited.

Peloton participated in the DATP project and lent its proprietary algorithms during the principal research period. Peloton did not continue their participation in the extended DATP research investigating fuel-efficiency anomalies.

An interview with a project partner truck original equipment manufacturer (OEM) indicated they were not currently pursuing U.S. deployment of CACC truck-platooning technology due to insufficient customer demand. It is typical of an OEM to routinely poll customers to ensure they are addressing the market landscape. During the latter stages of the PATP and DATP projects, Daimler, an uninvolved major truck OEM, notably announced they would not continue pursuing truck platooning.[(22)] This decision was based on low customer demand, as assessed through a customer poll, as well as findings from their own platoon fuel-efficiency tests and expected operating conditions.

Policy Outcomes

Research question 8: How did truck-platooning research affect Federal, State, or local policy or guidance on truck platooning?

Finding 8: A number of interviewees noted that, while the policy implications were not as clear, the PATP and DATP projects had an impact in terms of technology awareness and knowledge.

The truck-platooning demonstrations brought leadership to the table and sparked discussions—both positive and negative—on truck platooning. The PATP and DATP projects also may have contributed to some State and local agencies passing legislation allowing platooning on their roadways.

> *"[The] PATP and DATP [projects] started the discussion on how legislations/rules are needed for automation."*[69]

The PATP and DATP projects had an impact in terms of technology and knowledge moving into the market.

> *"The PATP [project] may have helped get pretty wide press. Companies like Peloton are doing a lot of lobbying to get State laws and policies related to driver assist, platooning, and automation."*[70]

[68]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on October 8, 2019.

[69]FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 30, 2019.

[70]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on July 2, 2019.

One interviewee highlighted the contribution of Federal funding in expanding technological knowledge, reaffirming the presumption that there will be too few resources to expand truck-platooning technology without government support—further supporting the economic case for public support for research.

> *"This is a good case of an overlap between Government and private sector interest. We are both getting something valuable of it. Not true for all other projects but truck platooning is a good example of that."*[71]

Some interviewees affirmed the PATP and DATP projects' positive impacts on policies and guidance. However, there are many political roadblocks to changing regulations.[72] See table 11 for Federal Trade Commission (FTC) statues from 2016 to 2019 specifically related to heavy trucks of all 50 States, the District of Columbia, and U.S. Territories and if that jurisdiction passed legislation allowing for the exemption of automated-vehicle platooning. The following are not directly related truck platooning but are examples of vehicle automation policies:

- California allowed caravanning following the demonstration on I–110 near the Port of Los Angeles.[73]
- Nevada allowed autonomous vehicle driving after testing supported by Nevada DOT on SR 722.[74]
- Florida conducted a study on truck platooning supported by Florida DOT, and the University of Florida conducted a study focusing on how changes in following distance affect traffic.
- Alabama enacted legislation authorizing automated truck platooning.[75]

Deployment

Research question 9: Did the PATP and/or DATP projects accelerate successful deployment of truck platoons in the United States?

Finding 9: OEMs have concerns over the economic viability of deploying truck-platooning technology.

In late 2018 and early 2019, the trucking industry split over whether platooning was still a viable technology.(23) Daimler released a statement saying it saw "no business case" for truck platooning. Daimler piloted several truck-platooning projects in recent years and concluded that the increases in fuel efficiency from truck platooning were marginal. Daimler instead focused on developing an SAE Level 4 autonomous vehicle. Numerous other OEMs remained committed to truck platooning as a near-term solution to high fuel costs in the trucking industry. The majority of startups in the self-driving truck space pressed forward with truck platooning. Volvo Group North America, for

71FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20 and 21, 2019.

72Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on July 24, 2019.

73Project partner; interview conducted by evaluation team members Katherine Pruitt, Christina Foreman, and Matthew Keen on June 18, 2019.

74Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on June 24, 2019.

75Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on October 8, 2019.

instance, showcased its platooning trucks several times over the last few years, while Alphabet's Waymo continues operating truck platoons in the Atlanta area.(23)

Interviews with FHWA staff provided a mixed interpretation of OEM interest in truck platooning using CACC as developed in PATP and DATP projects. One interviewee indicated a partner OEM was moving ahead with the technology,[76] though an interview with the partner OEM suggested they were not actively pursuing SAE Levels 1 or 2 truck platooning using CACC for commercial deployment outside the PATP and DATP projects.[77]

The results from Level 1 automation are relevant for higher levels of automation, and the EAR program funded research benefiting deployment at any SAE Level from 1 upward.(24) Peloton was reportedly pursuing following systems with SAE Level 4 automation possibly due to the limited cost savings from fuel efficiency alone.[78]

> *"Peloton was already a startup company doing this. Did our research help…probably they got commercial deployment from us and our research and fuel[-efficiency] testing. Could have done this on their own but we gave them a verification from us."*[79]

ROI

Research question 10a: What FHWA resources were committed for the EAR-funded PATP and DATP projects?

Finding 10a: Federal funding from the EAR program was over $3.4 million.

The PATP and DATP projects received approximately $1.7 million each in funding through the EAR Program (table 9). FHWA authorized additional funding to support further aerodynamic testing by Auburn University. This additional funding also supported Auburn University's development of truck-platooning algorithms when Peloton ended their working relationship with Auburn University after completing the originally agreed upon research tasks.

[76] FHWA staff member; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on July 9, 2019

[77] Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on October 8, 2019.

[78] Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on October 8, 2019.

[79] Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on October 8, 2019.

Table 9. Project funding. [80]

Project	Award Project	Award Number	Federal Costs (U.S. Dollars)	Matching Costs[81] (U.S. Dollars)
Prior	*Development and Evaluation of Selected Mobility Applications for VII*	DTFH61-07-H-00038	1,481,465	1,515,652
PATP	PATP	DTFH61-13-H-00012	1,640,280	490,874
DATP	PATP[82]	DTFH61-13-H-00019	1,638,689	449,214
DATP	*Class 8 Truck Platoon Track Testing Collaboration, Enhanced Data Collection and Analysis*[83]	693JJ319N300028	185,812	—

— Not applicable.

Finding 10b: Project partners committed to cost matching up to 20 percent (approximately $340,000) and met or exceeded that.

Interviewees, both FHWA staff and R&T Evaluation program members, reported that project partners (e.g., Caltrans) committed to cost matching up to 20 percent, and interviews suggested they met or exceeded that amount. This accurately reflects the cost matching shown in table 9.

Volvo Group North America, in their work with UC Berkeley PATH, was mentioned repeatedly by UC Berkeley PATH researchers and FHWA staff as providing large engineering support to the UC Berkeley PATH team, including several months in which an engineer worked directly with the UC Berkeley PATH team.

Finding 10c: Additional cost matching came from new partners.

UC Berkeley PATH and Volvo Group North America conducted fuel-efficiency test at Transport Canada's Motor Vehicle Test Centre in Blainville, Québec. Transport Canada expended a significant number of labor hours and expertise coordinating drivers, test track time, and expert staff to conduct the experiments. Additional runs testing the use of drag reducing equipment on the fuel efficiency of truck platoons were also supported. The precise value of these in-kind contributions was not provided, but a UC Berkeley PATH researcher stated the value exceeded $1 million.

Research Question 10b: What was the project ROI?

Finding 10d: All interviewees agreed the benefits outweighed the costs and all but one—who was unsure—had a positive impression of qualitative ROI. Having partners commit some funding showed potential payback, making the research viable.

[80]Provided by David Kuehn, FHWA Office of Corporate Research, Technology, and Innovation Management Team Director/Program Manager.

[81]These matching funds do not include in-kind contributions from organizations such as NRC Canada.

[82]Funding amounts for this award project represent the total with amendments for supplemental funding.

[83]Funding amounts for this award project refer to an interagency agreement with NREL for work with DATP. NREL contributed DOE funds to the project, though this is not shown, as it was not part of the interagency agreement.

All interviewees agreed the benefits outweighed the costs. Some of the benefits of the PATP and DATP projects included the following:

- Provided value to the trucking industry and spurred follow-on research.[84]
- Showed the potential of truck platooning to stakeholders, including its capabilities and how it can be safe.
- Pushed truck-platooning technology into deployment. However, truck platooning is still more advanced in some parts of the world; it will require more money for the United States to catch up.[85]

Some of the qualitative ROI assessments of the PATP and DATP projects included the following:

- Progressed truck-platooning technology enough to prove it is viable.
- Provided great value for the investment in time and money.[86]
- Allowed for balanced cost sharing with project partners and cost less than comparable DOT projects. These projects helped bring truck platooning from a topic of research to deployment.[87]

[84]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 20 and June 24, 2019.

[85]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, Matthew Keen, and Sarah Plotnick on June 18, 2019.

[86]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on May 30, 2019.

[87]Project partner; interview conducted by evaluation team members Margaret Petrella, Christina Foreman, and Matthew Keen on June 24, 2019.

5. Recommendations

Based on the evaluation of the two EAR-funded truck-platooning research projects, the R&T Evaluation program team developed the following set of recommendations for FHWA's consideration when planning and executing future projects.

Recommendation 1: Continue fostering partnerships and seeking future opportunities for collaboration with a range of partners, both within and outside DOT.

The DATP and PATP project teams involved formal funded research partnerships across multiple organizations, including Federal, State, and local agencies as well as academia and the private sector. These partners brought a range of expertise and skillsets (e.g., project management, technical, and public outreach) to the projects, enhancing the teams' ability to meet project objectives. In addition, these partnerships contributed to follow-on research with DOE, TARDEC, and FMCSA. The connections of different research partners led to new opportunities for both the PATP and DATP projects. These broad partnerships served as a means of outreach for the projects, with each of the partners championing the research within their respective communities.

Recommendation 2: Conduct periodic market forecasting or industry needs assessments to determine whether a future deployment of truck-platooning technology would be economically viable and allowing enough time for a pivot to ensure industry buy in.

Interviews revealed that truck OEMs conduct periodic market forecasting and industry needs assessments to gauge customers' interest in such technologies and guide their decision whether to invest in further research. FHWA could conduct the same checks—not necessarily during the scoping stage but at some point during a project—to ensure buy in from industry partners and to allow for enough time for a pivot. In a news article published in January 2019,[22] Daimler decided to abandon platooning to focus on higher SAE automation levels.

Recommendation 3: Consider ways to incentivize the speedy execution of agreements to avoid project delays.

Once the EAR program awarded the funds to Caltrans for the PATP project, it took an additional year for Caltrans to execute its agreement with UC Berkeley PATH, resulting in significant project delays. While FHWA does not control the acquisition process of its grantees, FHWA may be able to incorporate language in BAAs that incentivizes the speedy execution of agreements. FHWA should consider if there are other steps it can take to accelerate the execution of agreements to avoid project delays.

Recommendation 4: Continue disseminating FHWA knowledge and expertise when engaging stakeholders, particularly at public outreach events and technology demonstrations.

FHWA engagement in the demonstration on I–66 in northern Virginia allowed relevant stakeholders to connect with innovative truck-platooning technology and experts, which fostered greater public awareness and made future policy action in support of truck-platooning technology possible. Continuing to employ FHWA staff and resources, and potentially expanding their roles, will contribute to public awareness of the EAR Program and other project developments.

Recommendation 5: Collect data on resources committed to project success, including those from FHWA, project partners, and other stakeholders.

Assessing project ROI requires data on funds, in-kind contributions, and monetization of other resources committed to a project. Detailed monitoring and reporting of project costs and commitments would aid FHWA staff, evaluators, and other stakeholders in comparing project costs to benefits.

Recommendation 6: Ensure research products are broadly disseminated.

This evaluation found FHWA played a more minimal role in the dissemination of research findings, primarily through presentations at different venues (e.g., conferences, meetings). FHWA also created fact sheets related to the EAR-funded projects, but final research reports were not published or made publicly available on the FHWA website. FHWA should consider sharing the detailed findings on its website, which will reach a broader audience.

Appendix A. Evaluation Interviews Summary

Table below contains a description of the interviews conducted for this evaluation.

Table 10. Evaluation interviewees.

Interview Categories	Date Interviewed	Interviewers
FHWA staff	May 20, 2019	Margaret Petrella, Christina Foreman, Matthew Keen
FHWA staff	May 20 and 21, 2019	Margaret Petrella, Christina Foreman, Matthew Keen
FHWA staff	May 30, 2019	Margaret Petrella, Christina Foreman, Matthew Keen
Project partners	June 18, 2019	Christina Foreman, Matthew Keen, Katherine Pruitt
Project partners	June 24, 2019	Margaret Petrella, Christina Foreman, Matthew Keen
Project partners	June 24, 2019	Margaret Petrella, Christina Foreman, Matthew Keen
Project partners	July 2, 2019	Margaret Petrella, Christina Foreman, Matthew Keen
Project partners	July 9, 2019	Margaret Petrella, Christina Foreman, Matthew Keen
FHWA staff	July 9, 2019	Margaret Petrella, Christina Foreman
Project partners	July 24, 2019	Margaret Petrella, Christina Foreman, Matthew Keen, Sarah Plotnick
Other Federal DOT staff	August 20, 2019	Margaret Petrella, Matthew Keen, Sarah Plotnick
FHWA staff	September 12, 2019	Margaret Petrella, Matthew Keen, Sarah Plotnick
Project partners	October 8, 2019	Margaret Petrella, Christina Foreman, Matthew Keen, Sarah Plotnick

Appendix B. Truck Platooning Interview Guide (With Probes)

The questions in this appendix pertain to the EAR-funded project FHWA-PROJ-13-0112, "Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near-Term Deployment." These questions were asked to gain information on the following:

- Research and stakeholder engagement activities conducted by Auburn University and their partners regarding the DATP project.
- Research and stakeholder engagement activities conducted by UC Berkeley PATH and their partners regarding the PATP project.

Context

The following sections consist of questions asked to provide context for the PATP and DATP projects.

Project Background

1. Can you please tell me about your role at FHWA?
2. Have you done any previous work or research related to truck platooning (i.e., not including the DATP or PATP projects)?
3. Can you describe your role regarding the PATP and DATP projects?

PROBE for details, including the extent of involvement with each project to determine whether the respondent was able to answer questions about one or both projects.

Project Selection

4. Are you familiar with why FHWA decided to focus on truck platooning for the EAR program? Please explain.
5. Do you know why the PATP and DATP projects were selected as EAR projects? If yes, can you describe the selection process for the PATP and DATP projects?

PROBE: Why were these specific projects selected?

Prior State of Truck-Platooning Technology

6. The PATP and DATP projects were funded by EAR and initiated in 2013. Are you familiar with the state of knowledge on truck-platooning technology at that time? If yes, please describe.

PROBE: What was known about the capabilities of the technology in or around 2013? Had studies demonstrated the impacts of the technology? If yes, please describe. What were some of the gaps in research at that time?

Project teams and partnerships

The next set of questions focuses on the PATP and DATP project teams (i.e., organizations that were part of the cooperative agreement or were subcontractors) and any other partners involved in the PATP or DATP projects.

First, we will discuss the PATP project [if familiar with the PATP project].

7. Based on our understanding, the PATP project team included UC Berkeley PATH, Volvo Group North America, and NRC. Is that correct?

PROBE: Were there any other project team members?

8. Do you know how the PATP project team was formed? If yes, please describe.

PROBE: Had the project team members worked together previously? If yes, on what projects?

9. Can you describe the roles and activities of the different PATP project team members?

PROBE: Were these tasks all outlined in the cooperative agreement and in contracts?

   a. Do you know how activities were coordinated among the PATP project team members? If yes, please describe.

PROBE: Did FHWA play a role in coordinating the PATP project team members? Please explain. Were methods or processes developed to coordinate the activities of the PATP partners?

   b. Did the project team members work well together?
   c. Did the project team members face any issues or challenges in working together? If yes, please describe. Were they able to overcome these issues and challenges? Please explain.

PROBE: Did the project team members have different priorities?

10. Were there any changes to the project team (e.g., composition, roles, and activities) over the course of the study? If yes, please explain. How did those changes impact the study?
11. In addition to the project team members, were there other partners that played a role in the PATP research? If yes, please describe.

PROBE: What were partners' activities, resources they contributed, and so on.

PROBE: Federal partners.

   a. How did these partnerships contribute to the study?
   b. Were there any issues or challenges faced in the partnerships?

PROBE: Provide specific examples of issues/challenges.

PROBE: Were they able to overcome the challenges? If yes, how?

Next, we would like to ask you about the DATP project teams and partnerships [if familiar with the DATP project].

12. Based on our understanding, the DATP project team included Auburn University, ATRI, Meritor, Inc., Peloton, and Peterbilt. Is that correct?

PROBE: Were there any other project team members?

13. Do you know how the DATP project team was formed? If yes, please describe.

PROBE: Had the project team members worked together previously? If so, on what projects?

14. Can you describe the roles and activities of the different DATP project team members?

PROBE: Were these tasks all outlined in the cooperative agreement and in contracts?

   a. Do you know how activities were coordinated among the DATP project team members? If yes, please describe.

PROBE: Did FHWA play a role in coordinating the DATP project team members? Please explain. Were methods or processes developed to coordinate the activities of the DATP partners?

   b. Did the project team members work well together?
   c. Did the project team members face any issues or challenges in working together? If yes, please describe. Were they able to overcome these issues and challenges? Please explain.

PROBE: Did the project team members have different priorities?

15. Were there any changes to the project team (e.g., composition, roles and activities) over the course of the study? If yes, please explain.
    a. How did those changes impact the study?
16. In addition to the project team members, were there other partners that played a role in the DATP research? If yes, please describe.

PROBE: What were partners' activities, resources they contributed, and so on.

PROBE: Federal partners.

   a. How did these partnerships contribute to the study?
   b. Were there any issues or challenges faced in the partnerships?

PROBE: Please provide specific examples of issues/challenges.

PROBE: Were they able to overcome the challenges. If yes, how?

Stakeholder Demonstrations

For the PATP project, there were several stakeholder demonstrations of truck-platooning technology, including on I–110 near the Port of Los Angeles, I–66 in northern Virginia, as well as a practice demonstration at ITS America 2016 in San Jose, CA. The following questions pertain to stakeholder demonstrations.

17. Do you know if FHWA or some other entity determined how the truck-platooning technology would be demonstrated? How did [FHWA or other entity] determine the details of the demonstrations, including:
    a. Where the demonstrations would be held?
    b. The design of the demonstrations (i.e., protocols, procedures)?
    c. Who would be invited?
18. Did you attend any of the demonstrations? If yes, which ones?
    a. I–110 near the Port of Los Angeles?
    b. I–66 in northern Virginia?
    c. ITS America 2016 in San Jose, CA?

For demonstrations not attended, are you familiar with the demonstrations?

If yes, go to question 19 [probe on which ones].

If no, skip to question 20.

[If attended or familiar with any of the demonstrations, ask follow-up questions]:

19. For each demonstration you attended or are familiar with, I'd like to ask you a few questions.
    a. What were the goals of the demonstration?
    b. Do you think the goals of the demonstration were met? Please explain.

PROBE: What were key findings from the demonstration, and how did they align with the goals of the demonstration?

c. Were there any challenges or issues—either in the planning or the execution of the demonstration? If yes, please describe.

PROBE: Were you able to overcome the challenges? Please explain.

d. How did the demonstration contribute to the overall research effort?

PROBE: Did the demonstrations provide insight into the challenges of deploying truck-platooning technology? Please explain.

e. Were there any lessons learned from the demonstration?

Research Products

Next, we would like to discuss how the DATP and PATP project findings have been disseminated. These questions pertain to any reports, presentations, or other outreach by the project teams, but is separate from the demonstrations discussed previously.

20. What methods has FHWA used to disseminate the findings?

PROBE: Conferences? Post on website? Webinars?

PROBE: Differences between the two studies.

21. How effective has FHWA been in disseminating the research findings? Please explain.

PROBE: Do you have any suggestions for how FHWA could improve its dissemination of findings?

Impacts of the Research

Next, we would like to discuss the impacts of the PATP and DATP research and stakeholder demonstrations.

First, regarding the PATP project [if familiar with the PATP project]:

22. Do you think the PATP project has had an impact on the deployment of truck-platooning technology in the United States? Please explain.

PROBE: Can you point to any examples or evidence of this impact?

23. Overall, did the PATP project contribute to the state of truck-platooning knowledge? Please explain.
24. Do you know if the PATP project affected Federal, State, or local policy on truck platooning? Please explain.
    a. Has the PATP project affected Federal, State, or local guidance on truck platooning? Please explain.

PROBE: Have there been any informal discussions on possible changes to guidance or policy (e.g., areas of concern that have been discussed or noted)?

Now, turning to the DATP project [if familiar with the DATP project]:

25. Do you think the DATP project has had an impact on the deployment of truck-platooning technology in the United States? Please explain.

PROBE: Can you point to any examples or evidence of this impact?

26. Overall, did the DATP project contribute to the state of truck-platooning knowledge? Please explain.
27. Do you know if the DATP project affected Federal, State, or local policy on truck platooning? Please explain.
    a. Has the DATP project affected Federal, State, or local guidance on truck platooning? Please explain.

PROBE: Have there been any informal discussions on possible changes to guidance or policy (e.g., areas of concern that have been discussed or noted)?

Future Research Efforts

28. Did the PATP and/or DATP projects affect FHWA's follow-on research efforts related to truck platooning?

If yes, can you please describe any FHWA follow-on research efforts and how they have been shaped by the PATP and DATP projects?

PROBE: Do you know if the PATP and/or DATP projects affected the BAA on truck-platooning research that was issued in August 2018? If yes, in what way?

29. Do you know if the PATP and/or DATP projects have affected other non-FHWA research efforts, including research by State or local agencies, academia, or the private sector? Please describe.

PROBE: Have you attended other truck-platooning demonstrations since the PATP demonstrations? If yes, were those demonstrations informed in any way by the PATP demonstrations?

Wrap Up

30. From a qualitative perspective, how do you think the benefits of the two EAR-funded projects compare to the costs (i.e., how would you describe the expected ROI from the PATP and DATP projects)?
31. Do you have any other feedback you would like to share regarding the PATP and DATP projects?

Appendix C. Changes in Policy on Automated-Vehicle Platooning

State FTC statutes vary by class and type. There are three different classes of vehicles: cars, heavy trucks, and caravans (or motorcades). The following are the four different types of FTC rules:

- Reasonable and prudent, which requires a vehicle operator to follow the vehicle in front of them while allowing sufficient space to stop in an emergency. This standard is inherently subjective and grants law enforcement a large degree of leeway.
- Time, which specifies the time interval between vehicles.
- Distance, which specifies the precise safe following distance either by codifying a fixed interval or a proportional interval.
- Sufficient space to enter and occupy without danger, which allows roadway users to pass other vehicles safely and enter and exit the roadway. This is most common among heavy trucks and caravan classes.

To allow for automated vehicle platooning and testing, a simple amendment to these statutes is sufficient.

The R&T Evaluation program team constructed a timeline of State legislative changes related to truck platooning from 2016 to 2019 primarily based on Scribner.(11) Scribner summarizes the FTC statutes and regulations for each State, the District of Columbia, and U.S. Territories. Scribner notes that this is "an inventory of State law as published rather than as interpreted by the courts." This is not a legal analysis.

To recapitulate Scribner's summarization of the FTC statutes and present changes or lack of changes to State policy, table 11 is a presentation of statues from 2016 to 2019 specifically related to heavy trucks of all 50 States, the District of Columbia, and U.S. Territories and if that jurisdiction passed legislation allowing for the exemption of automated vehicle platooning.

Table 11. Summary of FTC statutes toward vehicle platooning.(11)

State/Territory	2016	2017	2018	2019
Alabama	Following distance: 300 ft	Following distance: 300 ft	In March 2018, Alabama enacted legislation to authorize automated truck platooning by stating “trailing trucks on a truck platoon are exempt from [FTC rules] if the truck platoon is engaged in electric brake coordination” for commercial trucks	Continues exemption for commercial automated truck platooning
Alaska	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger
Arizona	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger
Arkansas	Following distance: 200 ft	In April 2017, Arkansas enacted legislation to authorize automated truck platooning by exempting vehicles equipped with “driver-assistive truck platooning systems” from FTC rules	Continues exemption for automated truck platooning	Continues exemption for automated truck platooning
California	Following distance: 300 ft	In October 2017, Caltrans extended platooning test pilot until January 1, 2020. It had originally set to expire January 1, 2018. Outside of the Caltrans test pilot, platooning operations remain prohibited under the State’s FTC rules.	Continues exemption for automated platooning testing	Continues exemption for automated platooning testing
Colorado	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger
Connecticut	Undefined; default to car: reasonable and prudent	Undefined; default to car: reasonable and prudent	Undefined; default to car: reasonable and prudent	Undefined; default to car: reasonable and prudent
Delaware	Following distance: 300 ft	Following distance: 300 ft	Following distance: 300 ft	Following distance: 300 ft

State/Territory	2016	2017	2018	2019
District of Columbia	Undefined; lacks any formal following too closely rule. However, conduct generally prohibited by following too closely rules in other jurisdictions can be enforced under the District's reckless driving statute	Undefined; lacks any formal following too closely rule	Undefined; lacks any formal following too closely rule	Undefined; lacks any formal following too closely rule
Florida	On July 1, 2016, Florida became the second U.S. jurisdiction to explicitly exempt connected vehicle testing from following too closely rules. However, the current statute does not authorize nontesting operations.	Continues exemption for connected vehicle testing	In March 2018, a legislative proposal to exempt platooning heavy trucks, with a maximum platoon length of two trucks, from FTC rules passed the House but was indefinitely postponed and withdrawn from consideration in the Senate. Florida's 2016 platooning test pilot remains in place.	In 2019, similar legislation was introduced in the House and Senate but was withdrawn in May. Florida's 2016 platooning test pilot remains in place.
Georgia	Sufficient space to enter and occupy without danger	In May 2017, Georgia enacted legislation to authorize automated platooning by exemption "vehicles traveling in the same lane utilizing vehicle-to-vehicle communication technology to automatically coordinate the movement of such vehicle" from FTC rules	Continues exemption for automated vehicle platooning	Continues exemption for automated vehicle platooning
Guam	Undefined; default to car: reasonable and prudent	Undefined; default to car: reasonable and prudent	Undefined; default to car: reasonable and prudent	Undefined; default to car: reasonable and prudent
Hawaii	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger
Idaho	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger

State/Territory	2016	2017	2018	2019
Illinois	Sufficient space to enter and occupy without danger	In May 2017, a legislative proposal to exempt platooning vehicles from FTC rules—provided the operators' general plan is not rejected by the DOT or State police within 30 d of filling—was introduced in the House and referred to the Committee on Rules	No further action has taken place	No further action has taken place
Indiana	Following distance: 300 ft	Following distance: 300 ft	In March 2018, Indiana enacted legislation to authorize automated vehicle platooning by defining "vehicle platoon" as "a group of motor vehicles that are traveling in a unified manner under electronic coordination at speeds and following distances that are faster and closer than would be reasonable and prudent without electronic coordination" and exempting "a person who drives a motor vehicle in a vehicle platoon with respect to another motor vehicle in the same vehicle platoon" from FTC rules	Continues exemptions for automated vehicle platooning
Iowa	Following distance: 300 ft	In February 2017, a legislative proposal to exempt platooning heavy trucks from FTC rules was introduced in the House. It failed to pass session adjournment in April 2017.	Following distance: 300 ft; failed exemptions	Following distance: 300 ft; failed exemptions

State/Territory	2016	2017	2018	2019
Kansas	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	In February 2018, a legislative proposal to exempt platooning vehicles from FTC rules, provided the platoon operates on a four-lane divided highway, was introduced in the House. It failed to pass by session adjournment in May 2018.	Sufficient space to enter and occupy without danger; failed exemptions
Kentucky	Following distance: 250 ft	Following distance: 250 ft	In March 2018, Kentucky enacted legislation to authorize automated truck platooning by defining "platoon" as "a group of two individual commercial motor vehicles traveling in a unified manner at electrically coordinated speeds" and exempting "a trailing commercial motor vehicle involved in a platoon" from FTC rules	Continues exemptions for commercial automated truck platooning restricted to two commercial vehicles
Louisiana	Following distance: 400 ft	Following distance: 400 ft	In May 2018, Louisiana enacted legislation to authorize automated vehicle platooning by defining "platoon" or "platooning" as "a group of individual motor vehicles…utilizing vehicle-to-vehicle communication technology to travel in a unified manner at close following distances" and exempting "a nonlead motor vehicle in a platoon" from FTC rules	Continues exemptions for automated vehicles platooning
Maine	Following distance: 150 ft	Following distance: 150 ft	Following distance: 150 ft	Following distance: 150 ft

State/Territory	2016	2017	2018	2019
Maryland	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger
Massachusetts	Following distance: 200 ft	Following distance: 200 ft	Following distance: 200 ft	Following distance: 200 ft
Michigan	In December 2016, Michigan enacted legislation to authorize automated vehicle platooning by defining "platoon" as "a group of individual motor vehicles that are traveling in a unified manner at electronically coordinated speeds" and exempting "a vehicle in a platoon" from FTC rules	Continues exemption for automated vehicle platooning	Continues exemption for automated vehicle platooning	Continues exemption for automated vehicle platooning
Minnesota	Following distance: 500 ft	Following distance: 500 ft	In March 2018, a legislative proposal to exempt platooning vehicles from FTC rules was introduced in the House and Senate. It failed to pass by session adjournment in May 2018.	In May 2019, Minnesota enacted legislation to authorize automated vehicle platooning by defining "platooning system" as a "driver-assisted vehicle-to-vehicle technology that integrates electronic communications between and among multiple vehicles to synchronize speed, acceleration, and braking while leaving system monitoring and intervention in the control of each vehicle's human operator" and exempting vehicle platoons operating under an approved vehicle platoon plan from FTC rules. This exemption applies only to commercial vehicles and is limited to maximum length of three vehicles.

State/Territory	2016	2017	2018	2019
Mississippi	Following distance: 300 ft	Following distance: 300 ft	In April 2018, Mississippi enacted legislation to authorize automated vehicle platooning by defining "platoon" as "a group of individual motor vehicles traveling in a unified manner at electronically coordinated speeds at following distances that are closer than would be reasonable and prudent without such coordination" and exempting platoons from FTC rules. This exemption limits the maximum length of a platoon to two vehicles that can only be operated on limited-access, minimum four-lane divided highways.	Continues exemptions for automated vehicle platooning with restrictions on length and road type
Missouri	Following distance: 300 ft	Following distance: 300 ft	In January 2018, a legislative proposal to exempt platooning vehicles from FTC rules was introduced in the House. It failed to pass by session adjournment in May 2018.	In January 2019, similar legislation was introduced in the Senate and failed to pass
Montana	Undefined; default to cars: reasonable and prudent	Undefined; aefault to cars: reasonable and prudent	Undefined; default to cars: reasonable and prudent	Undefined; default to cars: reasonable and prudent
Nebraska	Following distance: 100 ft	Following distance: 100 ft	In January 2018, a legislative proposal to exempt platooning vehicles from FTC rules was introduced in the Legislature. It was indefinitely postponed.	No further action has taken place

State/Territory	2016	2017	2018	2019
Nevada	Following distance: 500 ft	In November 2017, Nevada enacted legislation to authorize automated vehicle platooning by defining “driver-assistive platooning technology” as “technology which enables two or more trucks or other motor vehicles to travel on a highway at electronically coordinated speeds in a unified manner at a following distance that is closer than would be reasonable and prudent without the use of the technology” and exempting platoons from FTC rules	Continues exemption for automated vehicle platooning	Continues exemption for automated vehicle platooning
New Hampshire	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger
New Jersey	Following distance: 100 ft	Following distance: 100 ft	Following distance: 100 ft	Following distance: 100 ft
New Mexico	Following distance: 300 ft	Following distance: 300 ft	Following distance: 300 ft	In January 2019, a legislative proposal to exempt platooning vehicles from FTC rules was introduced in the Senate. It failed to pass.
New York	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger

State/Territory	2016	2017	2018	2019
North Carolina	Undefined; default to cars: reasonable and prudent	In July 2017, North Carolina enacted legislation to authorize automated platooning by exempting "commercial motor vehicles traveling at close distances in a unified manner through the use of an electrically interconnected braking system" from FTC rules if "the Department of Transportation has by traffic ordinance authorized travel by platoon"	Continues exemptions for commercial automated truck platooning	Continues exemptions for commercial automated truck platooning
North Dakota	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	In April 2019, North Dakota enacted legislation to authorize automated vehicle platooning by defining "platooning" as "a group of motor vehicles using vehicle-to-vehicle communications to travel in a unified manner at close following distances on a multilane, limited-access divided highway" and exempting nonlead platooning vehicles from FTC rules
Ohio	Sufficient space to enter and occupy without danger; distance of 300 ft "while ascending to the crest of a grade beyond which the driver's view of a roadway is obstructed"	Sufficient space to enter and occupy without danger; distance of 300 ft "while ascending to the crest of a grade beyond which the driver's view of a roadway is obstructed"	Sufficient space to enter and occupy without danger; distance of 300 ft "while ascending to the crest of a grade beyond which the driver's view of a roadway is obstructed"	Sufficient space to enter and occupy without danger; distance of 300 ft "while ascending to the crest of a grade beyond which the driver's view of a roadway is obstructed"
Oklahoma	Following distance: 300 ft	Following distance: 300 ft	Following distance: 300 ft	Following distance: 300 ft

State/Territory	2016	2017	2018	2019
Oregon	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	In April 2018, Oregon enacted legislation to authorize automated vehicle platooning by defining "connected automated braking system" as "a system that uses vehicle-to-vehicle communication to electronically coordinate the braking of a lead vehicle with the braking of one or more following vehicles" and exempting vehicles operating as part of connected automated braking system from FTC rules	Continues exemptions for automated vehicle platooning
Pennsylvania	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	In October 2018, Pennsylvania enacted legislation to authorize automated vehicle platooning by defining "platoon" as a "group of buses, military vehicles, or motor carries vehicles traveling in a unified manner at electronically coordinated speeds at following distances that are closer than would be reasonable and prudent without the coordination" and exempting qualifying vehicles from FTC rules with a maximum platoon length of three vehicles	Continues exemptions for bus, military, and commercial automated vehicle platooning with restriction on length
Puerto Rico	Undefined; default to cars: reasonable and prudent	Undefined; default to cars: reasonable and prudent	Undefined; default to cars: reasonable and prudent	Undefined; default to cars: reasonable and prudent
Rhode Island	Undefined; default to cars: reasonable and prudent	Undefined; default to cars: reasonable and prudent	Undefined; default to cars: reasonable and prudent	Undefined; default to cars: reasonable and prudent

State/Territory	2016	2017	2018	2019
South Carolina	Sufficient space to enter and occupy without danger	In May 2017, South Carolina enacted legislation to authorize automated truck platooning by exempting "the operator of any nonleading commercial motor vehicle subject to Federal Motor Carrier Safety Regulations and traveling in a series of commercial vehicles using cooperative adaptive cruise control or any other automated driving technology" from FTC rules	Continues exemption for commercial automated truck platooning	Continues exemption for commercial automated truck platooning
South Dakota	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	In March 2019, South Dakota enacted legislation to exempt "groups of individual motor vehicles traveling in a unified manner at electronically coordinated speeds and distance intervals that are closer than otherwise allowed" from FTC rules
Tennessee	Following distance: 300 ft	In April 2017, Tennessee enacted legislation to authorize automated platooning by exempting "a group of individual motor vehicles that are traveling in a unified manner at electronically coordinated speeds" from FTC rules	Continues exemption for automated vehicle platooning	Continues exemption for automated vehicle platooning

State/Territory	2016	2017	2018	2019
Texas	Sufficient space to enter and occupy without danger	In May 2017, Texas enacted legislation to authorize automated platooning by permitting that "a vehicle equipped with a connected braking system that is following another vehicle equipped with that system may be assisted by the system to maintain an assured clear distance or sufficient space as required by this section"	Continues exemption for automated vehicle platooning	Continues exemption for automated vehicle platooning
Utah	In 2015, Utah became the first U.S. jurisdiction to explicitly exempt connected vehicle testing from following too closely rules. However, the current statute does not authorize nontesting operations for operations within urban areas	Continues exemption for connected vehicle testing	In March 2018, Utah enacted legislation to authorize automated vehicle platooning by defining "connected platooning system: as "a system that uses vehicle-to-vehicle communication to electrically coordinate the speed and braking of a lead vehicle to the speed and braking of one or more following vehicles" and exempting nonleading vehicles in a platoon from FTC rules	Continues exemption for automated vehicle platooning
Vermont	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger
Virginia	Undefined; defaulted to cars: reasonable and prudent	Undefined; defaulted to cars: reasonable and prudent	Undefined; defaulted to cars: reasonable and prudent	Undefined; defaulted to cars: reasonable and prudent

State/Territory	2016	2017	2018	2019
Virgin Islands	Undefined; lack of a formal following too closely rule. However, conduct generally prohibited by following too closely rules in other jurisdictions can be enforced under the Virgin Island's reckless driving statute	Undefined; lack of a formal following too closely rule	Undefined; lack of a formal following too closely rule	Undefined; lack of a formal following too closely rule
Washington	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger
West Virginia	Following distance: 200 ft	Following distance: 200 ft	Following distance: 200 ft	Following distance: 200 ft
Wisconsin	Following distance: 500 ft	In April 2017, Wisconsin enacted legislation to authorize automated vehicle platooning by defining "platoon" as "a group of individual motor vehicles traveling in a unified manner at electronically coordinated speeds" and exempting nonleading vehicles in a platoon from FTC rules	Continues exemption for automated vehicle platooning	Continues exemption for automated vehicle platooning
Wyoming	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger	Sufficient space to enter and occupy without danger

State/Territory	2016	2017	2018	2019
Summary	One State completely allows automated vehicle platooning. Two States allow for the testing of connected vehicle technology in a platoon	Six States completely allow for automated vehicle platooning. Three States allow for commercial truck automated platooning. One State allows for the testing of automated vehicle platooning. Two States allow for the testing of connected vehicle technology in a platoon. One State has legislation pending and one State has legislation that did not pass.	10 States completely allow for automated vehicle platooning. Four States allow for commercial truck automated platooning. Three States allow for commercial truck automated platooning with additional restrictions on length and roadway. Two States allow for the testing of automated vehicle platooning. Two States have legislation pending and five States have legislation that did not pass.	11 States completely allow for automated vehicle platooning. Four States allow for commercial truck automated platooning. Five States allow for commercial truck automated platooning with additional restrictions on length and roadway. Two States allow for the testing of automated vehicle platooning. Two States have legislation pending and five States have legislation that did not pass.

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