Incorporation of Department of Transportation Research

FY 2018

to

FY 2022

Report to Congress

as required by 49 U.S.C. §6504

(Infrastructure Investment and Jobs Act, Section 25016)

U.S. Department of Transportation

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ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ABS	address-based sampling
Access Board	Architectural and Transportation Barriers Compliance Board
ACRP	Airport Cooperative Research Program
ADAS	advanced driver assistance system
ADCMS	advanced digital construction management system
ADS	automated driving system
AEB	automatic emergency braking
AI	artificial intelligence
APTA	American Public Transportation Association
ARC-IT	Architecture Reference for Cooperative and Intelligent Transportation
ARPA-I	Advanced Research Projects Agency for Infrastructure
ASR	alkali-silica reaction
ASSURE	Alliance for System Safety of Unmanned Aircraft Systems through Research Excellence
ATD	anthropomorphic test device
ATTRI	Accessible Transportation Technologies Research Initiative
AV	automated vehicle
BEPS	bus exportable power system
BIL	Bipartisan Infrastructure Law (enacted as the Infrastructure Investment and Jobs Act, Pub. L. 117-58)
BIM	building information modeling
bSI	building SMART International
CACC	cooperative adaptive cruise control
CAMP	Collision Avoidance Metrics Partnership, LLC
CARMA	Cooperative Automation Research Mobility Applications
CATT	Cybersecurity Assessment Tool for Transit
CAV	connected and automated vehicle
CDA	cooperative driving automation
CFR	Code of Federal Regulations
CI	connected intersection

CIAMTIS	Center for Integrated Asset Management for Multimodal Transportation Infrastructure Systems
CLEEN	Continuous Lower Energy, Emissions, and Noise Program
CMTW	Countermeasures that Work
CMV	commercial motor vehicle
CMVRTC	Commercial Motor Vehicle Roadside Technology Corridor
CO_2	carbon dioxide
COVID-19	coronavirus disease 2019
CTI	connected transportation interoperability
CV	connected vehicle
CVRIA	Connected Vehicle Reference Implementation Architecture
DSRC	dedicated short-range communications
ECP	electronically controlled pneumatic
EDC	Every Day Counts
EICSS	Employee in Charge Software System
EMAT	electromagnetic acoustic transducer
EMS	emergency medical services
FAA	Federal Aviation Administration
FAST Act	Fixing America's Surface Transportation Act
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standards
FR	Federal Register
FRA	Federal Railroad Administration
FRP	fiber-reinforced polymer
FTA	Federal Transit Administration
FY	fiscal year
H3-50M	Hybrid III 50th-percentile male anthropomorphic test device
HBCU	Historically Black Colleges and Universities
HBM	human body model
HERS	Highway Economic Requirement System
HMR	Hazardous Materials Regulations

IFC	Industry Foundation Classes
IOO	infrastructure owner/operator
IoR	incorporation of research
ISO	International Standards Organization
ITE	Institute of Transportation Engineers
ITS	intelligent transportation system
ITS JPO	Intelligent Transportation Systems Joint Program Office
IWC	in-water cleaning
JSTAN	Joint Committee on Data Standardization
JTCEES	Joint Technical Committee on Electronic Engineering Standards (AASHTO)
LNG	liquefied natural gas
LODC	Large Omnidirectional Child (test dummy)
MARAD	Maritime Administration
MAT	multimodal and accessible transportation
MATSA	multimodal and accessible transportation standards assessment
MATSS	Multimodal and Accessible Transportation Standards Support
MetroLINK	Rock Island County Metropolitan Mass Transit District
ML	machine learning
MMITSS	Multi-Modal Intelligent Traffic Signal Systems
MOD	mobility on demand
MPO	metropolitan planning organization
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCAP	New Car Assessment Program
NHTS	National Household Travel Survey
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
NMSU	New Mexico State University
NPRM	notice of proposed rulemaking
NTCIP	National Transportation Communications for Intelligent Transportation Systems Protocol
NTIA	National Telecommunications and Information Administration
OA	operating administration

ODE	operational data environment
OEM	original equipment manufacturer
OMB	Office of Management and Budget
OSaaS	Optimizing Signal as a Service
OST	Office of the Secretary of Transportation
OST-R	Office of the Assistant Secretary for Research and Technology
PAEB	pedestrian automatic emergency braking
PG&E	Pacific Gas and Electric
PHMSA	Pipeline and Hazardous Materials Safety Administration
pig	pipeline inspection gauge
PTC	positive train control
Pub. L.	Public Law
PMHS	post-mortem human subjects
PTC	positive train control
R&T	research & technology
RD&T	research, development, and technology
REB	Research Executive Board (FMCSA)
ROW	right-of-way
RSU	roadside unit
RWP	roadway worker protection
SacRT	Sacramento Regional Transit District
SAE	SAE International (formerly Society of Automotive Engineers)
SAF	sustainable aviation fuel
SBIR	Small Business Innovation Research
SCMS	security credential management system
SFMTA	San Francisco Metropolitan Transit Authority
SHRP2	Strategic Highway Research Program
SHSO	state highway safety office
SMS	safety measurement system
SPaT	signal, phase, and timing
T2	technology transfer
THOR-05F	Test device for human occupant restraint 5th-percentile adult female frontal crash test dummy

THOR-50M	Test device for human occupant restraint 50th-percentile adult male frontal crash test dummy
TIDC	Transportation Infrastructure Durability Center
TPF	transportation pooled fund
Tran-SET	Transportation Consortium of South-Central States
TRB	Transportation Research Board
TSDD	traffic-speed deflection devices
TTC	Transportation Technology Center
UAS	unmanned aircraft system
UHPC	ultra-high-performance concrete
UL	Underwriters Laboratories
UMaine	University of Maine
UNII	Unlicensed National Information Infrastructure
U.S.C.	United States Code
UTC	University Transportation Center
V2I	vehicle-to-infrastructure
V2P	vehicle-to-pedestrian
V2V	vehicle-to-vehicle
V2X	vehicle-to-everything
Volpe Center	John A. Volpe National Transportation Systems Center
VRTC	Vehicle Research and Test Center (NHTSA)
WorldSID-05F	Worldwide Harmonized Side Impact Dummy 5th-percentile adult female crash test dummy
WorldSID-50M	Worldwide Harmonized Side Impact Dummy 50th-percentile adult male crash test dummy
WZDx	work zone data exchange

EXECUTIVE SUMMARY

The U.S. Department of Transportation (U.S. DOT or Department) is the Federal steward of the nation's transportation system. Our role as a department with respect to research and technology is to ensure that the enormous potential of U.S. transportation innovation advances our priorities, reflects American values, and ultimately serves to benefit our nation and its people. U.S. DOT consists of multiple modal operating administrations (OAs) that carry out RD&T programs supporting goals of the Department's RD&&T Strategic Plan. In total, the Department funds or conducts approximately $1 billion in RD&T annually.

Housed in U.S. DOT's Office of the Secretary, the Office of the Assistant Secretary for Research and Technology (OST-R) is responsible for coordinating, facilitating, and reviewing RD&T activities across the Department. OST-R plays a leading role in RD&T coordination within the Department and with a wide range of national and international stakeholders. OST-R also collects, reviews, synthesizes, and disseminates information on the Department's RD&T activities and its products to ensure that all statutory mandates are met. Increasingly, OST-R is also directly managing research that spans multiple operating administrations or that requires intensive coordination with partners outside of the Department.

Incorporation of Departmental Research

As detailed in the text box below, the Infrastructure Investment and Jobs Act (IIJA), also known as the Bipartisan Infrastructure Law (BIL)[1], included more than $5 billion for research activities and created new programs to drive innovation, create jobs, and support the deployment of transformative technologies. The Department is responsible for ensuring that the innovations resulting from RD&T are "incorporated" and used to the benefit of the American public. This concept of "incorporation" includes both:

1) Changing the Department's regulations, policy, and guidance to encourage or guide the use of innovations; and
2) Facilitating the uptake of innovations by others in the transportation sector in ways that will improve safety or provide other public benefits. IIJA included a new requirement that the Department report periodically to Congress regarding the incorporation of departmental research.[2]

The IIJA formalized this responsibility by mandating that the Department submit a new report on the incorporation of research results to Congress every five years. This report is the first submission to Congress in compliance with that new requirement, covering the time period of fiscal year 2018 to 2022.

As explained in section 2.3 below, OST-R is responsible for coordinating, monitoring, and reporting on RD&T activities across the Department. OST-R plays a crucial role in ensuring that departmental RD&T is consistent with the Department's mission and strategic goals. It also supports technology

[1] Pub L. 117-58 (Nov. 15, 2021).

[2] BIL Section 25016, codified at 49 U.S.C. § 6504.

transfer (T2) efforts across the Department. Each OA and the Intelligent Transportation Systems Joint Program Office (ITS JPO) has created processes to coordinate its RD&T with its development of regulations, guidance, and policy. Some of these processes are highlighted in the next section of this report.

Section 4 of this report highlights examples of incorporation of RD&T by each OA and the ITS JPO. Some of these examples feature innovations produced by the Small Business Innovation Research (SBIR) Program and the University Transportation Center (UTC) research program. Appendix A includes a more comprehensive listing of the Department's RD&T conducted during fiscal years 2018 to 2022.

Transportation Research Provisions of the Bipartisan Infrastructure Law (BIL)

- More than $4.5 billion in ongoing research activities across the Department's OAs focus on a range of key priorities, including research on vulnerable road users, the impacts on roads from self-driving vehicles, reduction of driver distractions, and emerging alternative fuel vehicles and infrastructure. This work also includes policy direction and investments in cybersecurity, investments in data infrastructure and data collection, and activities supporting workforce development in technology-related transportation fields.
- $500 million in funding to the Strengthening Mobility and Revolutionizing Transportation (SMART) Program, to kickstart a new generation of transportation innovation.
- Investments in University Transportation Centers (UTCs) that work on climate, equity, and innovation—including at historically black colleges and universities and other minority-serving institutions.
- Establishment of an Advanced Research Projects Agency for Infrastructure (ARPA-I) to scale up research and development efforts to keep pace with and to drive innovation.
- Authorization of $50 million per year in funding to establish a new Open Research Initiative to accelerate the achievement of the Department's priorities and goals by funding unsolicited research proposals that yield disruptive technologies with high-impact potential.
- Establishment in law of the Nontraditional and Emerging Transportation Technology Council, which will identify and resolve jurisdictional and regulatory gaps associated with nontraditional or emerging transportation technologies, including issues related to safety, environmental review, and funding/financing.
- Creation of the Smart Community Resource Center, an online resource on ITS and smart communities approaches for use by state, local, and Tribal governments.

1 INTRODUCTION

The report responds to Section 25016(a) of the IIJA,[3] which requires that the Department complete the following:

- Review the research conducted by U.S. DOT at least every five years.
- Identify any innovative practices, materials, or technologies resulting from the research that have demonstrable benefits to the transportation system.
- Determine whether statutory or regulatory modifications are required for adoption of the innovations and whether those modifications have already been made.
- If modifications are determined to be required, develop a proposal for those modifications.
- For innovations for which no statutory or regulatory modifications are needed, describe how the innovations will otherwise be incorporated into U.S. DOT policy or guidance, including as part of the Department's Technology Transfer (T2) Program.

Each OA and the ITS JPO have developed processes to incorporate the results of research, development, and technology (RD&T) into regulations, guidance, and policy. In addition, as described in more detail below, the OAs and the ITS JPO devote significant resources to T2 so that transportation innovations are deployed in practice. These processes are highlighted in section 3 of this report. Section 4 highlights examples of incorporation of RD&T by each OA and the ITS JPO. Some of these examples feature SBIR research. Also included in section 4 are examples of the incorporation of research conducted by University Transportation Centers (UTCs) on behalf of U.S. DOT. Appendix A includes a more comprehensive listing of the Department's RD&T conducted during fiscal years 2018 to 2022.

2 THE ROLE OF RESEARCH, DEVELOPMENT, AND TECHNOLOGY AT U.S. DOT

RD&T are critical elements of the nation's collective efforts to maintain and modernize the transportation system. Through transportation RD&T, organizations explore, test, and advance solutions to key challenges such as improving safety and reducing the environmental impacts of the movement of people and goods.

This section describes the Department's role in spurring technological progress in the U.S. transportation sector, as well as the statutory requirements and other guiding documents that govern the Department's RD&T efforts. It also highlights some of the ways in which U.S. DOT engages stakeholders such as academia and small businesses to develop and deploy transportation innovations.

2.1 U.S. DOT's Role in National Transportation RD&T

In the United States, transportation RD&T is performed by many different actors in the public, private, academic, and nonprofit sectors. The U.S. DOT plays a critical role in the transportation RD&T

[3] Codified at 49 U.S.C. § 6504.

"ecosystem" by shaping and executing a national RD&T program. This includes:

- Setting the research vision and direction for the nation's future transportation system and leading Federal research endeavors nee
- ded to achieve that vision, both in the short and long term.
- Funding and conducting research projects on issues of national significance that cannot or will not be addressed by other research sponsors.
- Sponsoring RD&T, in partnership with the private sector, academia, and other levels of government, to bring technologies with promising public benefits closer to commercialization.
- Encouraging the uptake of new transportation innovations through T2 activities.
- Incorporating research results into the Department's regulations, policies, and guidance to take full advantage of innovations.

Primary Purposes of the Department's RD&T per 49 U.S.C. 6503(c)(1)

Congress has articulated the primary purposes of the Department's RD&T programs as:

- Improving mobility of people and goods
- Reducing congestion
- Promoting safety
- Improving the durability and extending the life of transportation infrastructure
- Preserving the environment
- Preserving the existing transportation system
- Reducing transportation cybersecurity risks

The Department's RD&T program covers the entire innovation lifecycle: setting an agenda, conducting research, testing and evaluating technologies, and deploying and evaluating market-ready technologies and innovations.

2.2 Guiding Documents and Statutory Requirements

The Department's RD&T activities are conducted by the OAs, the ITS JPO, and OST-R. Those activities are driven by the specific mission, statutory requirements, and funding sources of each OA and the ITS JPO, and are guided by the priorities set in the Department's FY2022-2026 Strategic Plan. The Department is also required to develop a five-year RD&T Strategic Plan .[4] The Department's RD&T Strategic translates statutory requirements and U.S. DOT strategic goals into a cohesive RD&T strategy. Following the enactment of BIL, the Department also established six innovation principles guiding how resource are allocated to foster purpose-driven transportation innovation that serves the Administration's policy priorities. The OAs and the ITS JPO develop annual modal research plans that describe how they will address the Department's strategic goals and priorities in each coming fiscal year.[5]

These guiding documents and statutory requirements are shown in the top row of Figure 1. The bottom row of the figure shows mandated plans, reports, and funding processes that are guided by the RD&T Strategic Plan. This Incorporation of Research Results report is shown in the bottom right corner of the figure.

[4] 49 U.S.C. 6503.

[5] 49 U.S.C. 6501 requires annual modal research plans to align with the Department's RD&T Strategic Plan.

Figure 1. Guiding documents and statutory requirements for U.S. DOT RD&T. Source: U.S. DOT

2.3 Coordination of Departmental RD&T

OST-R coordinates the Department's RD&T programs to leverage and maximize the effectiveness of approximately $1.2 billion in annual investments across all OAs and Secretarial offices. OST-R ensures that the Department's priorities are implemented, and that research is purpose-driven and non-duplicative. Specifically, OST-R:

- Reviews OA research portfolios on behalf of U.S. DOT leadership and the stakeholders of America's transportation system.
- Conducts cross-modal research and facilitates research collaboration.
- Fosters T2 and facilitates technology deployment through partnerships within the Department and with private-sector and university partners.

Within OST-R, the Office of RD&T is responsible for leading implementation of the Department's RD&T portfolio. This work is done through setting the strategic direction, developing long-term and annual RD&T plans, stewarding the portfolio, coordinating among the OAs and OST offices on common themes, ensuring scientific integrity, and improving the performance of the RD&T portfolio to maximize the return on federal research investments. This office also ensures that the Department's research activities are coordinated with and communicated to the wider transportation research community.[6]

[6] 49 U.S.C. § 6502 requires posting of planned and active research to a public website annually. The U.S. DOT Research Hub serves this purpose.

2.4 Cross-Modal Research

In addition to coordinating Departmental research, OST-R's Office of RD&T oversees the conduct of research on topics that span multiple modes or require intensive coordination with research partners outside the Department. Research topics include:

- Infrastructure resilience and disaster recovery
- System-of-systems approach to integrating the various transportation modes into one seamless system
- Shared mobility for disadvantaged groups
- Racial equity and climate change
- Demonstration of automated vehicles to meet transportation needs in rural and Tribal communities

The results from these studies are advancing the Department's commitment to addressing transportation problems in a holistic manner through cross-modal collaboration. The research outcomes address DOT Secretarial priorities as well as meeting the research needs of Federal and non-Federal partners.

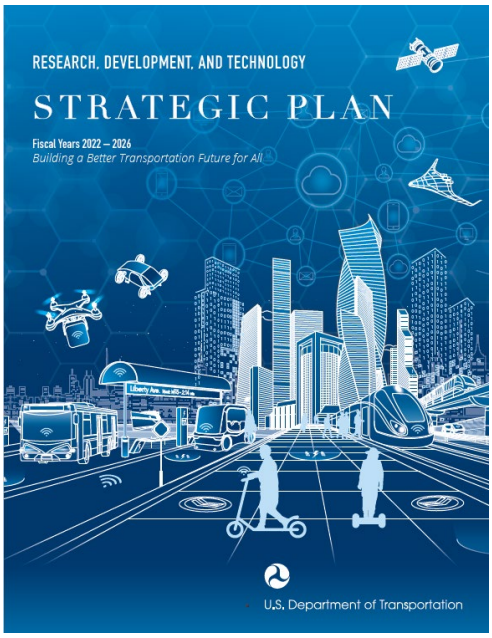

Figure 2. Cover of the U.S. DOT RD&T Strategic Plan for FY 2022 to FY 2026. Source: U.S. DOT

2.5 Technology Transfer

OST-R's Office of RD&T manages the Department's T2 Program, which leverages the Department's research products to facilitate commercialization, deployment, and subsequent "real world" benefits. The program works with the OAs and external stakeholders to assist them in understanding and implementing best practices in research product development and deployment, and in building T2 mechanisms into research planning early in the process.

The Department seeks to actively expand its T2 effort to identify and deploy-to-practice promising and priority innovations, pursue T2 agreements, and collaborate with other federal, state, local, Tribal, and territorial agencies to increase domestic manufacturing and deployment of technologies and other innovations arising from DOT research. The Department looks to accelerate domestic product commercialization and direct deployment funding to American small and disadvantaged businesses.

2.6 University Transportation Centers

The Department invests in the future of transportation through its UTC Program, which awards and administers grants to consortia of colleges and universities across the United States. Each UTC is a consortium of two- and four-year colleges and universities that come together to form a center of transportation excellence on a specific research topic. Together, the UTCs:

- Advance transportation expertise and technology in the varied disciplines that comprise the field of transportation through education, research, and T2 activities
- Provide for a critical multimodal transportation knowledge base outside of the U.S. DOT, and
- Address critical workforce needs and educate the next generation of transportation leaders and researchers.

BIL Funding for UTCs

The BIL authorizes 35 UTC consortia (5 national, 10 regional, and 20 Tier 1 UTCs) to receive a total of $90 million for each of fiscal years 2022 to 2026. In February 2023, Secretary Buttigieg announced up to $435 million in grant awards for 34 UTCs. The 35th UTC was selected in December 2023.

The Office of RD&T coordinates and evaluates the RD&T and educational activities of the UTCs. The results of the annual evaluations are submitted to Congress.

Invent it Here, Make it Here

On July 28, 2023, President Biden issued Executive Order 14104, "Federal Research and Development in Support of Domestic Manufacturing and United States Jobs." The Executive Order tackles four core objectives:

1. It will improve transparency, cut red tape, and streamline reporting requirements in the Federal RD&T process to better track progress towards our domestic manufacturing goals.
2. It will boost the incentive to manufacture new inventions in the United States when those inventions are developed using Federal funds.
3. It encourages the expansion of domestic production for critical industries while maintaining flexibility to build strong international RD&T partnerships
4. It will make the domestic manufacturing waiver process clearer, timelier, and more consistent, including when production is not commercially feasible.

2.7 Small Business Innovation Research Program

Congress established the SBIR Program to stimulate technological innovation, to engage small businesses in meeting federal RD&T needs, and to increase private-sector commercialization of innovations developed through federally sponsored RD&T. The Department's highly competitive SBIR program awards more than $10 million annually in contracts to U.S. small businesses to research and potentially commercialize innovative solutions to our nation's transportation challenges. The program favors research that has the potential for commercialization through products and applications sold to

the private-sector transportation industry, state and local departments of transportation, or other public or private entities.

As demonstrated by research profiled later in this report, small businesses that participate in U.S. DOT's SBIR program have developed new and innovative technologies that have benefited the Department and the public while providing a basis for growth for small businesses.

3 CURRENT PROCESSES FOR INCORPORATION OF DEPARTMENTAL RD&T

The Department of Transportation is composed of nine OAs and the Office of the Secretary (OST), each with its own management and organizational structure. Each organizational entity engages in RD&T, although the size of their respective research portfolios varies due to differing technical and regulatory needs and legislative mandates, among other factors. The various OAs and OST use different processes to 1) identify research priorities, 2) incorporate research innovations into regulation, policy, and guidance, and 3) promote the use of innovations through T2. In general, these processes are tailored to the structure, size, research needs, stakeholders, and overall mission of each organization.

For example, the Federal Motor Carrier Safety Administration (FMCSA) uses a chartered, cross-organizational board to make the connection between RD&T and policy, regulations, and guidance. OAs with significant regulatory roles such as NHTSA coordinate their RD&T more closely with regulatory staff to ensure that research projects align with emerging regulatory needs; this may not be as critical for OAs that do not hold significant or any regulatory authorities. This section features examples of processes that the OAs use to identify research priorities and eventually invest research dollars.

3.1 New or Modified Regulations and Guidance

3.1.1 Regulations

Within the Department, the OAs and OST are constantly engaged in promulgating new rules, modifying existing rules, or rescinding rules that are no longer needed. The Department's spring 2023 regulatory agenda included more than 200 ongoing regulatory or deregulatory actions. Not all of these actions are technological in nature, but many of them rely at least in part on the results of Departmental RD&T or pave the way for wider adoption of innovations generated by the Department's RD&T programs.

Table 1 provides a sample of the final rules promulgated during Fiscal Years 2018-2022 that incorporated Departmental RD&T. Some of these rulemakings, and the RD&T that informed them, are described in more detail in section 4 of this report.

Table 1. Examples of incorporation of departmental RD&T into recently promulgated rules.

Agency	Title of Rule	Incorporation of RD&T	Publication Date
NHTSA	Federal Motor Vehicle Safety Standards: Bus Rollover Structural Integrity	Informed by testing of different bus models against two existing roof crush/rollover standards.	12/29/2021
FHWA	Design Standards for Highways	Incorporated by reference the latest versions of design standards and standard specifications.	1/3/2022
NHTSA	Federal Motor Vehicle Safety Standards: Lamps, Reflective Devices, and Associated Equipment, Adaptive-Driving-Beam Headlamps	Research explored the feasibility of new approaches to regulating vehicle lighting performance. Research also validated a compliance test procedure for adaptive-driving-beam headlighting systems.	2/22/2022
FHWA	National Bridge Inspection Standards	Informed by research on the appropriate use of unmanned aircraft systems (UAS) for bridge inspections.	5/6/2022
NHTSA	Federal Motor Vehicle Safety Standards: Child Restraint Systems; Side Impact Protection	Reflects results of fleet testing of the performance of child restraint systems in side-impact crashes.	6/30/2022
NHTSA	Federal Motor Vehicle Safety Standards: Rear Impact Guards, Rear Impact Protection	Underlying field data used in development of the rule were from a NHTSA-funded study.	7/15/2022
FHWA	National Standards for Traffic Control Devices: Maintaining Pavement Marking Retroreflectivity	Incorporated research findings on driver nighttime visibility needs.	8/5/2022
PHMSA	Safety of Gas Transmission Pipelines: Repair Criteria, Integrity Management Improvements, Cathodic Protection, Management of Change, and Other Related Amendments	Research informed the rule's repair criteria for cracks.	8/24/2022
PHMSA	Hazardous Materials: Enhanced Safety Provisions for Lithium Batteries Transported by Aircraft	Supported by the findings of lithium battery research conducted by the Federal Aviation Administration's (FAA's) William J. Hughes Technical Center.	12/21/2022
FHWA	Manual on Uniform Traffic Control Devices for Streets and Highways; Revision	Incorporates devices that have resulted from nearly 200 official experiments that FHWA has approved.	12/19/2023

3.1.2 Guidance

The term "guidance document" includes any statement of agency policy or interpretation concerning a statute, regulation, or technical matter within the jurisdiction of the agency that is intended to have general applicability and future effect, but which is not intended to have the force or effect of law in its own right and is not otherwise required by statute to satisfy the rulemaking procedures specified in the Administrative Procedure Act.[7] Guidance documents can be generally applicable or can apply only to a particular party or parties. For example, a guidance document may respond to a request from a regulated entity that seeks guidance on how to act under a specific set of facts that the entity provides.

As permitted by statute and regulation, the Department's OAs regularly update their guidance documents to incorporate new technologies or processes. In doing so, the Department encourages the use of transportation innovations as a means of compliance with federal regulations or to promote U.S. DOT goals (e.g., safety advisories issued by the OAs). Table 2 provides examples of Departmental guidance that has incorporated (or may incorporate) Departmental RD&T.

Table 2. Examples of incorporation of departmental RD&T into departmental guidance.

Agency	Title of Guidance	Incorporation of RD&T
FHWA	Alternate Roadway Design Publications Recognized by FHWA under BIL and FAST Act	FHWA-sponsored research informed some of the roadway design publications referenced in this guidance.
NHTSA	Human Factors Design Guidance for Level 2 & Level 3 Automated Driving Concepts	Informed by ITS JPO research.
ITS JPO	Mobility on Demand (MOD) Planning and Implementation: Current Practices, Innovations, and Emerging Mobility Futures	Guidance documentation to assist practitioners with MOD concept development, planning, and implementation was developed under ITS JPO.
FRA	Accessibility guidelines for rail vehicles covered by the Americans with Disabilities Act	FRA-sponsored research on securement of wheeled mobility devices will inform update of accessibility guidelines.
FMCSA	Medical Examiner's Handbook	Currently conducting research on when high blood pressure is most likely to interfere with safe operation of a CMV. Will update the handbook based on the final report if warranted.

3.2 Research Coordinating Body

One method that OAs are using to incorporate innovations into departmental regulations, policy, and

[7] **U.S. DOT, "Regulations: Background on Guidance," last updated May 15, 2019.**

guidance is a cross-organizational board to ensure that its Research & Technology (R&T) program will meet the regulatory, policy, and enforcement needs of the OA. One such body at FMCSA is described below.

The primary mission of FMCSA is to reduce crashes, injuries, and fatalities involving large trucks and buses. One of the strategies employed to accomplish this goal is to carry out a multiyear R&T Program that provides scientific safety research on driver behavior, carrier operations, and technology applications. The R&T Program's research findings have proven critical in:

- Making rules that are firmly grounded on objective, impartial scientific data;
- Identifying enforcement priorities; and
- Facilitating the transfer of safety and inspection technology to the marketplace.

FMCSA created a Research Executive Board (REB) to ensure that its R&T program will meet the regulatory, policy, and enforcement needs of the agency. The REB is responsible for reviewing and recommending the content and priorities of the FMCSA R&T project portfolio. The REB provides an executive-level, cross-organizational forum that reviews the pool of proposed studies based on their technical and investment merits and on the basis of their fit within the overall Agency strategy.

The REB is chaired by the Office Director for Analysis, Research, and Technology and is made up of approximately a dozen voting members drawn from the FMCSA's headquarters and field offices. The REB is responsible for the following:

- Evaluating, prioritizing, and approving proposed analysis, research, and technology projects that have been submitted from across the organization—including field, safety, policy, enforcement, and chief counsel offices.
- Adding approved projects to FMCSA's Research Portfolio.
- Ensuring that proposals in the Portfolio are aligned with Agency priorities and consistent with budget objectives.

The REB meets annually during the budget formulation process to prioritize and approve research proposal submissions. The REB recommendations are then presented to the FMCSA's senior management for final approval. The approved project portfolio forms the basis for the R&T sections of FMCSA's annual budget request which is reviewed by the Office of the Secretary of Transportation (OST) and the Office of Management and Budget (OMB).

In identifying and selecting projects, the REB considers U.S. DOT and FMCSA safety priorities, U.S. DOT and FMCSA Strategic Plans, FMCSA rulemaking plans and activities, as well as input from the most recent industry stakeholder forums. The REB also conducts periodic reviews of the funded studies prior to or upon completion. The REB provides guidance on follow-up activities to completed studies, such as recommending further research or specific actions on policies, rules, standards, enforcement, or outreach actions.

3.3 Public-Private Bodies

Collaboration across the public, private, academic, and nonprofit sectors creates a better transportation future. U.S. DOT agencies work closely with stakeholders throughout research projects to understand research needs, develop and pilot practical solutions, promote the adoption of these solutions, and

evaluate their use and effectiveness. Public-private collaboration often includes cost-sharing. For example, the Federal Aviation Administration's (FAA) Continuous Lower Energy, Emissions and Noise (CLEEN) program uses a cost-sharing approach with the aviation industry to expedite integration of environmentally beneficial technologies into current and future aircraft.

In another example, U.S. DOT experts work with industry representatives on a wide range of advisory bodies. The composition of an advisory group is based on the legislative requirement and topic and could also include representatives of other federal agencies. For example, the U.S. Department of Energy participates with the Federal Railroad Administration (FRA) and other OAs on groups determining how best to meet the challenge of decarbonizing the transportation sector.

3.4 Standards Development

Federal law and OMB guidance requires federal agencies and departments, when carrying out policy objectives or activities, to use technical standards that are developed or adopted by voluntary consensus standards bodies (except in limited circumstances). Federal law also encourages federal agencies and departments to participate with such bodies in the development of technical standards, when such participation is compatible with agency and departmental missions, authorities, priorities, and budget resources.[8] U.S. DOT-funded RD&T has informed many industry standards over the years. In some cases, U.S. DOT incorporates those same standards by reference into its regulations. The Department is actively engaged in standards development on many fronts, as is evidenced by the work of the ITS JPO.

The ITS JPO collaborates across the OAs to coordinate and plan the U.S. DOT's multimodal ITS technology research program, working toward improving transportation safety, mobility, and efficiency and enhancing productivity through the integration of innovative technologies into the nation's transportation system. Standards play an important role in facilitating the deployment of ITS by helping ensure that technologies developed by different vendors are interoperable. Through its ITS standards program, the ITS JPO teams with standards development organizations and public agencies to accelerate the development of open, non-proprietary communications interface standards. These standards define how ITS systems and components interconnect and exchange information to deliver ITS services. The ITS JPO also works to harmonize U.S. standards with those of other nations and regions. Examples of standards development efforts by the ITS JPO are in section 4.6 of this report.

3.5 Technology Transfer

T2 is the process by which the transportation community receives and applies the results of research. T2 helps ensure that innovations developed through RD&T are widely adopted and will not just "sit on a shelf." In many cases, the Department does not initiate RD&T solely to inform regulations, policy, and guidance. Rather, the goal of the RD&T is to develop and test solutions to specific transportation needs that can eventually be adopted by the transportation sector. The "incorporation" of this kind of RD&T is

[8] Pub. L. 104-113, National Technology Transfer and Advancement Act of 1995, as amended by Pub. L. 107-107, Section 1115, on Dec. 28, 2001, Utilization of Consensus Technical Standards by Federal Agencies. See also OMB Circular A-119, Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities.

evidenced by innovations being commercialized or otherwise being deployed.

OST-R coordinates T2 across DOT's OAs and the ITS JPO, broadly engages transportation stakeholders as the Department's T2 lead, and secures resources to assist modal partners as they engage in T2 activities. Within each OA, T2 activities are tailored to the mission of the OA and to the types of research it sponsors. FHWA's Every Day Counts (EDC) initiative is highlighted here as an example of one successful and long-running T2 program. Each of the other OAs is also actively engaged in T2; information about all of those efforts is available here.

The EDC program identifies, rapidly transfers, and deploys proven-but-underutilized innovations to shorten the project delivery process, enhance roadway safety, reduce congestion, and integrate automation. Every two years, FHWA works with state, local, and Tribal transportation departments to identify a new set of innovations to champion. FHWA then provides technical assistance, training, and other resources to support the implementation and widespread adoption of those innovations. The seventh EDC round spans 2023 to 2024.

Figure 3. EDC logo. Source: FHWA

After selecting EDC innovations, transportation leaders from across the country gather at a virtual summit to discuss and identify opportunities to implement the innovations that best fit the needs of their respective state transportation programs. Following the summit, states finalize their selection of innovations, establish performance goals for the level of implementation and adoption over the upcoming two-year cycle, and begin to implement the innovations with the support and assistance of the technical teams established for each innovation.

Throughout the two-year deployment cycle, specifications, best practices, lessons learned, and relevant data are shared among stakeholders through case studies, webinars, and demonstration projects. The result is rapid T2 and accelerated deployment of innovation across the nation. The EDC program has made a significant positive impact in accelerating the deployment of innovations and in building a culture of innovation within the transportation community. Since the inception of EDC, each state has used 26 or more of the 57 innovations promoted through EDC, and some states have deployed more than 45.[9] Many of these innovations have become mainstream practices across the country.

[9] FHWA, "About Every Day Counts," last updated June 16, 2023.

4 PROJECT HIGHLIGHTS: EXAMPLES DEMONSTRATING INCORPORATION OF INNOVATIONS

This section describes a small cross-section of departmental RD&T and how the resulting innovations have been (or will be) incorporated into regulations, policy, and guidance, or deployed through T2.

4.1 FAA

4.1.1 Continuous Lower Energy, Emissions, and Noise Program

Project Description

Research Sponsor: FAA
Research Conducted by: Multiple industry parties
Project Timeline: 2010–present
Funding: $340M cumulatively from FY 2010 through 2023, covering phases 1, 2, and work to date on phase 3 (exceeded by cost match from industry); $38M in FY 2023 appropriations

Background

The Continuous Lower Energy, Emissions and Noise (CLEEN) Program is FAA's principal environmental effort to accelerate the development of new aircraft and engine technologies that will reduce noise, emissions, and fuel burn. FAA partners with the aviation industry via a cost-sharing approach to enable the industry to expedite integration of environmentally beneficial technologies into current and future aircraft. Started in 2010, the CLEEN Program is implemented in five-year phases and has goals for noise, fuel burn, and emissions. The third phase of the CLEEN Program was launched in 2021 with RD&T activities planned to run through 2026. The fourth phase of the program is in development. Through the first two phases of CLEEN, industry contributed $388 million to this program, which exceeded the FAA's contribution of $225 million.

In addition to the aircraft technology development work under CLEEN, the first two phases of the program have supported testing and demonstrations of sustainable aviation fuel (SAF). These tests have generated data to support ASTM International approval of these sustainable fuels for safe use in today's aircraft, engines, and ground infrastructure.

Goal

All three phases of the CLEEN Program have targeted reductions in aviation noise, emissions, and fuel burn. The goals of the CLEEN Program are tied to the environmental standards that aircraft and engines are required to meet as a part of airworthiness certification. As industry meets the goals, the FAA has made the goals increasingly more stringent. Furthermore, the third phase of the CLEEN Program is also targeting reductions in community noise exposure and particulate matter emissions from aircraft engines.

Incorporation of Research

The CLEEN Program has matured technologies that have entered the fleet, and the industry anticipates that additional technologies will enter into service in the coming years as opportunities arise for their insertion into new aircraft and engine designs. Additionally, the knowledge gained from the development of these technologies is leading to improved design codes and fabrication methods that are being applied throughout these companies' product lines, leading to improved environmental performance across the industry.

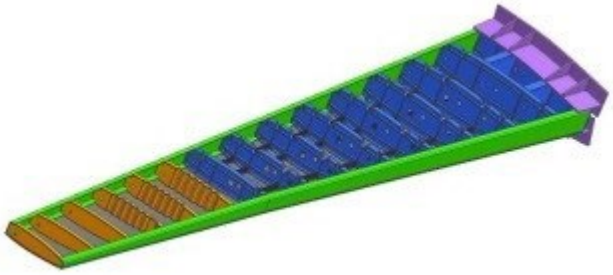

Figure 4. Structurally efficient wing. Under CLEEN Phase II, Boeing developed and demonstrated advanced aircraft wing technologies. Source: FAA

CLEEN Phase I and II are estimated to save the aviation industry 34.7 billion gallons of fuel by 2050, reducing airline costs by $69.5 billion and lowering carbon dioxide (CO_2) emissions by over 400 million metric tons. These CO_2 reductions are equivalent to removing 2.9 million cars from the road from 2020 to 2050.[10] Technologies from the first phase of CLEEN are estimated to decrease land area exposed to noise by 14 percent. These technologies, as well as the use of sustainable aviation fuels, will also dramatically reduce nitrogen oxide and soot emissions from aircraft operations.

The CLEEN Program has also resulted in better analysis and design tools that improve the aircraft or engine products produced by these companies, well beyond the benefits provided by individual technology applications. In addition, the program has enabled development of supporting technologies with lower readiness level that may otherwise have been unsupported, such as developing viable manufacturing alternatives and advancing state of the art materials that can be used in various applications.

Relevant Links

FAA, Continuous Lower Energy, Emissions and Noise (CLEEN) Program, last updated August 29, 2023.

FAA, Continuous Lower Energy, Emissions, and Noise (CLEEN) Program: Summary and Status Report, September 10, 2021.

[10] FAA, "Continuous Lower Energy, Emissions and Noise (CLEEN) Program," last updated August 29, 2023.

4.1.2 Fly Neighborly: Reducing Helicopter Noise Near Communities

Project Description

Research Sponsor: FAA

Research Conducted by: FAA, Volpe Center, and the National Aeronautics and Space Administration (NASA)

Project Timeline: 2016–2023

Funding:

- Helicopter Flight Noise Measurements - $1.78M
- Fly Neighborly Support - $647K

Background

Helicopter noise can be a concern in communities and metropolitan areas across the United States. In particular, New York City and the Los Angeles Basin have been seeking noise-reducing solutions for helicopter tour and charter companies, as well as for police and air ambulance operations.

Goal

The research goal was to produce noise abatement procedures and situational awareness tools that helicopter pilots can use to minimize the impact of helicopter noise on communities.

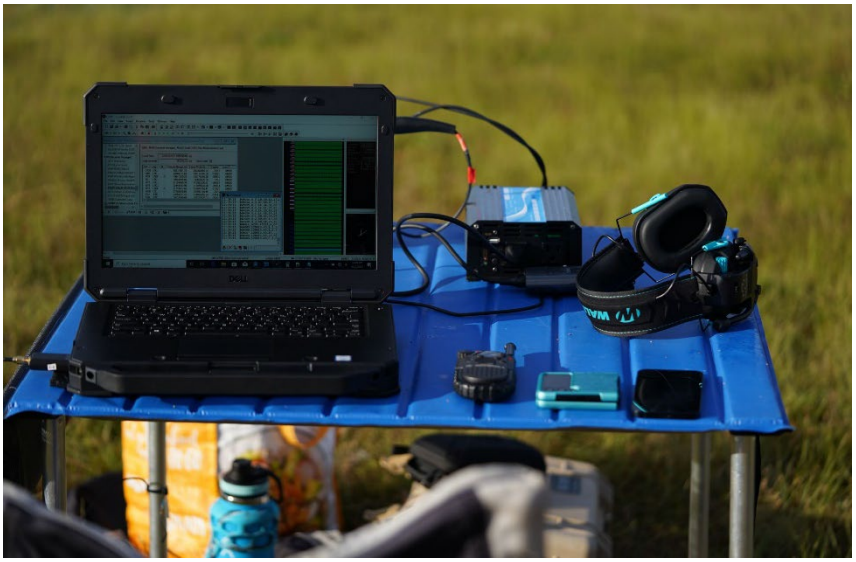

Figure 5. Equipment used to take acoustical measurements of helicopter maneuvers. Source: Volpe Center

Methodology

FAA and the U.S. DOT Volpe Center collaborated with the National Aeronautics and Space Administration (NASA) in the planning and execution of helicopter acoustic flight tests involving nine different helicopter models. Data from these tests were then used in conjunction with computer modeling to determine the noise levels for various combinations of glide slope, airspeed, rate of descent, and deceleration.

Research Findings

The joint research resulted in a series of operational noise plots that provide guidance on reducing overall noise levels over a wide area, and directional (left-center-right) operational noise plots, which can be used to tailor noise reduction in specific areas relative to the flight operation.

Incorporation of Research

Based on the research results, Volpe Center experts developed the content for an introductory online noise abatement training, as well as training modules for each of the tested helicopter models. Those training modules are based on higher-fidelity analysis of the empirical acoustical data and enable pilots to employ reliable and accurate decision-making during pre-flight planning and in flight. The training also addresses safety, pilot workload, passenger comfort, as well as environmental justice and other sensitive land-use considerations.

With support from FAA, Helicopter Association International created a voluntary noise reduction program called Fly Neighborly that promotes the use of the noise abatement procedures. It seeks to create better relationships between communities and helicopter operators by establishing noise mitigation techniques and improving communications. Eventually, noise abatement guidance may be incorporated into mandatory FAA flight training for pilots.

Relevant Links

U.S. Department of Transportation. Volpe National Transportation Systems Center. Fly Neighborly Pilot Training Program Aims to Reduce Helicopter Noise Near Communities. April 20, 2022.

Helicopter Association International. Fly Neighborly.

FAA online training: Introduction to Fly Neighborly Training.

Fly Neighborly Acoustic Animations (YouTube).

4.1.3 Ground Collision Severity Evaluation for Unmanned Aircraft Systems

Research Sponsor: FAA

Research Conducted by: Alliance for System Safety of UAS through Research Excellence (ASSURE)

Project Timeline: Phase 1: 2015–2017. Phase 2: 2017–2019

Funding:

Phase 1 (ASSURE Research Project A4) - $382K

Phase II (ASSURE Research Project A14) - $2.0M

Project Description

Background

The FAA collaborates with industry and communities to advance the use of UAS and to integrate them safely into the national airspace. In 2016, the FAA published a much-anticipated rule that allowed people to begin conducting routine, civil small UAS operations.[11] That rule established operating limits for civil, small UAS weighing less than 55 pounds, as well as certification requirements for remote pilots.[12]

Small UAS operations over people were limited to operations over people who are directly participating in the operation, located under a covered structure, or inside a stationary vehicle. The 2016 rule did not permit the operation of small

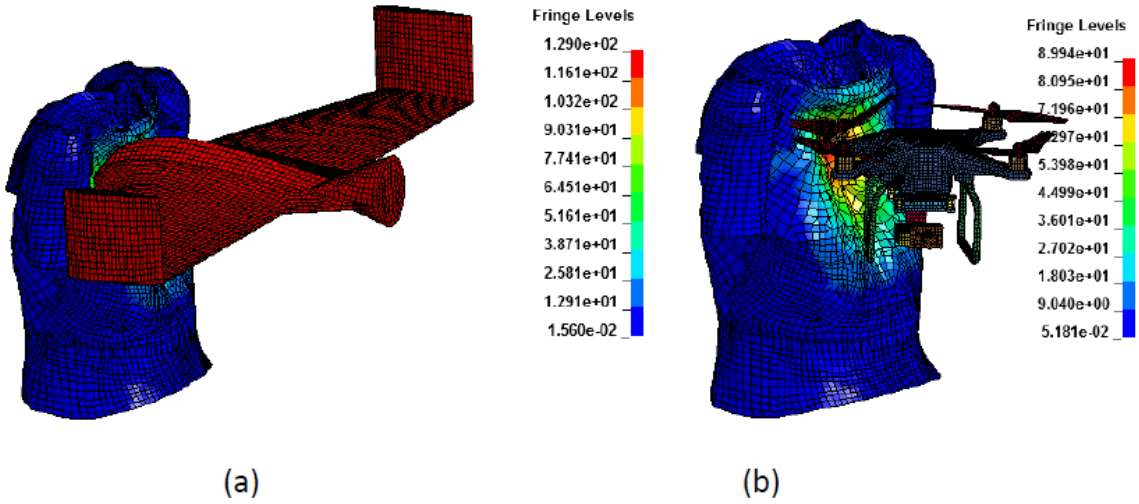

Figure 6. Model simulated typical deformation response of human torso under the impact of UAS (a) aluminum fixed wing; (b) aluminum rotary wing. Source: ASSURE

[11] See 14 CFR part 107.

[12] As a result of Public Law 115-254, part 107 does not apply to limited recreational UAS operations under 49 U.S.C. 44809.

UAS at night or over people without a waiver. Before providing more operational flexibility, the FAA sought better information on the potential for human injury from being hit by a falling small UAS.

Goal

Since 2015, the FAA has sponsored UAS research through the UAS Center of Excellence under the Alliance for System Safety of UAS through Research Excellence (ASSURE). ASSURE is composed of 29 research institutions and more than 100 industry and government partners. The FAA engaged ASSURE to conduct research to answer the following questions:

- What should the hazard severity criteria be for a UAS collision?
- What is the severity of a UAS collision with people on the ground?
- What are the design characteristics of a UAS that could minimize the potential injury during a ground collision?
- Can the severity of UAS collision with a person be characterized into categories based on the UAS?

Methodology

Between 2015 and 2019, ASSURE performed more than 500 impact tests and simulations with 16 different fixed-wing and multi-rotor UAS, as well as various objects and payloads of varying weights and with a range of velocities. The research team initially performed testing using crash test dummies to review and determine thresholds of serious but non-lethal injury. ASSURE then increased the fidelity of the injury modeling and testing by utilizing post-mortem human subjects (PMHS) and compared the thresholds for serious but non-lethal injury established using the crash test dummies with the injury thresholds yielded from PMHS testing.

Research Findings

During Phase 1, researchers established that small UAS do not always impact a person or surface in the same manner that a rigid object impacts them. The initial research also highlighted the necessity for safer blade designs or restrictions that could limit the effects of exposed rotating parts. As part of this phase, researchers also developed an initial process for the testing and evaluation of small UAS models for human injury potential.

During Phase 2, researchers assessed the injury potential of various small UAS of different material properties and construction. This research established that small UAS do not behave like rigid objects during an impact. Instead, a small UAS can impact a human being with a much higher kinetic energy than a rigid object with the same mass and cause a comparable level of injury.

The findings as organized by the research questions are as follows:

- What should the hazard severity criteria be for a UAS collision?
    - The ASSURE research results were aligned with the injury/kinetic energy thresholds in the proposed rule showing that the small UAS tested could operate within the parameters of the proposed rule by placing reasonable operational

limitations on the small UAS (e.g., altitude limits, speed restrictions, or other risk mitigations).

    - goFAA determined that the ASSURE results supported the proposed rule as written and the eventual final rule.

- What is the severity of a UAS collision with people on the ground?
    - The ASSURE results showed that injury caused by a rigid object at kinetic energy levels (Cat 2/Cat 3) in the proposed rule is equivalent to the injury caused by a small UAS at a higher kinetic energy. This indicates that a small UAS can exert much higher kinetic energy than a rigid object and stay within the parameters of the proposed rule.
- What are the design characteristics of a UAS that could minimize the potential injury during a ground collision?
    - The results provided in the ASSURE comment on the proposed rule show that the small UAS cited could operate within the parameters of the proposed rule by placing operational limitations on the small UAS such as altitude/speed restrictions or other risk mitigations such as parachutes or softer bodies that can absorb energy on impact.
- Can the severity of UAS collision with a person be characterized into categories based on the UAS?
    - The collision dynamics of small UAS differ from falling objects of other structures and materials.
        - Multi-rotor UAS fall slower than metal debris of the same mass due to higher drag on the drone
        - Small UAS are flexible during collision and retain significant energy during impact, whereas wood and metal debris do not deform and transfer most of their energy upon impact.
    - Three dominant injury metrics are applicable to small UAS:
        - Blunt force trauma injury – most significant contributor to fatalities
        - Lacerations – blade guards required for flight over people
        - Penetration injury – hard to apply consistently as a standard
    - Payloads can be more hazardous due to reduced drag and stiffer materials.
    - Lithium polymer batteries need a unique standard suitable for small UAS to ensure safety, because damaged or defective batteries could cause casualties from battery fires or explosions.

Incorporation of Research

In 2021, FAA published a final rule allowing expanded routine operations of small UAS over people without a waiver or exemption, provided that the operation meets the requirements of one of four operational categories. The rule was an important step in the FAA's incremental approach to integrating UAS into the national airspace system. FAA used the research results when determining the injury

severity limits that are included in the rule.

Relevant Links

Arterburn, David, et al. Final Report for the FAA UAS Center of Excellence Task A4: UAS Ground Collision Severity Evaluation, 2017.

Arterburn, David, et al. Final Report for Task A14: UAS Ground Collision Severity Evaluation 2017-2019. FAA Center of Excellence for UAS Research.

FAA final rule: Operation of Small Unmanned Aircraft Systems Over People. 86 FR 4314, January 15, 2021.

FAA notice of proposed rulemaking (NPRM): Operation of Small Unmanned Aircraft Systems Over People. 84 FR 3856, February 13, 2019.

4.1.4 Detect Cabin Air Quality Events from Engine Bleed Air Contaminants

Project Description

Background

Research Sponsor: FAA
Research Conducted by: FAA Center of Excellence for Commercial Space Transportation
Project Timeline: 2021–2024 (expected)
Funding: $1.1M

On most of today's large transport category airplanes, the ventilation systems provide a mix of fresh air and recirculated airflow. The fresh air is typically taken from the compressor stage of a gas turbine upstream of the turbine's fuel-burning sections. Air from this source is called engine bleed air. The primary use of bleed air by a civil aircraft is to pressurize the aircraft cabin. The FAA has strict cabin air standards, and studies have shown cabin air is as good as or better than the air found in offices and homes. In rare instances, however, certain mechanical issues can cause fumes to enter the cabin. Exposure to contaminated bleed air could cause adverse health effects in cabin crews and passengers.

Airlines are required to report these incidents to the FAA, which investigates the causes of these events and ensures the cause is fixed before the aircraft is returned to service. The FAA Modernization and Reform Act of 2012[13] directed the FAA to implement a research program for the identification or development of appropriate and effective air cleaning and sensor technology for the engine bleed air supplied to the passenger cabin and flight deck of a pressurized aircraft. Since 2004, the FAA has sponsored numerous research projects on the cabin air environment.

[13] Pub. L. No. 112-95, Section 917. Section 917 is specific to the detection and removal of oil-based contaminants entering the cabin through the engine and auxiliary power unit bleed air.

Goal

The purpose of one ongoing, multiphase research study is to:

- Identify and measure levels of contaminants of engine bleed air.
- Identify sensor technologies to detect and provide warnings of bleed air contaminant events.
- Identify techniques to minimize airplane diversions from smoke, odor, and fume events.
- Assess the potential health-related risks of human exposure to chemicals generated during contaminated air events.

Methodology

In Phase I of the research, a Kansas State University research team reviewed data and technical reports from three extensive cabin air studies to determine the type and concentration levels of bleed air contaminants likely to occur in an airplane cabin during normal aircraft operations. Phase I also included planning a series of tests using a small turbine engine on a test stand operating under a variety of engine conditions and with a range of potential bleed air contaminants and concentration levels.

Phase 2 work will involve static aircraft engine stand tests and ground-based, on-aircraft tests. Phase 2 tests will assess the capability of current, commercial off-the-shelf sensors to detect bleed air contaminants resulting from engine oil, hydraulic fluid, and deicing fluid. Phase 2 will also involve the collection and chemical analysis of engine bleed air contaminants resulting from engine oil, hydraulic fluid, and deicing fluid. Phase 3 will involve the toxicological review and interpretation of the chemical sample data to examine the potential health-related risks of human exposure to engine bleed air contaminants.

Research Findings

The overall study will produce multiple data sets and technical reports on sensor technology performance, chemical analyses of engine bleed air contaminants, and a toxicological assessment of the potential health effects of engine bleed air contaminants on passengers and crew members.

Incorporation of Research

The results of this research will inform regulatory efforts for appropriate onboard sensors to alert the crew of impending air quality events, resulting in an overall decrease in cabin air quality events and minimizing diversions/air turnbacks due to smoke, odor, or fume events. The new sensors will constitute an innovative practice, material, or technology that has demonstrable benefits to the transportation system, as specified in statute.

Relevant Links

FAA Center of Excellence for Commercial Space Transportation. William J. Hughes Technical Center. Detection of Airplane Cabin Air Quality Events from Engine Bleed Air Contaminants. Project description in the Research in Progress database of the Transportation Research Board (TRB). Created May 26, 2022.

FAA Civil Aerospace Medical Institute, Aircraft Cabin Bleed Air Contaminants: A Review, DOT/FAA/AM-15/20, 2015.

4.1.5 Effects of Cabin Seat Pitch and Alternative Seat Configurations on Evacuations

Project Description

Background

Research Sponsor: FAA
Research Conducted by: AIR/AAM
Project Timeline: 2022
Funding: $223K

In the FAA Reauthorization Act of 2018,[14] Congress required the FAA to issue regulations that establish minimum dimensions for passenger seats on aircraft operated by air carriers in interstate air transportation or intrastate air transportation. This mandate came after years of passenger advocacy groups calling on the FAA to do the same, with the rationale that American travelers' physical dimensions have been getting larger while seat sizes and available seated space (i.e., seat pitch) have been reduced.

The FAA and the aviation industry have conducted a considerable amount of research on airplane evacuations; however, none of the research specifically focused on the effect of airplane seat dimensions have on evacuation speed and safety. FAA determined that more information was required to determine how changes to seat dimensions or available space may affect evacuation speed and safety and to provide data on how changes in the physical size of travelers may affect the ergonomic minimums required within the airplane cabin.

Goal

This research project had two objectives, the first of which was to determine what percentage of the American population would be unable to sit in transport airplane passenger seats at the currently narrowest width and even narrower seat pitch. The second objective was to determine the effect of seat pitch and seat width on individual egress time.

Methodology

Researchers first collected anthropometric data from 775 study participants to be used for ergonomic analyses of current and future seat designs. Second, researchers asked all participants to sit in a seat mock-up that matched the narrowest seat pitch they would experience in the evacuation trials. They were also asked to sit in a seat mock-up of a narrower seat pitch than what would be presented in the evacuation trials or, presumably, in the active-duty fleet of commercial transport category airplanes. This extra step was selected to investigate what percentage of the population would be unable to sit, and thus be unable to fly, should the occupiable seat space be further reduced. The second research question

[14] Pub. L. 115-254, Section 577.

was addressed by filming and timing participants as they exited configurations of airplane seats with different dimensions and spacing.

Research Findings

The study confirmed other survey data that the general U.S. population is getting larger and heavier, although this did not significantly impact egress time as expected based on previous research. Researchers found no significant statistical differences in egress time based on seat pitch, seat width, or a combination of the two. Based on this study's results, currently flying seat pitches using seats of

Figure 7. The flexible aircraft cabin simulator during a trial day. Source: FAA

similar size or smaller than those used in this project can accommodate and not impede egress for 99 percent of the American population.

Incorporation of Research

FAA will use the research findings as it responds to the congressional mandate to establish minimum dimensions for passenger seats on aircraft operated by air carriers. In addition, the anthropometric data points and measurement procedures resulting from the research will inform future evacuation research studies.

Relevant Links

FAA Civil Aerospace Medical Institute. Effects of Airplane Cabin Interiors on Egress I: Assessment of Anthropometrics, Seat Pitch, and Seat Width on Egress, DOT/FAA/AM-21/01, January 2021.

4.2 FHWA

4.2.1 Building Information Modeling for Infrastructure

Project Description

Background

Building Information Modeling (BIM) is a collaborative work method for structuring, managing, and using digital data and information about transportation assets throughout their lifecycle. BIM, also known as better information management, enables users to share digital information to maximize the benefit of the data collected at various stages of a highway project, resulting in cost savings and time efficiencies. BIM makes digital construction management systems possible by integrating project delivery phases and connecting project delivery with eventual program/performance/asset management by re-using data more effectively.

Research Sponsor: FHWA – Office of Infrastructure and Office of Infrastructure Research & Development

Research Conducted by: Multiple consultants. FHWA has also provided grants to states for implementation pilots and case studies.

Project Duration: 2011–present

Funding: $40M+

BIM represents a paradigm shift in how projects are delivered, and assets maintained. The focus on an asset's life cycle recognizes that digital data and models created in project design can be used to build projects more efficiently and safely during project construction. In addition, using construction data to develop digital as-builts provides key information as agencies maintain those assets over time.

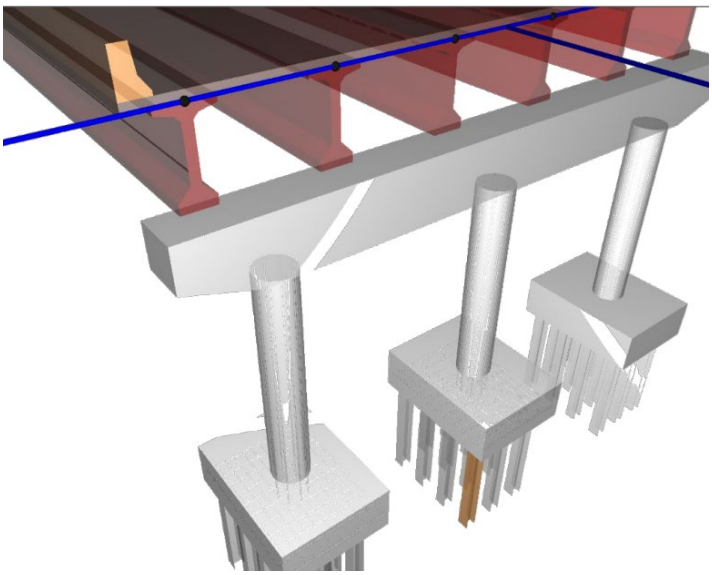

Figure 8. Digital rendering of pier with multiple columns. Source: FHWA

Goal

Dating back to 2011, FHWA has been advancing the concepts of three-dimensional modeling, digital delivery, intelligent construction, and construction automation that constituted aspects of BIM for infrastructure.

Methodology

FHWA is accomplishing its goal by documenting and sharing successful and cutting-edge practices and providing funding to states to pilot methods that advance the digitalization of project delivery.

Research Findings

FHWA efforts promote an open exchange of data so that the investments made during project development and construction can be realized throughout the project lifecycle (from conception to demolition). The idea is to collect data once and use it often. Achieving this requires not only addressing technology gaps, but also agency processes, data standards, and personnel capacity building.

FHWA developed foundational frameworks, including a National BIM Roadmap and BIM Global Benchmarking Study. FHWA's focus on BIM and showcasing of leading agencies has received the attention of state DOTs and industry. As a result, many agencies are piloting related technologies and approaches. FHWA conducted a BIM Global Benchmarking Study, which documented how six BIM-mature European nations and their public agencies use BIM to better deliver transportation projects and manage assets. Connections made with European counterparts continue to pay dividends through the exchange of information with U.S. audiences.

Incorporation of Research

FHWA is advancing the digital transformation of how highway projects are delivered and how enterprise data is leveraged for better decision-making. FHWA's EDC program has been championing various aspects of BIM, with the current focus on digital as-builts. FHWA research has fed into the various EDC initiatives. FHWA has also been instrumental in establishing pooled-fund studies, one on bridges and one on infrastructure as a whole, with each having more than 20 State DOT members working together to advance BIM. Pooled-fund projects are co-funded by the member organizations and help ensure that states are moving forward in a coordinated effort and sharing a unified message with the industry.

The American Association of State Highway and Transportation Officials (AASHTO) has recognized the importance of BIM and has taken the following specific steps/actions to lead and support advancement:

- AASHTO passed a resolution (AR-19) titled "Adoption of Industry Foundation Classes (IFC) Schema as the Standard Data Schema for the Exchange of Electronic Engineering Data," recognizing the IFC schema as the national open data exchange standard for its members.
- AASHTO has formally joined building SMART International (bSI), the governing body for IFC so that the state DOTs have a voice in the international arena as IFC is further developed.
- AASHTO has established a Joint Technical Committee on Electronic Engineering Standards (JTCEES) to identify data needs, information requirements, and industry standards necessary to

facilitate the exchange of information between transportation agencies and their industry partners.

- AASHTO has also established a Joint Committee on Data Standardization (JSTAN) to champion and coordinate the implementation of open data standards and schema development with the goal of enhancing seamless information exchanges throughout the lifecycle of all assets, with the goal of improving the management of transportation systems and assets.

In March 2023, FHWA helped convene the first BIM Week in Washington, DC. It brought together members from BIM pooled funds, JTCEES, JSTAN, and representatives from bSI. During BIM Week, FHWA held a workshop that featured BIM activities and lessons learned presented by speakers from the Netherlands, Denmark, and Finland. In addition, a workshop was held by JSTAN and bSI to acquire U.S. input on bSI's InfraRoom Roadmap in advance of a bSI Summit in Rome in March 2023.

The BIL[15] provides $20 million annually to accelerate state adoption of advanced digital construction management systems (ADCMS) applied throughout the construction lifecycle (including through the design and engineering, construction, and operations phases). The ADCMS program grants will promote, implement, deploy, demonstrate, showcase, support, and document the application of advanced digital construction management systems, practices, performance, and benefits.

To continue and increase the coordination of BIM activities by FHWA, the pooled funds, AASHTO, and others and to increase awareness and leverage the activities of the ADCMS grants, FHWA is establishing a Digital Delivery Stakeholder Group. This group will provide a forum for States, industry and other interested parties to regularly learn about the many ongoing BIM activities. All meetings will have a virtual component or be entirely virtual so that they can be open to all. This will help meet a need that many stakeholders have expressed to increase coordination and awareness of BIM activities.

Lastly, FHWA recently became a Standard member of bSI and buildingSMART USA. This provides FHWA with as seat at the table as international open data exchange standards for infrastructure data are being developed.

Relevant Links

FHWA, Building Information Modeling (BIM) for Infrastructure Products, last updated October 6, 2022.

FHWA, Building Information Modeling Practices in Highway Infrastructure, Global Benchmarking Program Report. FHWA-PL-024. March 2021.

FHWA, Advancing BIM for Infrastructure: National Strategic Roadmap. FHWA-HRT-21-064. June 2021.

[15] BIL, Section 13006(a)(5).

4.2.2 Developing and Deploying the National Household Travel Survey

Project Description

Background

FHWA has been collecting national travel behavior data since 1969 through the currently branded National Household Travel Survey (NHTS) program. The NHTS provides nationally representative data and information, including all travel modes, covering who, why, how, and when travel occurs. This data and information provide the foundation for understanding national travel demand and trends, supporting Congressional legislative actions and federal, state, and local transportation decision-making.

Research Sponsor: FHWA – Office of Policy and Governmental Affairs

Research Conducted by: Battelle Memorial Institute, Oak Ridge National Laboratory, MacroSys, LLC, and Ipsos Public Affairs

Project Duration: 2021–2023

Funding: $2.8M

Starting in 2015, FHWA was explicitly directed to collect the data per the Fixing America's Surface Transportation (FAST) Act[16] and, later, the IIJA.[17] To address declining public participation and increased costs, data collection methods and approaches have evolved from the original face-to-face personal interviews and random-digit-dialing telephone interviews to address-based sampling (ABS) with various data collection modes such as paper, internet (push to the web), cellular phone, and landline phone interviews.

Goal

The 2022 NHTS development and deployment initiative attempts to develop new data collection approaches while gaining the latest national travel behavior information and meeting federal data quality standards.

Methodology

The 2022 NHTS development and deployment initiative consists of two independent data collection approaches. The traditional ABS approach randomly selects household samples from the sampling frame of all U.S. residential mailing addresses, which is treated as a controlled test—the data gathered is considered as the official statistics, which can be used for a broad range of topics covering legislation, policy, and program development and deployment.

Parallel to the ABS approach, the study deployed a more cost-saving approach by using a pre-established online probability-based panel frame sample (PFS). This study's online panel cost is about 50 percent lower than the traditional ABS approach. The pre-established online panel is commercially available and is not specially designed for any particular survey subject. The online recruitment used a probability-

[16] Pub. L. 114-94, Section 6028.

[17] BIL, Section 13003.

based ABS sample. The usage of such a panel reduces the recruitment cost and improves the response rate. However, the representativeness of such a panel and the final data needs further evaluation and analysis. In addition, the initiative will provide a quantitative analysis of the differences and similarities between the two methods and determine the new method's validity.

Research Findings

The major product of this initiative was the delivery of the 2022 official national travel behavior data and the development of a new and more economical online panel data collection method. Data collection for the 2022 NHTS was carried out from January 2022 to January 2023.

Overall, in 2022, Americans traveled substantially less than they did in 2017 (254 billion trips in 2022 vs. 371 billion in 2017) due to a combination of factors, including changes in daily life related to the pandemic and subsequent recovery, the rise of working from home, new opportunities to carry out errands such as shopping, banking, and telehealth/home health care, and a decrease in personal trips.

On the PFS method development front, compared to the ABS survey method, the final analysis indicated that the PFS method offered the same conclusions at a statistically 95-percent confidence level based on both weighted and unweighted data with the panel frame method being determined to be “fit for purpose.” Key travel metrics such as person trip rates, vehicle miles traveled, travel mode, trip purpose, and telework frequency varied little between the survey methods. The PFS method represents a significant improvement in survey methodology as the new method costs substantially less while offering a more dependable schedule.

Incorporation of Research

The result of this 2022 NHTS study enables Federal, State, and local transportation agencies to refine and recalibrate their travel demand modeling programs for more realistic travel demand projections. In addition, the data will enable travel behavior research related to travel safety, exposure, teleworking, online shopping, and disaster recovery relating to travel demand, enabling more efficient and robust transportation program planning and operations.

The FHWA will further analyze the PFS method and deliver a formal presentation to the Office of Management and Budget under the Paperwork Reduction Act, requesting approval to use the new method for future NHTS data collection. The PFS method will reduce costs and improve data timeliness for the travel behavior data program; With its potential of being adopted by state and local agencies, its cost saving could be significant for public agencies.

Relevant Links

FHWA, National Household Travel Survey.

FHWA, Summary of Travel Trends: 2022 National Household Travel Survey (ornl.gov)

4.2.3 Long Life, Low-Cost Mini-Roundabouts

Project Description

Background

A modern roundabout is a proven safety countermeasure for reducing vehicle speed and crash severity. On average, single-lane roundabouts reduce fatal and serious injury crashes by 80 percent.[18] However, the construction cost of a single-lane roundabout is about $1.5 million, making it too expensive for consideration by many roadway agencies. Mini-roundabouts share the same design and operating features of modern roundabouts, but they have traversable central and splitter islands for occasional use by large vehicles. Mini-roundabouts are expected to have comparable potential safety and operational benefits as single-lane roundabouts. The cost of converting an existing intersection into a mini-roundabout is about $350,000 (in 2015 dollars).

Research Sponsor: FHWA – Office of Safety & Operations R&D

Research Conducted by: ZKxKZ, LLC

Project Duration: 2015–2022

Funding: $1.M from FHWA (Phases I, II, and IIB), $750K from the Department of Defense (DOD) (Phase IIB)

Goal

The purpose of this research project was to investigate whether there are more cost-effective ways of constructing mini-roundabouts from simple modular shapes and recycled material.

[18] Steyn, Hermanus, et al. Accelerating Roundabouts in the United States: Volume IV of VII – A Review of Fatal and Severe Injury Crashes at Roundabouts, FHWA-SA-15-072 2015.

Methodology

Figure 9. Mini-roundabout. Source: ZKxKZ, LLC

In 2015, FHWA initiated a SBIR project to explore approaches to constructing mini-roundabouts using prefabricated modular components. The project was carried out in phases. During Phase I, researchers developed a proof of concept, and during Phase II, they built a prototype and demonstrated it at actual intersections. During Phase IIB, researchers improved the product design and commercialized the product.

Research Findings

Between 2015 and 2022, ZKxKZ produced a prototype design for building mini-roundabouts using modular components fabricated using recycled milk jugs and plastic bottles. The company demonstrated the concept in three demonstration projects in Georgia, Virginia, and California, each with improved product designs. The modular mini-roundabout product created with FHWA financing is suitable for both temporary and permanent projects, making it suitable for demonstration projects that allow people to experience the safety and performance of mini-roundabout design. Additionally, it is possible to remove the plastic boards and restore the intersection to its previous condition.

Incorporation of Research

ZKxKZ was given a U.S. patent for its "Modular Block System for Roundabouts" design. ZkxKZ recorded commercial sales for the installation of twelve modular mini-roundabouts. In addition to the three demonstration projects delivered under FHWA funding, ZKxKZ recorded commercial sales totaling $2.1 million for the installation of modular mini-roundabouts at 12 intersections in Alberta, Canada, Virginia, Maryland, California, Nebraska, and North Carolina. The average cost of a modular mini-roundabout is about $177K, which is roughly half the cost of the conventional method of building a mini-roundabout.

Although this project focuses on the modular building of mini-roundabouts, the same methodology could be applied to the construction of any type of raised curbs, a market that is even larger than that of roundabouts. Each modular mini-roundabout construction project utilizes tens of thousands of pounds of plastic garbage that would otherwise be disposed of in landfills.

Relevant Links

Modular Block System for Roundabouts (U.S. Patent).

FHWA, SBIR Success Story – Mini-Roundabout. FHWA-HRT-22-080. June 2022.

FHWA. Developing Crash Modification Factors for Mini-Roundabouts. FHWA-HRT-23-019. April 2023.

4.2.4 Pavement Structural Assessment and Analysis Without Lane Closure

Project Description

Background

The pavement management systems currently used by state highway agencies are primarily based on surface condition data, and surface cracking is the main indicator of the pavement structural condition. However, for several reasons including the use of increasingly thicker pavements, surface cracks can no longer be relied on as an indicator of structural condition or "health" of the pavement structure. The true pavement structural condition and rate of deterioration are needed not only to plan optimal structural rehabilitation activities and future budget needs, but also to assess meaningful progress under a performance-based federal-aid program.

Research Sponsor: FHWA – Office of Infrastructure and Transportation Pooled Fund Study

Research Conducted by: FHWA and Virginia Tech Transportation Institute

Project Duration: 2012–present

Funding: $1.2M (excludes Transportation Pooled Fund and Eastern Federal Lands Highway Division data collection effort)

With an aging pavement network on our most trafficked highways, the fear is not when the next preservation treatment is needed, but when that will no longer be effective, resulting in the need for major rehabilitation/reconstruction. The state-of-the-practice pavement condition data collection is inadequate to meet this increasingly critical need. Some state highway agencies have investigated the use of falling weight deflectometers to fill this gap. While falling weight deflectometers are the preferred devices for project-level structural evaluation, they are inefficient at the network level. Falling weight deflectometer measurements are made at discrete points along the pavement sections, and the equipment must remain stationary on the road at each testing point (typically for 1 to 4 minutes, depending on the data collection protocol). Because the equipment has to be stationary during measurements, this requires lane closures that disrupt traffic and restricts when testing can be done. This limits productivity and the number of discrete points where measurements can be obtained, in addition to creating a potential safety hazard for both testing personnel and road users.

Goal

Due to the limitations of the falling weight deflectometer and the need to describe the structural condition of the pavement at the network level, research has been done to find, test, and demonstrate

traffic-speed deflection devices (TSDDs). These devices can collect data at high traffic speeds and do not require lane closures.

Methodology

Dating back to 2010, FHWA coordinated with other research entities to pursue a systematic approach for the use of TSDDs to evaluate pavement structure. They include the Second Strategic Highway Research Program 2 (SHRP 2) R06(F), two FHWA-sponsored research projects, three national transportation pooled fund (TPF) studies that FHWA has been instrumental in establishing— TPF-5(282) led by FHWA, TPF-5(385) and TPF-5(518) led by Virginia Department of Transportation, and two National Cooperative Highway Research Program projects (10-105 and 01-63). Building upon FHWA's and collaborators' research efforts, research continues toward the development of analysis methodologies and tools to help state highway agencies leverage TSDD data for the effective network- and project-level pavement applications.

Research Findings

Research findings to date confirmed that TSDDs are capable of collecting network-level pavement structural condition information for network-level pavement management and project-level applications. Several use cases have been identified and demonstrated, including:

- Identifying structurally weak versus strong pavement sections for effective treatment selection
- Estimating jointed concrete pavement load transfer efficiency at the joints and transverse cracks
- Back-calculation of pavement layer properties that could inform overlay design
- Estimating remaining structural life, and
- Predicting future pavement condition incorporating pavement structure

Incorporation of Research

Research findings support the use of TSDD data for the applications mentioned above, as collected by over 26 state DOTs in the current pooled-fund study TPF-5(385). In addition, FHWA's Eastern Federal Lands Highway Division has used the TSDD data and research results in various use cases. The Eastern Federal Lands Highway Division manages the network of paved roads for the National Park Service. As part of this effort, FHWA collected TSDD data on over 2,000 miles of high-priority National Park Service routes, including the National Mall Area, George Washington Memorial Parkway, the Baltimore-Washington Parkway, and the Blue Ridge Parkway. The pavement management performance models used by Eastern Federal Lands are currently being revised to incorporate TSDD data, where available, to incorporate pavement structural conditions to adaptively adjust deterioration models to improve prediction accuracy.

Relevant Links

Rada, G. R., Nazarian, S., Visintine, B. A., Siddharthan, R., and Thyagarajan, S. (2016). "Pavement Structural Evaluation at the Network Level." FHWA-HRT-15-074.

Rada, G. R., Nazarian, S., Visintine, B. A., Siddharthan, R., and Thyagarajan, S. (2016). "TechBrief

Pavement Structural Evaluation at the Network Level." FHWA-HRT-15-075.

Katicha. S., Flintsch, G., Shrestha, S., and Thyagarajan, S. (2017). "Demonstration of Network-Level Pavement Structural Evaluation with Traffic Speed Deflectometer." Transportation Pooled Fund Program.

Nasimifar, M., Chaudhari, S., Thyagarajan, S., and Sivaneswaran, S. "Pavement Structural Capacity from Traffic Speed Deflectometer for Network-Level Pavement Management System Application," In Transportation Research Record Journal of the TRB, National Academies, 2018.

Nasimifar, M., Thyagarajan, S., and Sivaneswaran, S. "Pavement Structural Evaluation at Network Level Pavement Management – A Case Study." Airfield and Highway Pavements 2019 Design, Construction, Condition Evaluation, and Management of Pavements, ASCE, 2019, pp. 343-353.

4.2.5 Alkali-Silica (ASR) Aggregate Research Program

Project Description

Background

Research Sponsor: FHWA – Office of Infrastructure R&D

Research Conducted by: Turner-Fairbank Highway Research Center Chemistry Laboratory

Project Duration: 2019–2022

Funding: $818K

Concrete is widely used around the world for the construction of infrastructure, including highways and bridges. The heterogeneous nature of concrete makes it susceptible to various deterioration mechanisms. If timely repair or replacement action is not taken, concrete deterioration may jeopardize the serviceability and safety of structures, leading to economic losses and ultimately to catastrophic failures and fatalities. Therefore, it is necessary to properly evaluate the materials used to produce concrete for such structures to prevent premature deterioration, safeguard their longevity, and extend their service life.

Alkali-silica reaction (ASR) is a concrete deterioration mechanism that involves the reaction of certain silica-rich phases in the aggregates with ions in the solution found in the material's pores, referred to as concrete pore solution. The main product of the reaction is a mixture of high alkali-silica gels, some of which have high water swelling capacity that can ultimately result in cracking and subsequent damage to the concrete. First discovered in 1940, ASR remains as one of the main deterioration mechanisms affecting concrete infrastructure in the United States. Once a concrete structure suffers from ASR gel, deterioration generally cannot be repaired, and the concrete structure must be replaced at a significant cost.

The cost of rehabilitating ASR-affected structures is high, so reliable testing of aggregates for ASR reactivity is of utmost importance to prevent ASR in new construction. The slow kinetics and complexity of the reaction, as well as the diverse mineralogy of the aggregates used in concrete production, are significant factors behind the absence of an accurate and efficient accelerated laboratory test to predict the development of ASR in the field.

The first test method to evaluate the alkali-silica reactivity of aggregates was introduced in 1947. Since then, there have been many tests, most of which rely on physical engineering measurements of concrete or mortar specimens. None of the tests work very well, tending to both overestimate and underestimate aggregate reactivity. At best, they typically show 65- to 70-percent agreement with field experience. A concrete expansion test is currently the most popular test to evaluate the alkali-silica reactivity of aggregates. Significant drawbacks of this test render it inadequate to predict the ASR reactivity and field performance efficiently and accurately of some aggregates.

Goal

The major objective of this study was to demonstrate the possibility of using the concentration of silicon, aluminum, and calcium ions in the concrete pore solution as a predictor of ASR for any type of aggregate.

Methodology

Foundational work was carried out to better understand the effect of concrete pore solution on the characteristics of the ASR reaction products under accelerated laboratory conditions. The influence of changes in concentrations of common components of the concrete pore solution, such as silicon, aluminum, and calcium, on the nature of ASR reaction products was studied using a multi-analytical approach. The observed changes in the concrete pore solution were correlated with physical expansion in ASR-affected mortar and concrete lab specimens and the historical performance of concrete blocks in outdoor exposure sites.

Research Findings

Figure 10. An example of concrete cracking caused by alkali-silica reaction gels. Source: FHWA

The principal outcomes of this research effort are the development of new tests. The first test, named Turner-Fairbank Highway Research Center ASR Susceptibility Test (T-FAST), detects the presence of silica reactive phases in the aggregate. The second test, named Alkali Threshold Test, measures the alkali threshold that will trigger the ASR reaction in the concrete. The T-FAST method has been accepted by AASHTO as a provisional test method TP 144-23. The Alkali Threshold Test method has been accepted by ballot within AASHTO and will be published as a provisional test method in the summer of 2024. The tests take only 21 days to complete, compared with one year for the best test currently available. FHWA has analyzed over three hundred aggregates from various states and compared the results with those from block farm exposure tests in Massachusetts, Texas, and Ontario. These concrete blocks have been exposed to the weather for between 16 and 27 years. The results gathered with a modified version of T-FAST show 100-percent agreement with field observations of ASR.

Incorporation of Research

This research program fulfilled the urgent need of DOTs for a reliable laboratory test to predict ASR that accurately reflects field performance. The development of a reliable, efficient, and sensitive test method to predict the ASR reactivity of aggregates and concrete job mixtures will expand the use of certain locally available, slow-reactive aggregates, as well as opening the door to better mitigation strategies.

FHWA is in the process of helping State DOTs, industry partners, and testing laboratories learn how to carry out the new tests through a pooled-fund study (TPF(5)-521) and other implementation-focused activities.

Relevant Links

AASHTO Provisional Standard Test for Determining the Potential Alkali–Silica Reactivity of Coarse Aggregates (TFHRC-TFAST), TP 144-23. Washington, DC: AASHTO, approved January 2023.

Arnold, Terence, et al., Method for the Assessment of Alkali - Silica Reactivity of Aggregates and Concrete Mixtures, U.S. Patent Application Publication No. US 2022/0317109 A1, October 6, 2022.

Balachandran, Chandni, et al. Applying Raman Spectroscopy to Study Alkali-Silica Reaction Gels, FHWA-HRT-20-042, June 2020.

Munoz, Jose, et al. A Novel Approach for the Assessment of ASR Susceptibility of Concrete Mixtures in Airfield Pavements and Infrastructure, FHWA-HRT-21-103, December 2021.

Muñoz, J. F., Balachandran, C., & Arnold, T. S. (2021). New Chemical Reactivity Index to Assess Alkali–Silica Reactivity. Journal of Materials in Civil Engineering, 33(4), 04021037.

Muñoz, J.F., C. Balachandran, and T.S. Arnold (2021). New Turner-Fairbank Alkali-Silica Reaction Susceptibility Test for Aggregate Evaluation. Transportation Research Record, 2675 (9)798-808. doi10.1177/03611981211004584.

4.2.6 Roadside Unit Standardization

Project Description

Background

Research Sponsor: ITS JPO and FHWA Office of Safety & Operations R&D

Research Conducted by: ITE and SAE

Project Duration: 2019–2022 (maintenance is ongoing)

Funding: $800K

Interoperable connectivity is a cornerstone to modernizing infrastructure to meet U.S. DOT's priorities of delivering safer, cleaner, and more equitable transportation systems. Multiple technological, economic, and policy alternatives are currently available to chart a path toward interoperable connectivity. Voluntary technical standards are needed to enable replicable, secure, and interoperable ITS implementations nationwide.

An essential cornerstone of interoperable and vehicle-to-everything (V2X) connectivity is the roadside unit (RSU). The RSU provides connections between vehicles and infrastructure elements such as signal controllers, allowing vehicle-to-infrastructure (V2I) applications like red-light violation warning (RLVW), and signal priority and preemption for transit and emergency vehicles.

Goal

The primary objective of this task was to make available a voluntary RSU Standard that gained the approval of both the traditional infrastructure stakeholder community and the automobile original equipment manufacturer (OEM) community.

Methodology

ITE led the effort to develop a new RSU standard in partnership with SAE International (SAE). RSU standard development utilized a systems engineering process. Researchers started with the previously developed Roadside Unit Specification 4.1, National Electrical Manufacturers Associations (NEMA) TS-10 Connected Vehicle (CV) Infrastructure—Roadside Equipment, as well as experiences from early deployers, to define the initial concept of operations.

The concept of operations described the key operational scenarios, capabilities, and user needs for RSUs, which were vetted and approved by the community of deployment agencies, infrastructure equipment vendors, and automobile OEMs. After the development of the concept of operations, user needs were broken down into more technical functional and performance requirements and ultimately into detailed design elements that met those requirements. The final step of the RSU standards development process was formally balloting across the infrastructure and automobile OEM stakeholder communities.

Research Findings

Version 1 of the approved standard was published in November 2021. After the initial publication, the RSU Standard Working Group met with RSU vendors to discuss the RSU standard and determine if there

were any problematic or ambiguous areas in the standard when they attempted to implement it in their RSU design. These discussions uncovered a few areas where additional guidance could be provided in the standard. Version 1.01 was published in September 2022 with updated guidance to resolve the ambiguities.

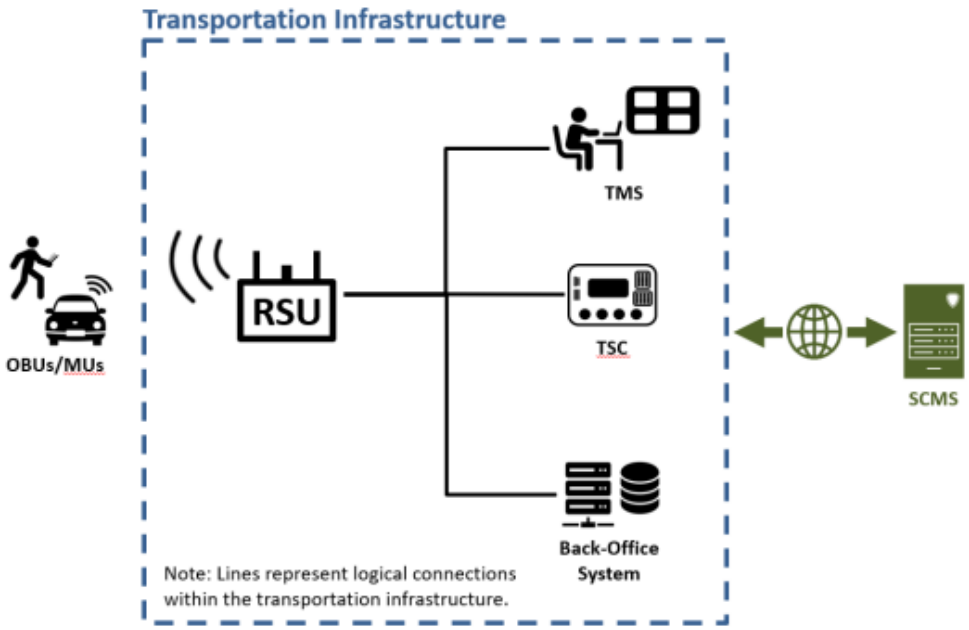

Figure 11. V2X system. Source: ITE

Incorporation of Research

The Connected Transportation Interoperability (CTI) 4001 RSU Standard is an industry-consensus standard that reflects the needs of the infrastructure and automobile OEM stakeholder communities. Vendors are now working on developing CTI 4001-compliant RSUs that will soon be available for deployment agencies to procure. CTI 4001 also includes cellular-vehicle-to-everything functionality to support the deployment of RSUs that comply with the Federal Communications Commission (FCC) guidance on the use of devices in the 5.9-gigahertz band.

As a product of the ITS Standards program, the CTI 4001 RSU standard falls within ITE's standards maintenance contract, ensuring that issues found in the standard or changes necessary from future FCC reports and orders can be quickly addressed by updating the standard.

Relevant Links

ITE Technical Resource: RSU Standardization.

4.2.7 Street Lighting for Pedestrian Safety

Project Description

Background

In 2020, 6,516 pedestrians were killed in traffic crashes—77 percent of those fatalities occurred at night, and an additional 4 percent occurred during dawn or dusk.[19] Enhancing nighttime visibility where non-motorists mix with traffic during darkness will save lives. In past visibility research, most studies focused on adults. A specific focus on pedestrian safety for school-age children was needed because they are especially vulnerable to traffic and often travel to and from school during dawn and dusk hours.

Research Sponsor: FHWA – Office of Safety & Operations R&D

Research Conducted by: Virginia Tech Transportation Institute

Project Duration: September 2018–December 2020

Funding: $300K

Goal

The project objectives were to:

- Evaluate the visibility of child-sized pedestrians alongside a lighted roadway at night
- Evaluate the visibility of trip hazards in a lighted crosswalk at night
- Assess the impact of roadway lighting on the decision of when to cross a roadway
- Determine recommendations for lighting that benefit both drivers and pedestrians

Methodology

The research study for this report comprised three human factors-based experiments. Each of the evaluations compared different light types and mounting heights, and the two pedestrian experiments included children as participants.

[19] NHTSA, Traffic Safety Facts: Pedestrians (2020 Data). DOT HS 813 310, May 2022.

Research Findings

The research results indicated that brightness does not automatically translate to an increase in detection distance for both motorists and pedestrians. Researchers also concluded that urban and rural environments warrant two different lighting designs to enhance the visibility of pedestrians. Neither light level nor light scale influenced the responses of children and adults with regard to the extent they would no longer attempt to cross a roadway. However, children underestimate the acceptable crossing period compared to adults. Adults were more conservative than children by an average of 30 meters (100 feet) or a range of 2 to 3 seconds with vehicle speeds of 35 and 25 mph (56 and 40 km/h), respectively.

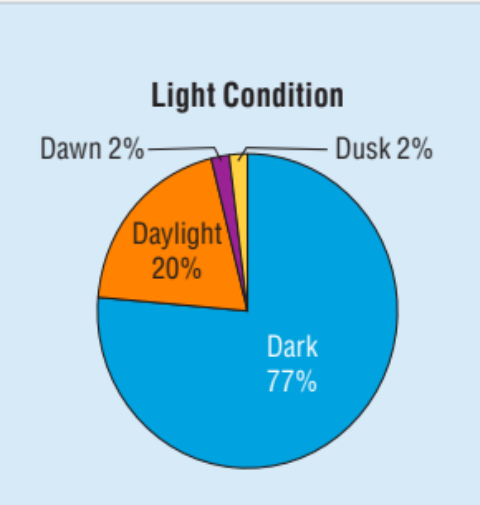

Figure 12. Percentage of pedestrian fatalities in relation to light condition, 2020. Source: NHTSA

The research provided recommendations for lighting for pedestrian safety for both adults and children. Lighting recommendations for improving the visibility of pedestrians, both adult and child, were developed from a driver's point of view. Additionally, visibility for both adults and children in detecting hazards on walkways and crosswalks are factored into the research method and recommendations. Based on the research results, recommended light level criteria for pedestrian facilities were developed for locations with pedestrian activities. The rural and urban recommendations have different lighting design criteria.

Figure 13. View of a child-sized mannequin using different light sources. Source: FHWA

Incorporation of Research

In addition to a final research report, a companion document titled "Pedestrian Lighting Primer" was published to highlight the research outcomes for safety practitioners. The research outcomes were incorporated as part of the update effort for a recent FHWA publication – FHWA Lighting Handbook

2023. The research results were also included in the latest update of a national lighting design document – Recommended Practice – Lighting Roadway and Parking Facilities RP-8-22, by Illuminating Engineering Society.

Relevant Links

FHWA, Street Lighting for Pedestrian Safety Research Report, FHWA SA-20-062, December 2020.

FHWA, Pedestrian Lighting Primer Report, FHWA-SA-21-087, April 2022.

FHWA, Lighting Handbook 2023, FHWA-SA-23-004, February 2023.

4.3 FMCSA

4.3.1 High Blood Pressure and Medical Certification of Commercial Motor Vehicle Drivers

Project Description

Background

Research Sponsor: FMCSA
Research Conducted by: Applied Research Associates, Inc.
Project Duration: 2022-2024 (planned)
Funding: $258K

FMCSA administers the Federal Motor Carrier Safety Regulations (FMCSRs) concerning the medical qualifications of commercial drivers in interstate commerce. The federal physical qualification standard for hypertension states that a person is physically qualified to drive a commercial motor vehicle (CMV) if that person has no current clinical diagnosis of high blood pressure likely to interfere with the ability to operate a CMV safely.[20] Cardiovascular disease is the leading cause of medical illness and sudden death in drivers of CMVs. Although only a small percentage of crashes are caused by cardiovascular disease, they are responsible for significant mortality and morbidity.

FMCSA's Medical Program Division promulgates and implements medical regulations, guidelines, and policies that ensure CMV drivers engaged in interstate commerce are physically qualified to do so. The guidelines assist medical examiners in the evaluation and certification of drivers. Periodically, FMCSA updates these guidelines to incorporate the latest medical research and changes in standards of care.

Goal

To assist with the update of its guidance for medical examiners on when high blood pressure is most likely to interfere with safe operation of a CMV, FMCSA is conducting a research project with the following objectives:

- To identify and review the most current literature related to high blood pressure and the measurement at which high blood pressure is likely to interfere with a driver's ability to operate a CMV safely.
- To evaluate the likelihood of individuals with high blood pressure being involved in a motor vehicle crash.
- To evaluate whether guidance on high blood pressure that is available to medical examiners who conduct physical qualification examinations of CMV drivers is consistent with the literature.
- To develop a hypertension guidance table to assist medical examiners in determining whether high blood pressure is likely to interfere with an individual's ability to operate a CMV

[20] 49 CFR 391.41(b)(6).

safely.

Methodology

The research team is conducting a literature review for evidence-based guidelines, standards, practice parameters, best practices, and research studies from relevant government healthcare agencies, professional organizations, and medical professionals. They will then develop a guidance table that will be informed by findings from the literature review and input from an expert panel of board-certified cardiologists and physicians certified in either internal medicine or occupational medicine. The publication date for the final report is estimated to be in late 2024.

Incorporation of Research

FMCSA will use the findings of the research to inform its update to its cardiac guidance for medical examiners.

Relevant Links

FMCSA, High Blood Pressure and Medical Certification of Commercial Motor Vehicle Drivers, research project description, last updated March 29, 2023.

FMCSA, Cardiovascular Advisory Panel Guidelines for the Medical Examination of Commercial Motor Vehicle Drivers, 2002, FMCSA-MCP-02-002.

4.3.2 Model AV Operational Safety Plan for Motor Carriers

Project Description

Background

Research Sponsor: FMCSA
Research Conducted by: Volpe National Transportation Systems Center
Project Duration: 2022-2024
Funding: $500K

Motor carriers will implement a wide range of automation technologies into automated CMVs. The integration of higher-level (SAE Levels 3 and 4) automation features into fleet operations will require careful consideration by motor carriers. A motor carrier's safety management systems will be influenced by the design, build, operation, maintenance, and inspection of hardware, as well as by the training, qualification, relative location, and hours of service of human drivers and operators.

This project will examine the aspects of the developer's safety case for automated truck features that motor carriers integrate into their automated vehicle operations safety plan. The safety case is based on automotive industry standards including International Standards Organization (ISO) 26262 (Road Vehicles — Functional Safety), Underwriters Laboratories (UL) 4600 (Standard for Safety for the Evaluation of Autonomous Products), and applicable ISO/SAE standards and guidelines.

Goal

The objective of this project is to develop a model safety plan as a template for carriers operating CMVs equipped with automated driving systems (ADS). Such a plan must consider, consistent with existing requirements on motor carriers and CMV drivers, the specific automation technologies to be implemented and how the CMV is to be operated. The vehicle operational design domain and staffing requirements may vary for different phases of its journey. For example, a CMV may be unoccupied during platooning operations on a limited-access highway, inspected by a technician upon exit from the

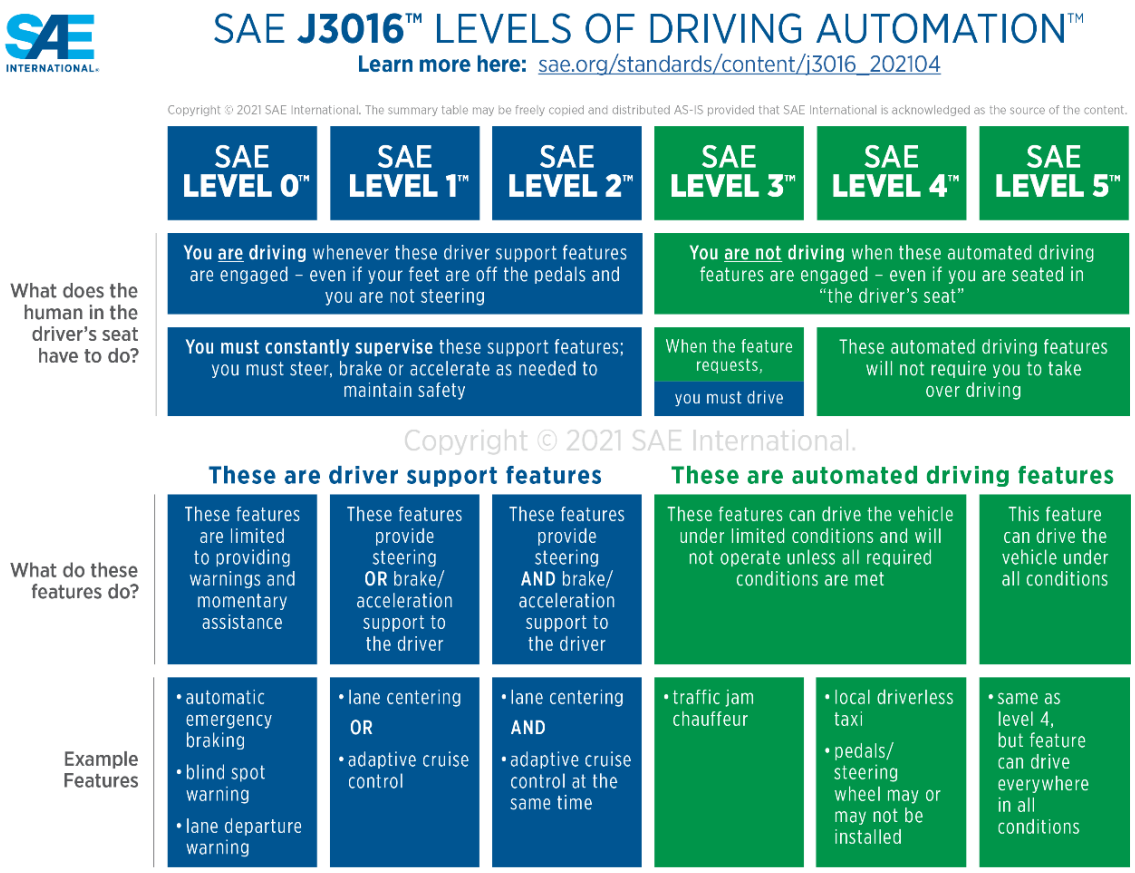

Figure 14. SAE levels of driving automation. Source: SAE

highway, and docked at a warehouse either autonomously, manually by a driver with a commercial driver's license, or through teleoperation. Therefore, the model AV safety plan should be modular and consider the system safety operational requirements determined by the technology developer.

Incorporation of Research

Once developed, the model AV operational safety plan will be offered to motor carriers as a template, facilitating the safe integration of automated CMVs into carrier fleets.

Relevant Links

FMCSA, Model AV Operational Safety Plan for Motor Carriers, research project description, last updated February 2, 2023.

Luckuc, Mike, Model AV Operational Safety Plan for Carriers, presentation for 2023 FMCSA Analysis, Research, and Technology Forum, April 12, 2023.

4.3.3 Review of the Federal Motor Carrier Safety Regulations for Automated Commercial Vehicles

Project Description

Background

Research Sponsor: FMCSA
Research Conducted by: Volpe National Transportation Systems Center
Project Duration: FY2017–FY2018
Funding: n/a

Like all conventional CMVs in the United States, automated CMVs operating in interstate commerce must conform to the FMCSRs. The FMCSRs were drafted without consideration of the possibility that they might one day apply to CMVs that are either partially or entirely driven without input from a human driver, or even without a human driver onboard. As a result, existing requirements in the current FMCSRs may present challenges for motor carriers looking to operate automated CMVs, as well as for enforcement personnel looking to apply the FMCSRs to automated CMVs. Both groups require clarity on the extent to which automated CMVs are compatible with the existing regulations.

Goal

The goal of the research effort was to understand the extent to which the FMCSRs might pose compliance and enforcement challenges for automated CMVs.

Methodology

The Volpe National Transportation Systems Center (Volpe) conducted a comprehensive review of the FMCSRs. The first step was to identify automated CMV operating concepts representing a range of plausible applications of automation to commercial vehicle operations. These hypothetical concepts ranged from near-term driver-assistance features to highly automated CMVs that do not require direct driver input. The Volpe team then assessed how specific requirements in the FMCSRs would apply to each of the operating concepts.

Research Findings

In general, the Volpe team found that several broad potential challenges exist for every automated CMV operating concept considered, including near-term driver assistance features. These potential challenges include:

- Restrictions on the use of additional equipment or accessories that decrease the safety of operation of a CMV in interstate commerce (49 CFR part 393).
- Restrictions on the operation of a CMV in interstate commerce in such a condition as to likely cause an accident (49 CFR part 396).
- Requirements for the driver of a CMV to be restrained by a seat belt if the CMV is equipped with a seat belt assembly at the driver's seat (49 CFR part 392).

However, many of the issues identified for such near-term systems could potentially be clarified through regulatory interpretations. Operating concepts that do not require active human driver involvement, including concepts with onboard (non-driving) technicians or driverless concepts that are supervised remotely, will likely face more significant challenges, including:

- Applying existing training, licensing, and operating requirements (e.g., hours of service) to an onboard (non-driving) technician or a remote supervisor.
- Applying knowledge requirements, physical fitness qualifications, alcohol and controlled substance restrictions, and hours of service restrictions to an automated driving system.
- Complying with cargo and equipment inspection requirements, particularly those that apply to CMVs that are in transit.

Incorporation of Research

The findings of this research project have helped FMCSA understand which requirements in the FMCSRs may need to be revised or clarified to enable the deployment of different operating concepts for automated CMVs.

Relevant Links

Perlman, David, et al., Review of the Federal Motor Carrier Safety Regulations for Automated Commercial Vehicles: Preliminary Assessment of Interpretation and Enforcement Challenges, Questions, and Gaps, FMCSA-RRT-17-013, March 2018.

4.3.4 Safe Driver Apprenticeship Pilot Program

Project Description

Background

The trucking industry has long struggled with a shortage of drivers. One way of alleviating that shortage would be to permit drivers under the age of 21 years to operate CMVs in interstate commerce. In the IIJA, Congress mandated that FMCSA conduct a three-year commercial driver apprenticeship program.[21] This program will allow qualified drivers ages 18-20 who hold intrastate commercial driver's licenses to explore interstate trucking careers.

Research Sponsor: FMCSA

Research Conducted by: M. Davis and Company

Project Duration: Carriers submitted applications for the pilot program in July 2022; pilot program will last from 2022-2025

Funding: $1.1M

FMCSA will grant apprentice drivers approval to operate CMVs in interstate commerce while they are under 21 years of age. During the pilot program's probationary periods, apprentice drivers can operate in interstate commerce only when accompanied by a qualified, experienced driver in the passenger seat. After each probationary period, an apprentice must demonstrate they have mastered specific performance benchmarks. Upon completion of both probationary periods, an apprentice may operate in interstate commerce without an experienced driver in the passenger seat.

Apprentices must be accompanied by an experienced driver in the passenger seat and operate vehicles equipped with an automatic manual or automatic transmission, an active braking collision mitigation system, and a governed speed of 65 miles per hour at the pedal and under adaptive cruise.

Goal

The primary goal of the research is to determine the safety impacts of allowing commercial drivers under the age of 21, with specialized training and experience, to operate a CMV in interstate commerce. The secondary goal is for the data collection and analysis to answer questions such as the following:

- How do the safety records of participating apprentices compare to other CMV drivers?
- How do the safety records of participating drivers compare before, during, and after each probationary period?
- What is the average on-duty time, driving time, and time spent away from each home terminal of participating drivers before, during, and after each probationary period?

[21] Pub. L. 117-58, § 23022.

Methodology

Researchers are currently collecting safety data (crash, violation, and onboard monitoring system events) from participating drivers, along with exposure data (hours driving, hours on duty, and vehicle miles traveled). They will analyze the data among carriers, apprentices, controlling for different factors, and will develop a comparison group of drivers, likely aged 21-24 from similar carrier profiles, to compare safety differences, as well as look at the safety differences between intrastate drivers under 21 years of age (currently authorized) and those participating in the pilot program. Researchers may also compare the differences in performance of participating carriers before and after they began participating in the apprentice program.

Incorporation of Research

At the conclusion of the pilot program, the Department must submit a report to Congress that presents the findings and conclusions resulting from the pilot program, as well as a recommendation regarding whether the level of safety achieved by the pilot program is equivalent to, or greater than, the level of safety for equivalent CMV drivers aged 21 years or older.

Relevant Links

FMCSA, Safe Driver Apprenticeship Pilot Program, research project description, last updated February 2, 2023.

FMCSA, Safe Driver Apprenticeship Pilot Program (fact sheet), last updated May 16, 2023.

Federal Register notice: Safe Driver Apprenticeship Pilot Program To Allow Persons Ages 18, 19, and 20 To Operate Commercial Motor Vehicles in Interstate Commerce, 87 FR 2477, January 14, 2022.

4.3.5 CMV Driver Readiness Assessment Technology

Project Description

Background

In CMV operations, impaired alertness from driver fatigue contributes to a significant number of collisions and safety-critical events. Driver fatigue can impair vigilance, working memory, and higher-order cognitive and physical processes. This highlights the need for an objective, quantifiable measure to assess a driver's readiness before operating a CMV. FMCSA is currently sponsoring two SBIR projects to develop "readiness assessment" technologies that can assess a driver's alertness before he/she starts driving a CMV.

Research Sponsor: FMCSA

Research Conducted by: Pulsar Informatics and Design Interactive, Inc.

Project Duration:

PVT DriveFit: Phase I: June 2021-December 2021; Phase II: June 2022-November 2023

Greenlight: Phase I: June 2021-December 2021; Phase II: June 2022-June 2024

Funding:

PVT DriveFit (Phases I and II): $1.1 million

Greenlight (Phases I and II): $1.1 million

Goal

The goal of both SBIR projects is to reduce the contribution of driver fatigue to CMV collisions and other safety-critical events. The research will do this by advancing the development of readiness assessment technologies so that the alertness of drivers can be assessed more easily.

Methodology

Pulsar Informatics is developing a readiness assessment product called DriveFit that is based on a psychomotor vigilance test (PVT). A PVT is a commonly used tool in sleep research that measures the consistency with which subjects respond to a visual stimulus over a sustained period. This system will alert drivers when assessments indicate alertness deficits and support the timely delivery of fatigue countermeasures. Drivers will complete a three-minute PVT on a schedule set by CMV carrier policy. When a driver scores above a set threshold indicating a potential fitness for duty concern, a workflow will be triggered to address the source of the problem. For example, the driver may receive a recommendation to take a 20- to 30-minute nap in the sleeper berth before returning to service.

Design Interactive is developing a product called Greenlight that uses wrist-worn sensors to capture data directly relevant to CMV drivers' alertness. Data from these and other sensors are integrated into a mobile application, allowing for real-time, objective quantification of readiness. Greenlight provides CMV drivers with the capability to assess their current and future fatigue levels. This capability allows drivers to select the appropriate times to get behind the wheel and schedule breaks based on accurate alertness assessments. Greenlight also provides tools for improving readiness by mitigating fatigue by, for example, monitoring and managing stress.

Research Findings

Both companies have successfully completed Phase I of their research, during which they explored the technical merit, feasibility, and commercial potential of their technologies.

Incorporation of Research

The companies are now engaged in Phase II, with a goal of developing and commercializing the Phase I technologies.

Relevant Links

FMCSA, SBIR Phase II: DriveFit Readiness Assessment Technology, research project description, last updated May 10, 2023.

FMCSA, SBIR Phase II: Greenlight Readiness Assessment Technology, research project description, last updated May 10, 2023.

4.4 FRA

4.4.1 Improving the Accessibility of Passenger Railcars

Project Description

Background

Research Sponsor: FRA
Research Conducted by: Multiple parties
Project Timeline: Ongoing
Funding: $642K for accessibility research in FY 2022

Passenger rail transportation is the preferred form of public transportation for most people who use wheeled mobility devices. Accessibility research has yielded recommendations for improved accessibility on passenger railcars, thereby enhancing the travel experience for passengers with disabilities and ultimately all rail passengers. FRA is in a unique position to collaborate with stakeholders to ensure that new standards for accessibility are feasible and safe, balancing the requirements of the law with the capability of the equipment. As described in more detail below, FRA-funded research supports the development of new and improved accessibility standards for rail vehicles, ensuring that the standards are safe and technically feasible. One such research project is described below.

Goal

The objective of research recently conducted by Oregon State University (with support of the Volpe Center) was to evaluate the securement of wheeled mobility devices and occupant restraint on passenger trains.

Methodology

Figure 15. An anthropomorphic test device in the pre-crash setup. Source: FRA

Researchers tested three off-the-shelf wheelchair securement systems in a train-to-train collision as a proof of concept to mitigate the effects of second impact velocity. The tests evaluated the performance of the securement devices regarding human injury, compartmentalization, structural integrity, and attachment. The team conducted a full-scale train-to-train impact test at the Transportation Technology Center in Pueblo, Colorado in August 2022. These experiments included different types of wheelchairs, restraint systems, and anthropomorphic test devices (i.e., crash test dummies) equipped with instrumentation to measure force, moment, acceleration, and displacement data.

Research Findings

The experiments showed that "off-the-shelf" securement systems designed and tested for bus transit provided adequate protection of an anthropomorphic test device seated in a surrogate wheeled mobility device. All of the backboards, wheelchair securement, and occupant restraint systems used in the experiments maintained their structural integrity and remained attached to the carbodies during the tests. The injury values measured by the H3-50Ms were well below the limits and met the performance requirements specified in American Public Transportation Association's seat and table standards.

Incorporation of Research

In 2020, the U.S Architectural and Transportation Barriers Compliance Board (Access Board) published an advance NPRM to begin the process of updating its existing accessibility guidelines for rail vehicles covered by the ADA. These Access Board guidelines serve as the basis for legally enforceable accessibility standards issued by U.S. DOT, which is the federal entity responsible for implementing and enforcing the ADA's non-discrimination provisions related to transportation vehicles.

FRA-sponsored research will inform this update of accessibility guidelines for rail vehicles covered by the ADA. FRA's Office of RD&T is engaging with the Access Board as it considers rulemaking recommendations for improved accessibility on passenger rail equipment for larger spaces, greater maneuverability in restrooms, and better communication systems. FRA also continues to work with the Access Board and the rail industry to develop guidance for the securement of wheeled mobility devices on board passenger railcars.

Relevant Links

Improved Collision Protection for Train Passengers Seated in Wheelchairs: Evaluation of Active and Passive Strategies, April 2023, DOT/FRA/ORD-23/12.

Inclusive and Universal Design Considerations for Next Generation of Passenger Railcars, July 2020, DOT/FRA/ORD-20/28.

Architectural and Transportation Barriers Compliance Board, Advance NPRM: Americans With Disabilities Act Accessibility Guidelines for Transportation Vehicles; Rail Vehicles, 85 FR 8516, February 14, 2020.

4.4.2 Short Line Safety Institute (SLSI) Safety Culture Assessment Process

Project Description

Background

Research Sponsor: FRA

Research Conducted by: American Short Line and Regional Railroad Association University of Connecticut, and the Volpe Center

Project Duration: FY 2014-the present

Funding: Since FY 2015, Congressional report language has provided FRA RD&T with at least $2M annually for SLSI's programmatic activities.

There are approximately 600 short line and regional railroads (Classes II and III) in the U.S. These smaller railroads have limited resources to support safety training and education. Since FY 2014, FRA has partnered with the Short Line Safety Institute (SLSI) to develop, pilot test, and implement an innovative safety culture assessment process. Recommendations resulting from the safety culture assessment process have provided Class II and III railroads with information and actionable processes that can be implemented to operate at a higher level of safety. These assessments are voluntary, non-punitive, and confidential.

Goal

The goal of the research was to develop a methodology for assessing a short line railroad's "safety culture," which is defined as the shared values, actions, and behaviors that demonstrate a commitment to safety over competing goals and demands.

Methodology

Figure 16. Logo of the Short Line Safety Institute. Source: SLSI

Through the pilot project in 2014–2015, researchers designed a process model for assessing the strength of a railroad's safety culture to include empirical and methodological best practices appropriate for a multi-dimensional and nuanced construct such as "safety culture." After the pilot project, the SLSI became incorporated as a nonprofit organization, and began its program implementation phase in 2016. SLSI refined the model using lessons learned during two years of using it for safety culture assessments. SLSI's mission is to enhance the safety culture and safety performance of short line and regional railroads through meaningful and productive partnerships. SLSI accomplishes this mission through four primary categories of activities: assessments, training, education, and research.

Research Findings

The safety culture assessment model uses teams of paired assessors and a multi-method, data-focused, site-customized, in-depth process that involves a survey, observation, interview, and document inventory. SLSI employs research-based practices and engages in continuous improvement efforts with

the support of RD&T through an independent program evaluation. FRA RD&T believes the SLSI's Safety Culture Assessment process and follow up engagement activities help Class II and Class III railroads identify opportunities for improvement on their properties that may lead to a stronger, sustainable safety culture and ultimately improve safety. SLSI utilizes the most robust safety culture model in the U.S. railroad industry, and also across the globe and across sectors, based on a systematic review of the academic literature.

Incorporation of Research

As of June 2023, SLSI's safety culture assessment model had been applied to more than 133 Class II and Class III railroads. Railroads have described the safety culture assessment process as highly valuable and have taken actions to strengthen safety culture based on their individual assessment report. Following a safety culture assessment, the assessors synthesize the data and identify the railroad's safety culture strengths and gaps. Every gap in safety culture is accompanied by an opportunity – a strategy for closing the identified gap in safety culture. SLSI develops new service offerings (e.g., leadership development training, hazardous materials training) to address gaps identified in safety culture assessments.

Relevant Links

Short Line Safety Institute.

FRA, Short Line Safety Institute: The Most Robust Model for Assessing Safety Culture in the U.S. Railroad Industry, Research Results 19-15, June 2019.

FRA, Short Line Safety Institute, Early Outcomes After a Safety Culture Assessment, Research Results 19-18, September 2019.

FRA, Short Line Safety Institute: Measuring Safety Culture Across Four Railroads, Research Results 21-16, September 2021.

FRA, Short Line Safety Institute: 2021 Systematic Review, Research Results 22-09, June 2022.

FRA, Short Line Safety Institute: 2022 Systematic Review, Research Results 23-05, May 2023.

4.4.3 Compliance Testing for Locomotive LED Headlights and Auxiliary Lights

Project Description

Background

Research Sponsor: FRA
Research Conducted by: ENSCO, Inc., and Engineering Systems, Inc.
Project Timeline: Ongoing since 2017
Funding: $856K

Light-emitting diode (LED) technology is now commonly found in motor vehicle headlights and is also being used on the roadway for applications such as street lighting, road studs, and signage. The aviation and marine industries have also begun transitioning to LEDs. The railroad industry is introducing LED technology for locomotive headlights and auxiliary lights. If implemented properly, LED lighting could improve visibility (with ensuing safety benefits) while reducing operations and maintenance costs.

Federal regulations require locomotive headlights to meet the specifications in 49 CFR 229.125, but the safety requirements stipulated in current regulation may not adequately accommodate the safe use of LED lamps by the railroad industry. Consequently, FRA funded research to validate that LED lighting samples comply with applicable standards and codes and to develop other recommendations for effective use of LED lighting on locomotives.

Goal

FRA, in cooperation with the Association of American Railroads (AAR), supported the development of a comprehensive four-phase research and test program to evaluate the performance of LED lamps in a railroad environment.

Methodology

In Phase I, researchers conducted tests to determine that currently available LED lamps satisfied applicable regulatory requirements and illumination characteristics under laboratory conditions. During Phase II, the researchers evaluated visibility and glare aspects of human-sized objects in lighting conditions produced by different lamps in a stationary locomotive. Phase III testing focused on the lighting conditions produced by LED and halogen lamps while a locomotive was in motion. The research team evaluated visibility aspects from the viewpoint of an occupant inside the locomotive cabin and that of an observer outside and away from an approaching locomotive. Phase IV focused on the performance of the LED lamps under severe cold weather conditions. Throughout the testing, halogen lamps, currently standard equipment on freight locomotives, were used as a performance benchmark.

Figure 17. LED light fixtures after 30 minutes of operation at -20 degrees. Source: FRA

Research Findings

Phase I: When used in a dual-lamp headlight arrangement, all LED lamps were capable of meeting the peak luminous intensity requirements established in 49 CFR §229.125. In a single-lamp headlight arrangement, four of the five tested lamp models met the regulatory requirements. All tested LED lamps exhibited more uniform and consistent photometric distributions than halogen lamps, while halogen lamps produced a wider lateral spread of illuminance than LED lamps.

Phase II: Results showed that LED lamps provide better contrast discrimination than halogen lamps along the tracks, but worse contrast discrimination than halogen lamps at an angle offset of 7.5° from the centerline of the locomotive. For glare rating in bright mode, results showed no statistically significant differences between LED and halogen lamps. However, for glare ratings made in dim mode, statistically significant differences between both headlamp types were found, with LED lamps producing worse glare ratings than halogen lamps.

Phase III: The primary outcome of this study was that while there may be subtle differences in the light output, distribution, and color temperature of various LED and halogen lamp models, there were no statistically significant differences found in the ability of observers to detect objects illuminated with either light source. Overall, there were no detrimental effects to the use of LED technology for locomotive headlights and auxiliary lights under dynamic conditions.

Phase IV: The halogen lamps were more successful than LED lamps at melting an existing layer of ice on the lens. However, when tested in windy, snowy conditions, the LED lamps exhibited less accumulated ice in comparison to the halogen lamps, which formed larges domes of ice protruding several inches from the lens.

Incorporation of Research

This project will improve cab/locomotive visibility at night, provide extra alerting for track workers and attempting trespassers, provide extra visibility/alerting when approaching grade crossings, unify an optimized cab display across all railroad providers, increase freight and passenger rail safety, and reduce operating and maintenance costs for locomotives.

Relevant Links

Compliance Testing for Locomotive LED Headlights and Auxiliary Lights, Phase I

Compliance Testing for Locomotive LED Headlights and Auxiliary Lights, Phase II

Compliance Testing for Locomotive LED Headlights and Auxiliary Lights, Phase III

Compliance Testing for Locomotive LED Headlights and Auxiliary Lights, Phase IV

4.4.4 Positive Train Control and Next-Generation Train Control

Project Description

Background

Research Sponsor: FRA
Research Conducted by: Multiple parties
Project Duration: Ongoing since FY 2018
Funding: $17.5M

Positive train control (PTC) systems use communication-based and processor-based train control technology to prevent train-to-train collisions, over-speed derailments, incursions into established work zones, and movements of trains through switches left in the wrong position. The Rail Safety Improvement Act of 2008 (RSIA) mandated the implementation of PTC systems on Class I railroads' main lines over which 5 million or more gross tons of annual traffic and certain hazardous materials are transported, and on any main lines over which intercity or commuter rail passenger transportation is regularly provided.

On December 29, 2020, FRA announced that PTC technology was in operation on all 57,536 required freight and passenger railroad route miles, prior to the statutory deadline set forth by Congress.[22] This

[22] FRA, "Positive Train Control," (website), last updated October 10, 2023.

accomplishment was the culmination of over a decade of sustained and direct engagement and collaboration among FRA and the 41 railroads currently subject to the statutory mandate.

To facilitate the development and deployment of Next Generation Train Control, FRA, in close collaboration with railroads and academia, has funded and continues to fund many research projects. These projects span research areas in train control, communication, grade crossing protection, trespass prevention, and simulation and modeling. The research is focused on developing standard interoperable technologies to be adopted by the railroads in their effort to deploy next generation train control systems.[23]

Goal

Research will focus on providing additional functionality, improving reliability, and supporting integration with other technologies, all of which improve safety and throughput. Multiple areas of consideration are under review for potential development, including signaling, communications, and infrastructure enhancements.

Methodology

FRA will conduct automated train operation research and development, testing of an advanced head- and end-of-train positioning system, standardization of new rail communication security techniques, and development of a locomotive-based hazard sensing platform prototype. Additionally, requirements will be developed for a road remote control locomotive system.

Incorporation of Research

As noted above, FRA-funded research will focus on providing additional functionality, improving reliability, and supporting integration with other technologies — all of which will support the objectives of improving safety and throughput. The work will result in improved rail network capacity and decreased delays caused by PTC, rail network safety and efficiency improvements through interoperable automation, and increased cyber security of train control systems.

Relevant Links

FRA webpage on PTC research.

[23] FRA, "Positive Train Control Information (R&D)," (website), last updated November 13, 2019.

4.4.5 Predictive Analytics

Project Description

Background

Research Sponsor: FRA
Research Conducted by: Multiple parties
Project Timeline: Ongoing
Funding: $2.0M

Predictive analytics (in the context of Track Research) refers to the application of large volumes of historical data to develop routines and numerical tools for accurately predicting adverse track structure/substructure conditions. This includes, but is not limited to, developing and training advanced analytical models designed to forecast track-related conditions that deviate from safe operating parameters (e.g., track geometry exceptions) as well as methodologies for evaluating the effectiveness of track inspection technology for future assessment of safety risk, either on a segment-by-segment basis or for an entire rail network. Further, by leveraging advances in artificial intelligence (AI) and machine learning (ML), FRA is also developing automated processing and reporting capabilities so relevant, data-driven, safety-critical information is delivered to field operations personnel in a timelier manner.

Goal

The objective of the Predictive Analytics research program is to convert the massive amount of data currently being collected in the railroad industry into actionable information to reduce or eliminate track-related accidents/derailments and, in turn, improve the operational safety of rail transportation in our nation.

Methodology

Individual projects comprising the predictive analytics research program are aimed at developing and implementing analytical frameworks designed to leverage the large amount of operational data (e.g., foot-by-foot track geometry data) for forecasting and risk analysis. Each effort is fundamentally guided by the regulations established in 49 CFR Part 213 (Track Safety Standards), which establish critical safety limits with regard to the track structure and substructure. These efforts include (but are not limited to) development of innovative mathematical methods to produce short- and long-term predictions of track geometry degradation outside of regulated safety limits, using AI/ML to enable near real-time processing and reporting of track geometry measurement trends to identify areas that will need maintenance soon, establishing a statistics-based approach to determining the effectiveness of track inspection technology in assessing/measuring certain parameters, and developing computer vision algorithms to remotely monitor the operation of safety-enabling infrastructure (e.g., gate arms and mast lights) at highway-rail grade crossings.

Incorporation of Research

The Office of Research, Development, and Technology is actively working with the Office of Railroad Safety to implement the analytical frameworks developed for inspection prioritization for the Automated Track Inspection Program fleet and for assessing the risk associated with different inspection regimes.

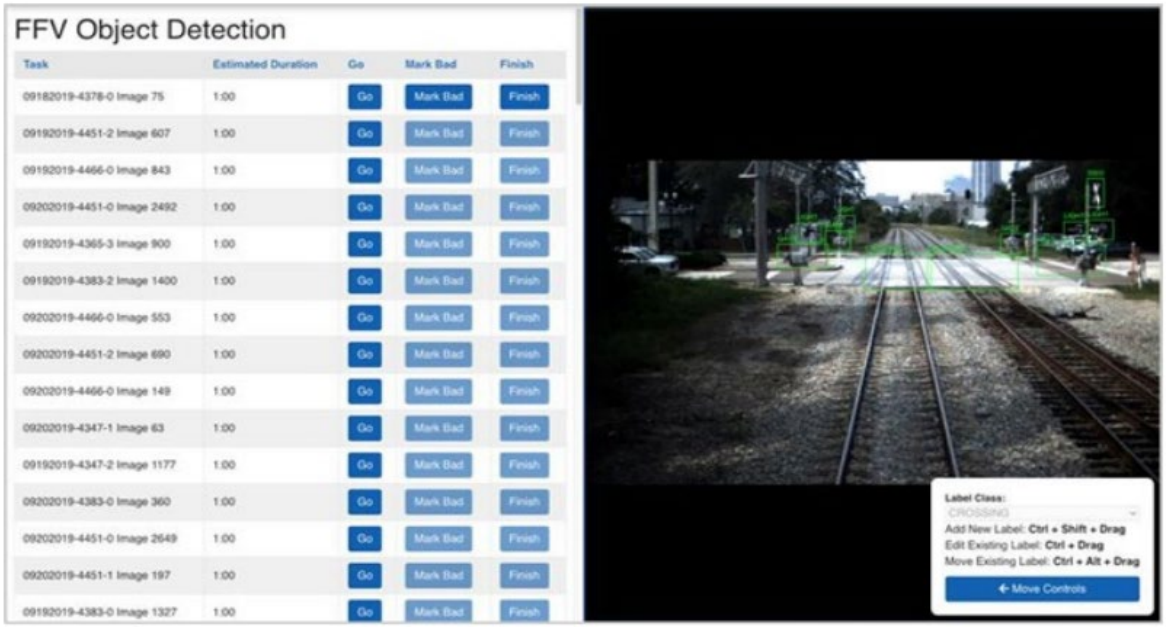

Figure 18. Artificial intelligence training for RailLinks. Source: FRA

In terms of technology transfer, a Class I railroad and a short line railroad have engaged FRA's contractor responsible for developing the remote monitoring system for at-grade crossings to initiate the first steps toward deploying the technology on their locomotive fleet. This will enable the railroads to actively verify that the warning devices and infrastructure at highway-rail grade crossings are operational and in a state of good repair with each train pass, protecting motorists and pedestrians at these dangerous intersections.

Forthcoming Reports (Currently Under Review):

- AI-Aided Broken Rail-Caused Derailment Risk Analysis, Technical Report
- AI-Aided Track Risk Analysis: Phase I – Proof of Concept Pilot Study and System Prototype, Technical Report
- AI-Aided Machine Vision for Grade Crossing Safety, Research Results
- Track Geometry Predictions Using Point and Segment Processing, Research Results
- Predictive Reporting of Autonomous Track Geometry Data, Technical Report
- Advanced Track Geometry Measurement System Forecasting Models, Technical Report
- An Anomaly Detection Data Processing Approach for Ultrasonic Rail Inspection, Technical Report
- AI-Aided Track Risk Analysis: Phase II, Technical Report
- Developing Machine Learning Methods for Facilitated Track Condition Assessment, Technical Report

Relevant Links

Methods for Evaluation of Track Inspection Technology Effectiveness, DOT/FRA/ORD-20/03, February 2020.

Feasibility of Applying Model-Assisted Probability of Detection to Track Inspection, Research Results 21-18, September 2021.

Model-Assisted Probability of Detection for Ultrasonic Rail Flaw Detection, Research Results 21-19, September 2021.

Machine Vision Data Products for the Automated Track Inspection Program, Research Results 21-20, September 2021.

Automated Video Inspection System for Grade Crossing Safety, Research Results 21-05, April 2021.

4.5 FTA

4.5.1 Wayside Worker Protection Technology—TrackSafe Phase II Research & Demonstration

Project Description

Background

Research Sponsor: FTA
Research Conducted by: Metropolitan Atlanta Rapid Transit Authority and Bombardier Transportation
Project Completed: May 2021
Funding: $4.2M

Since the advent of rail transit operations, the task of inspecting and repairing track, signals, and infrastructure located in the wayside or right-of-way (ROW) has been essential to safely moving millions of people every day. It has also been one of the most hazardous jobs in the rail transit industry. Public rail transit agencies have seen an increase in worker fatalities in recent years. According to the U.S. Bureau of Transportation Statistics, between 2010 and 2019, 59 percent of reported transit worker fatalities were rail-related incidents. To address this issue, the FTA has provided support for research and demonstration of advanced ROW warning system technologies that mitigate the risks and accidents for ROW workers.

FTA is also proceeding with a rulemaking for rail transit roadway worker protection. The new rule would establish minimum baseline standards and requirements for risk-based redundant protection.

The rule would apply to rail fixed guideway public transportation systems, and state safety oversight agencies would oversee rail systems' implementation of the requirements. The insights gained from FTA's research and demonstration projects of advanced ROW warning technologies will inform how transit agencies choose to comply with the rule.

Goal

The goal of one such project was to demonstrate a roadway worker protection (RWP) warning technology developed by Bombardier Rail called TrackSafe. The project also assessed the feasibility and benefits of a systemwide deployment of TrackSafe.

Methodology

The technology was designed, manufactured, installed, and commissioned along a three-mile stretch of the Red Line of the Metropolitan Atlanta Rapid Transit Authority. A team of ROW inspectors, rail controllers, and others used the system and provided feedback from their experience.

Research Findings

The final report details the proof of concept, design, construction, commissioning, and operation of the technology, shares issues experienced during the project, and provides a qualitative assessment

supported by lessons learned. One major point of emphasis is the cost of deployment. Researchers identified the need to better leverage and overlay the TrackSafe dedicated fiber infrastructure with other synergistic products (e.g., intrusion detection) to reduce the initial costs of deployment.

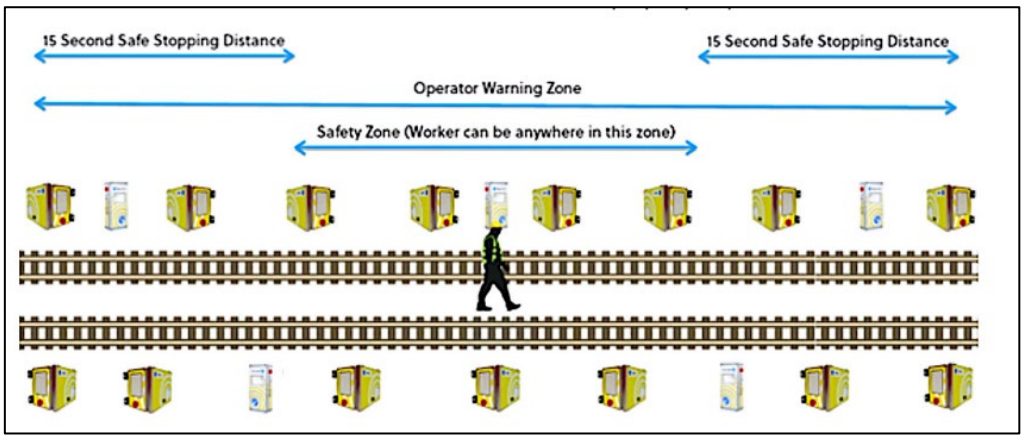

Figure 19. TrackSafe concept. Source: FTA

Incorporation of Research

Exposure of TrackSafe to the rigors of an operating transit environment provided a significant amount of information to aid in the development of an improved future version. The results of the demonstration will help RWP technology providers to refine their offerings and will inform other transit agencies investing in RWP technologies. Transit agencies need better information on RWP technologies, because they may choose to implement track worker safety technology as a means of complying with the proposed rail transit roadway worker protection rule.

Relevant Links

FTA, Wayside Worker Protection — TrackSafe Phase II: Research and Demonstration Report, FTA Report No. 0194, May 2021.

OMB, Rail Transit Roadway Worker Protection rulemaking, Unified Regulatory Agenda, Spring 2024.

4.5.2 Roadway Worker Protection Secondary Warning Device and Employee in Charge Software System

Project Description

Research Sponsor: FTA
Research Conducted by: Sacramento Regional Transit District
Project Completed: February 2021
Funding: $870K

Background

To accelerate the development of secondary warning systems for track workers, FTA funded the demonstration and evaluation of a secondary warning device by the Sacramento Regional Transit District (SacRT). Produced by Protran Technology, the system provides a

visual and audible advance warning alert to train operators of workers ahead, as well as a visual and audible advance warning to track workers of a train approaching a work zone. The technology involves a vehicle-mounted device that transmits an alert to a personal alert device worn by a roadway worker. At the same time, the train's mounted detection device will sound an alert to train operators communicating the presence of a roadway worker.

In parallel with the implementation of the personal alert devices, SacRT also demonstrated Protran Technology's Employee in Charge Software System (EICSS), which uses smartphone technology to validate and authorize roadway worker access to a section of track. This access is controlled by a dispatcher and has acknowledgment features and tracking abilities.

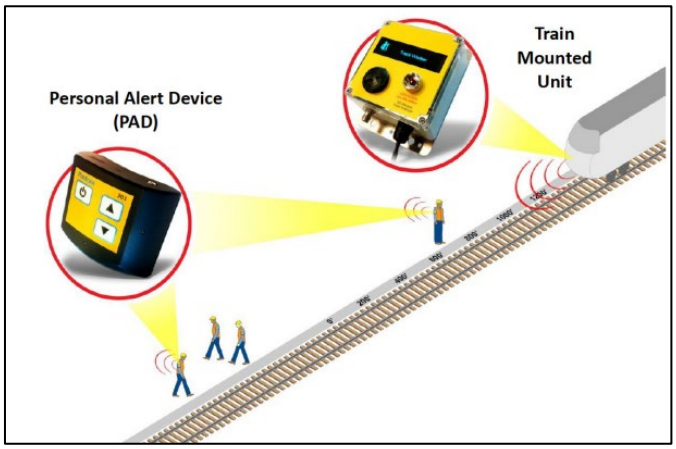

Figure 20. Illustration of the personal alert device and train-mounted unit that are part of the secondary warning system that was demonstrated. Source: FTA

Goal

The goals of the project included:

- Demonstrating the ability of the device to effectively warn track workers of approaching trains.
- Demonstrating the ability of the device to effectively warn train operators of the presence of track workers.
- Demonstrating the ability to warn both train operators and track workers in enough time to safely clear to a place of safety well in advance of train passage.
- Determining the effectiveness of the EICSS.

Methodology

Both track workers and train operators were trained in how to use the secondary warning system. Dispatchers and roadway workers were tasked with noting any unusual occurrences related to the secondary warning devices. Selected roadway workers were trained on the EICSS smartphone app, and control center employees were trained on the EICSS desktop browser software. To avoid disruption of safety measures already in use, the technologies being evaluated were used in addition to the transit agency's pre-existing safety program.

Research Findings

There were no reported injuries or near-miss events related to roadway worker protection during the demonstration period. System effectiveness was measured in terms of work zone intrusion rates and employee survey responses. In general, most roadway workers felt the personal alert device improved their safety. The technology system worked well in most SacRT rail environments except for downtown work zones. Initially, downtown central business district workers received an average of 74 work zone

intrusion alerts per day. This issue was attributed to the inability of the system to differentiate between train movements on adjacent tracks. The system was later modified to discontinue providing alerts in the downtown area.

Incorporation of Research

Lessons learned from each of the deployments inform FTA and the transit industry about the maturity and use cases for such technologies. In addition, product limitations identified during the demonstration led Protran to develop newer versions of the piloted technology, which are now available on the market.

Each technology has its shortcomings, and transit agencies need to evaluate them carefully to see if the technology suits their specific use case. SacRT decided to continue using the secondary warning system for its frontline workers who are performing maintenance activities in open track areas along an active right-of-way. The transit agency opted not to use the EICSS, as it was determined that the system did not provide enough benefit to roadway workers or the control center.

Relevant Links

FTA, Roadway Worker Protection Secondary Warning Device and Employee in Charge Software System, FTA Report No. 0184, February 2021.

4.5.3 Cybersecurity Assessment Tool for Transit

Project Description

Background

The COVID-19 pandemic forced agencies to change how they operated, bringing in new technologies to manage critical operations and to facilitate remote work, many of which exponentially increased the number of threat vectors. In parallel, cyberattacks and network intrusions continue to proliferate. Recent incidents demonstrate that even small and mid-sized transit agencies are vulnerable to system disruptions due to cyberattacks.

Research Sponsor: FTA

Research Conducted by: Rock Island County Metropolitan Mass Transit District (MetroLINK), with support from Max Cybersecurity and Grayline Group

Project Completed: February 2023

FTA Funding: $400K federal funding, total funding with local match: $525K

Goal

As part of its Public Transportation COVID-19 Research Demonstration Grant Program (described in the text box below), FTA awarded a grant to MetroLINK to develop a transit-specific cyber-resilience assessment tool. The goal of the tool is to help a transit organization's cyber team perform a self-assessment of its various systems, assets and networks, identify risks, and prioritize activities to mitigate them.

Prior to this project, no cybersecurity assessment tools had been developed specifically for the unique context and conditions faced by transit agencies.

Methodology

MetroLINK worked closely with the project team to demonstrate the assessment concepts, iterate, and refine the tool in cooperation with FTA. The Cybersecurity Assessment Tool for Transit (CATT) incorporates the guidance of the Cyber Resilience Review and the National Institute of Standards and Technology (NIST) cybersecurity framework, but it takes the additional steps of tailoring the assessment process to transit organizations that would benefit from more introductory materials and transit-aware guidance.

Research Findings

Research findings consist of an electronic assessment form (to be completed in a group setting at the agency) and ten resource guides that address different aspects of cybersecurity such as asset management and service continuity management. Each resource guide has additional CATT- and transit-relevant resources from the American Public Transportation Association (APTA), Center for Internet Security, NIST, and other beginner-friendly cyber resource guides.

Incorporation of Research

The self-assessment tool (CATT) is available for download from the FTA Cybersecurity webpage. The availability of the tool is being promoted in partnership with industry trade organizations such as APTA and AASHTO, as well as regulatory organizations such as the U.S. Department of Homeland Security and the Cybersecurity and Infrastructure Security Agency. FTA's CATT webpage had been visited about 1,000 times as of July 2023.

Relevant Links

CATT Self-Assessment Tool

CATT Self-Assessment Package

Public Transportation COVID-19 Research Demonstration Grant Program

Public Transportation COVID-19 Research Demonstration Grant Program

The COVID-19 public health emergency had a significant impact on transit operations. Transit agencies asked FTA to support research to identify solutions to address the operational challenges that they were facing because of COVID-19. In response, FTA announced a new FY 2020 Public Transportation COVID-19 Research Demonstration Grant Program.

In January 2021, FTA awarded $15.8 million to 37 projects in 35 states and one territory to develop, deploy, and demonstrate solutions to improve the operational efficiency of transit agencies and enhance rider mobility during the COVID–19 public health emergency. MetroLINK was one of the recipients.

4.5.4 National Transit Adaptation Strategy

Project Description

Background

Research Sponsor: FTA
Research Conducted by: San Francisco Metropolitan Transit Authority (SFMTA)
Project Completed: February 2023

The COVID-19 pandemic intensified challenges that the transit industry was already facing in terms of both ridership and financing. Public transit ridership nationally was already declining before the COVID-19 pandemic, due to a confluence of factors including the prominence and prevalence of ride-hailing companies, aging infrastructure, and historically low gas prices. The pandemic cut ridership and revenues to new lows. Working from home, health and safety concerns, and shifts in daily routines have all pulled riders away from public transportation, leaving public transit systems and agencies in a precarious position.

Public transit agencies must identify ways to restore both trust and ridership. To assist the industry, FTA provided funds to SFMTA and its partners to develop a National Transit Adaptation Strategy that provides a set of tools to support the public transportation industry's adaptation through and beyond the COVID-19 pandemic.

Goal

The primary objective for this project was the development of tools and data-supported initiatives that any U.S. transit agency can implement to rebuild confidence in public transportation and quickly increase ridership.

Methodology

The project partners used strategic foresight methods and interviews with experts and stakeholders to identify critical forces that are shaping the future. They interviewed subject-matter experts in transportation, land use, climate, infrastructure, and government. They also spoke with users and potential users of public transportation and conducted workshops with SFMTA and San Francisco government workers.

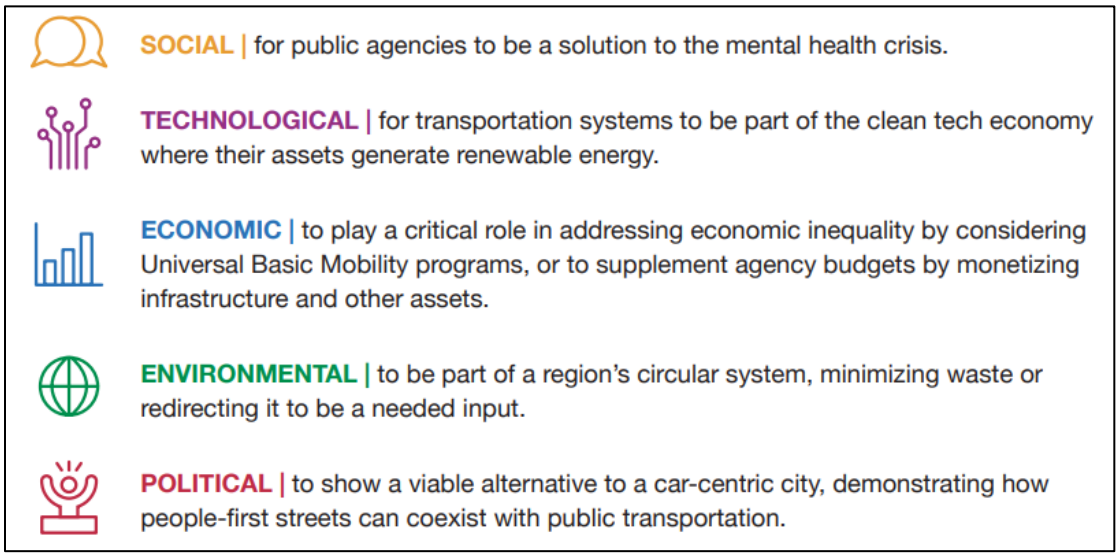

Figure 21. Future forces affecting the public transportation industry, as identified by the SFMTA team. Source: FTA

Research Findings

The National Transit Adaptation Strategy deliverables include:

- A Future Forces report investigating the major drivers and signals of change that are demanding strategic responses from public transit agencies,
- A scenario report that builds on the Future Forces report and presents a series of provocative scenarios for public transit agencies, and
- A final report that brings the Future Forces and scenario reports together along with tools and frameworks including:
    - Ridership profiles and personas that provide the industry with key market segments
    - Specific marketing campaigns and messaging, all of which can be replicated and targeted to a particular rider persona and the future scenario anticipated by a transit system
    - Ridership model for transit agencies to model potential ridership scenarios based on potential futures.

Incorporation of Research

From the project deliverables, governments will be able to gain a better understanding of the forces that will shape public transportation over the next decade, so that they can make future-focused decisions today to prepare for an uncertain future.

Relevant Links

National Transit Adaptation Strategy: Future Forces Shaping the Future of Public Transportation, prepared for FTA by the San Francisco Metropolitan Transit Authority and Institute for the Future, 2023.

4.5.5 Bus Exportable Power Systems

Project Description

Research Sponsor: Federal Transit Administration (FTA)

Research Conducted by: Inventev

Project Timeline: Completion expected in FY 2024

FTA Funding: $1M federal funds, total funding with local match: $1.14M

Background

During major power disruptions, critical infrastructure in local communities, including schools, healthcare facilities, government offices, and businesses, cannot maintain their required operations, which can directly impact the safety of the community's population. When electricity goes out at hospitals or nursing homes with vulnerable populations, death from heat exposure is a distinct possibility when air conditioning systems are no longer operable.

Communities potentially could use electric transit buses as mobile generators. FTA is funding research to develop and deploy additional power electronics equipment, referred as a bus exportable power supply (BEPS) system, that will transform electric, hybrid or fuel cell buses into mobile generators by exporting power using the buses' primary power supply within the hybrid propulsion system.

FTA's BEPS program enables public transportation agencies, communities, and states to access resilient and flexible power options by transforming hybrid, electric, and fuel cell buses into mobile power generators. To test the efficacy of the BEPS system prototype, a demonstration was performed in 2018. The BEPS was able to power up seamlessly and follow the facility loads, even with an unbalanced load on the three-phase connection with the test facility. Results from the demonstration proved that exportable power from a hybrid bus could be used to power a facility in a power outage event. This project builds on FTA's previous research.

Goal

The goal of the research is to develop national interoperable BEPS standards – working with FTA, industry stakeholders, and technical partners – so that different manufacturers' systems can use the same technology base and applications for BEPS solutions.

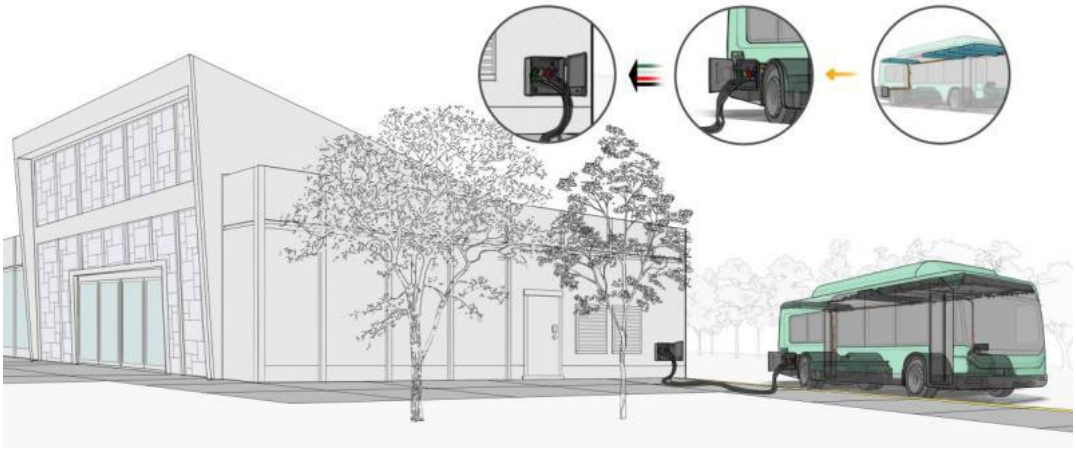

Figure 22. Integrated BEPS configuration. Source: FTA

Methodology

Inventev and its partners have now started the process of developing standards and specifications for BEPS technologies. The primary objectives of project are to:

- Complete an industry literature review assessing system parameters, specifications, past results, and recommendations.
- Demonstrate a "plug-and-play" BEPS system that includes minimum specifications and parameters for interoperability.
- Develop standards that allow interoperability for BEPS systems developed by different manufacturers.
- Produce a guide to implementing a BEPS system using these standards.

Incorporation of Research

BEPS will perform a critical role in emergency situations:

- Electric buses will have the ability to drive up to buildings such as schools, community centers, or medical facilities and within a very short time be able to provide backup power to maintain all important functions.
- The power source will let the buildings function as an emergency shelter or at least perform in a normal capacity.
- In addition to electric buses, hybrid or fuel-cell buses will also be able to provide this emergency power due to standards compatibility.

Relevant Links

FTA BEPS webpage

Hanlin, Jason, et al., Bus Exportable Power Supply System Use Strategy: Investigating the Use of Transit Buses as Emergency Generators, FTA Report No. 0146, November 2019.

FTA, Report Summary: Bus Exportable Power Supply System Use Strategy: Investigating the Use of Transit Buses as Emergency Generators. FTA Report No. 0146, November 2019.

4.6 ITS JPO

4.6.1 ITS Architecture Reference & Tools Evolution and Implementation Support

Project Description

Background

The ITS Architecture Program provides the systems architecture reference and software tools to allow for tailored yet interoperable ITS installations nationwide, covering over 150 services (analogous to "apps"); allowing for interoperable, cross-jurisdictional ITS and connectivity services for vehicles.

Research Sponsor: ITS JPO
Research Conducted by: Iteris
Project Duration: Ongoing
Funding: $3M annually

Goal

The Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) is a reference architecture that provides a common basis for planners and engineers with differing concerns to conceive, design, and implement systems using a common language. However, it does not mandate any specific implementation. The National ITS Architecture was developed over 25 years ago in order to:

- Provide a national "vision" for ITS
- Guide sound ITS planning and investments at the state and local level
- Identify and scope needs for ITS standards

The current version of ARC-IT begins to incorporate automated vehicle and automation-specific service packages, as well as updates to better reflect multimodal and accessible transportation. To meet the needs of multiple users, the architecture also incorporates connectivity and multiple views covering organizational, physical, and functional objects, and their interrelationships. It includes detailed identification of suitable standards—as well as standards gaps requiring further action—for connectivity services identified via an extensive, international cooperative effort. International cooperation by U.S. DOT has allowed access to broader expertise along with reduced cost to U.S. DOT, and has resulted in the incorporation of European, Japanese, Australian, and Canadian ITS and connected vehicle solutions. As the architecture evolves, the tools must also be updated.

Methodology

This project is based upon and follows the system engineering process in identifying user needs based on a large community of stakeholders, including infrastructure owner operators (IOOs), planning organizations, private sector service providers, auto manufacturers, standards organizations, federal partners, and users in both urban and rural settings. The basic approach is to gather and validate user needs, specify the requirements to meet those needs, and then design the architecture to best meet those requirements. The project team gathers feedback from users of the architecture and corresponding tools that assist with the regional customization and project development framework for implementation. Future efforts under this task will include expansion of the architecture reference and tools to add new services requested by users and identified via analysis of technological evolution, along with updates to improve security and increase the level of detail for key services. The task also includes direct support to state/local implementers, updating training materials in coordination with the ITS Professional Capacity Building Program, and specific standards-related support to address high-priority needs not covered elsewhere in the ITS Architecture and Standards program.

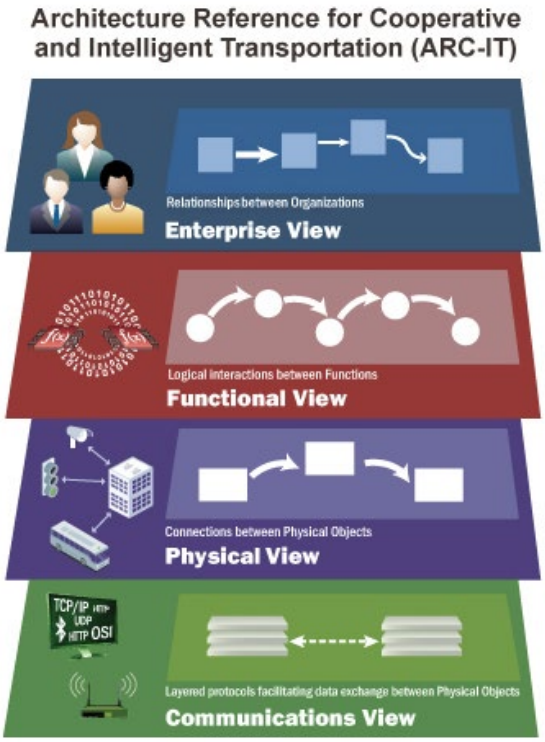

Figure 23. Schematic of ARC-IT. Source: ITS JPO

Research Findings

The research provided a complete, technologically up-to-date ITS system architecture reference, inclusive of connected and automated vehicle technologies, along with tools and implementation support to enable safe, secure, efficient, and effective nationwide ITS implementation that benefits all transportation system users.

Incorporation of Research

The desired outcome is a framework or reference model that supports beneficial, interoperable ITS and connected and automated vehicle (CAV) implementations. This task provides products and services essential to accelerating successful deployment and achieving that desired outcome.

Relevant Links

U.S. DOT webpage for ARC-IT, last updated June 19, 2023.

Architecture Use, (Systems Engineering Tool for Intelligent Transportation (SET-IT), Regional Architecture Development for Intelligent Transportation (RAD-IT)).

4.6.2 Vehicle-to-Everything Messaging/Communication Standards

Project Description

Background

Research Sponsor: ITS JPO
Research Conducted by: SAE and ITE
Project Duration: Ongoing
Funding: $2M annually

V2X technologies have the potential for significant transportation safety and mobility benefits, both on their own and as complementary technologies when combined with in-vehicle sensors supporting the integration of automated vehicles and other innovative applications. However, nationwide standards are needed to realize these benefits; such standards will ensure that all the different technologies involved in making V2X a reality will work well with each other. These V2X communications and messaging standards need to provide message sets that allow a variety of vehicle-to-vehicle (V2V) and V2I applications to work the same across different automotive OEMs and state and local infrastructure systems. These V2V applications include forward collision warning, intersection movement assist, electronic emergency brake light (EEBL), among others, and V2I applications include red light violation warning (RLVW), transit signal priority (TSP), probe data collection, and pedestrian crossing.

Goal

These V2X communications and messaging standards also need to be able to be updated with real-world deployment experience without breaking backward compatibility of V2X communications/messaging. ITS JPO has provided funding to SAE to develop these standards.

Methodology

SAE uses a systems engineering approach whenever developing V2X standards that are funded by the ITS standards program. SAE conducts their standards development activities within technical committees where subject matter experts from the automobile OEMs, their equipment suppliers and other industry professionals and consultants will develop a concept of operations that details user cases/operational scenarios and user needs. Those user needs are then broken down into more technical functional and performance requirements and then ultimately traced to specific communications protocols and message data elements in the system design. These SAE technical committees utilize existing documents or real-world deployment experience, such as the experience from the connected vehicle (CV) pilot projects, when developing these user needs, requirements, and designs. When the final full standard has been developed, the technical committee will then ballot the standard, which requires the majority of the voting members on that committee to approve of the standard. After the technical committee formally approves the standard, it goes to the Motor Vehicle Council (MVC) for approval and after it is approved will then be published.

Research Findings

The V2X communications and messaging standards developed under this project have supported many interoperable deployments across the United States and were directly referenced within the 2016

NHTSA notice of proposed rulemaking on V2X radios. Through SAE's standards development processes, these deployment experiences are incorporated into future updates to these standards, clarifying any guidance or data elements that may have been ambiguous and further improving interoperability between deployments. The foundational interoperability of these standards was demonstrated at Turner Fairbanks Highway Research Center (TFHRC) in June 2018. All three CV pilot projects brought their vendors and specific device configurations for an in-person event, demonstrating that V2X applications successfully worked between every combination of device and deployment configuration at the test event.

Incorporation of Research

Industry-approved V2X standards supported and were referenced by NHTSA's V2V rulemaking in 2016. The June 2018 CV pilot interoperability test demonstrated that these V2X messaging standards support interoperable communications and applications across multiple vendors and deployment locations and can be utilized by many real-world deployments to enable interoperable V2X applications.

Relevant Links

SAE J2735 - J2735_202309: V2X Communications Message Set Dictionary - SAE International

SAE J2945/1 - J2945/1_202004: On-Board System Requirements for V2V Safety Communications - SAE International

SAE J2945/2 - J2945/2_201810: Dedicated Short-Range Communications (DSRC) Performance Requirements for V2V Safety Awareness - SAE International

SAE J2945/3 - J2945/3_202201: Requirements for Road Weather Applications - SAE International

SAE J2945/4 - J2945/4_202305: Road Safety Applications - SAE International

SAE J2945/5 - J2945/5_202002: Service Specific Permissions and Security Guidelines for Connected Vehicle Applications - SAE International

SAE J2945/C - J2945/C_202206: Requirements for Probe Data Collection Applications - SAE International

4.6.3 Connected Intersections (CI) Implementation Guide

Project Description

Background

Research Sponsor: ITS JPO
Research Conducted by: ITE and SAE
Project Duration: 2019-2025
Funding: $1M annually

Interoperability is crucial in realizing the full benefits of deploying connected intersection (CI) technologies. However, early deployers identified several ambiguities and gaps associated with implementing interoperable connected signalized intersections. Additional guidance and standardization were necessary to deploy connected signalized intersections that interoperate reliably across the country. Many current standards dealing with connected signalized intersections did not provide enough guidance to effectively broadcast

messages, limiting the development of truly interoperable applications. This is especially important for the continued development of automated transportation systems, as they are expected to be important users of connected intersection technology.

Goal

The Department provided financial and technical support to the ITE effort to produce a Connected Intersection (CI) Implementation Guide, an important element of V2X communications. The CI Implementation Guide defines the key capabilities and interfaces that a connected signalized intersection must support to ensure nationwide interoperability with production vehicles for state and local IOOs. A connected signalized intersection is defined as an infrastructure system that broadcasts signal, phase, and timing (SPaT), mapping information, and position correction data to vehicles.

Methodology

Following a systems engineering process, the CI Implementation Guide v01.00 was developed by a team of subject matter experts and volunteers from various sectors of the transportation industry. This first version of the CI Implementation Guide focuses on harmonizing the implementations of existing SPaT, MAP, and Radio Technical Commission for Maritime Services messages, using the U.S. DOT-sponsored Cooperative Automated Transportation Clarifications for Consistent Implementations to ensure National Interoperable Connected Signalized Intersections as a starting point. The CI Implementation Guide has benefited from the active participation and leadership from the CI Committee, from IOOs, OEMs, and the mobility user community, with active support from the following standard development organizations who were crucial in the production of this implementation guide: American Association of State Highway and Transportation Officials (AASHTO), Institute of Electrical and Electronics Engineers 1609 Working Group, National Electrical Manufacturers Association (NEMA), and SAE.

Research Findings

The CI Implementation Guide addresses many of the ambiguities and gaps identified by early deployers, providing guidance to generate messages and develop interoperable applications for signalized intersections across the United States.

Incorporation of Research

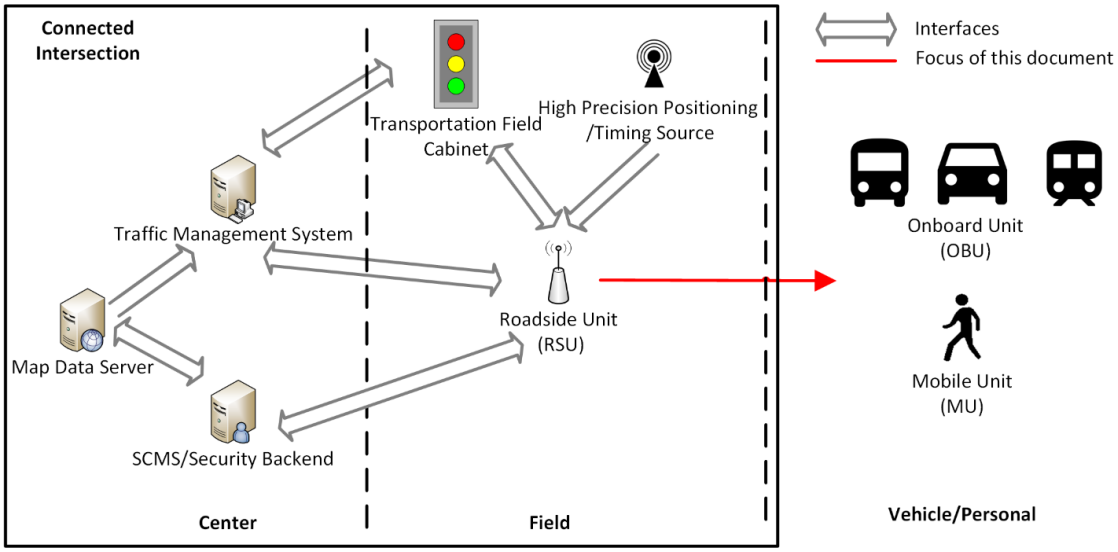

Figure 24. Technological infrastructure for connected intersections. Source: ITE

The CI Committee conducted a validation phase to validate and verify the products developed as part of the CI Implementation Guide. A solicitation for letters of interest to serve as a validation site was issued in January 2021, and 13 agencies and organizations representing 15 sites across the United States and Canada responded. All 13 agencies and organizations volunteered their staff, time and resources to participate in the validation phase, which consisted of capturing and analyzing SPaT and MAP messages broadcasted from each site for conformance to the CI Implementation Guide. These organizations were also asked to provide feedback on the usefulness of the CI Implementation Guide and identify gaps or ambiguities. Details on security implementations were also surveyed. Some of the analysis results and feedback resulted in changes to the published CI Implementation Guide, making it a more robust standard.

Some of the other accomplishments of the CI project include:

- The CI project was an important first step to establish an open dialogue between IOOs, OEMs, and the traffic signal controller industry to "provide an explanation on what data and connected vehicle messages are being broadcast from an interoperable connected intersection so safety applications can be developed for production vehicles, with an initial focus on the Red-Light Violation Warning (RLVW) application."
- The publication of the CI Implementation Guide, which defined requirements for the key capabilities and interfaces for interoperable connected signalized intersections that IOOs, production vehicles, and application developers can build to.

- SPaT and MAP messages broadcasted from validation sites were captured and analyzed by an impartial third party during the validation phase. The analysis of the messages led to many insights, some of which led to changes to the deployment, changes to the guidance in the CI Implementation Guide, and helped identify areas where future research may be needed.
- The validation phase also provided insights into what future testing may look like to ensure the proper performance of a connected intersection.

Relevant Links

ITE, Connected Intersections.

4.6.4 Multimodal and Accessible Transportation Standards Support

Project Description

Background

Research Sponsor: ITS JPO
Research Conducted by: Iteris
Project Duration: 2020- 2025
Funding: $500K annually

A strategic goal of U.S. DOT is to provide more efficient, affordable, and accessible transportation options for underserved communities that often face greater challenges in accessing essential services, with a specific focus on people with disabilities, older adults, low-income individuals, rural residents, veterans, and limited English proficiency travelers. Multimodal and Accessible Transportation Standards Support (MATSS) is necessary to ensure that the needs of these persons are properly considered in ITS JPO-sponsored standards development.

Goal

After standards are developed, the practitioner community must be encouraged to adopt and use the new standards. This requires providing training and guidance to ensure that practitioners understand and have the ability to apply new standards. There is a need to include multimodal and accessible transportation standards in the ITS Professional Capacity Building program standards training to educate a wide variety of stakeholders and system designers/integrators in interpreting and understanding the standards.

Methodology

The MATSS task order will transition the activities completed under the Multimodal and Accessible Transportation Standards Assessment (MATSA), which concluded in FY20, from assessment to implementation. A key deliverable of the MATSA work was a standards development roadmap. This MATSS task will validate the roadmap with key stakeholders, identify appropriate Standards Development Organizations to be tasked with development of individual standards for multimodal and accessible transportation, scope the standards development efforts, and provide a SME for the standards development. The development of several white papers on selected challenges for multimodal and

accessible transportation will support standards development, knowledge transfer to U.S. DOT grantees, and information sharing with other modal administrations within U.S. DOT. The MATSS contractor will participate in grantee cohort meetings as needed to provide updates, technical assistance, and expertise on multimodal and accessible transportation standards. Ultimately, this project will develop a Technology Transfer plan to support the dissemination of best practices for multimodal and accessible transportation technology implementations that are shaping standards development, as well as peer-to-peer and trainings to disseminate published standards to increase adoption.

Research Findings

This project supports the scoping and development of multimodal and accessible transportation standards identified in the MATSA roadmap. Near-term objectives include stakeholder validation of the standards development roadmap and scoping of standards development efforts. Work began in FY 2023.

Incorporation of Research

ITS standards will incorporate MAT features moving forward. Validation of the MATSA and support for PCB Training on MAT-relevant standards will be integrated.

Relevant Links

ITS JPO. Survey of Standards and Emerging Standards for Multimodal and Accessible Travel Standards Assessment. FHWA-JPO-19-774. October 28, 2019.

ITS JPO. Forward-Looking Assessment for Multimodal and Accessible Travel Standards Assessment – Task 2. FHWA-JPO-18-744. April 15, 2019.

ITS JPO. Multimodal and Accessible Travel Standards Assessment – Outreach Report. FHWA-JPO-21-844. August 1, 2020.

ITS JPO. Roadmap for Multimodal and Accessible Traveler Standardization Work. FHWA-JPO-21-845. February 16, 2021.

ITS JPO. "ITS4US: It's Transportation for All of Us," webpage for ITS4US deployment program.

4.7 MARAD

4.7.1 Guidelines for Testing Ship Biofouling In-Water Cleaning Systems

Project Description

Background

Research Sponsor: MARAD
Research Conducted by: University of Maryland Center for Environmental Studies
Project Completed: 2022
Funding: $750K

In-water cleaning (IWC) biofouling — used to either maintain or reset submerged ship surfaces to a hydrodynamically smooth state — is a common approach to increase ship performance and fuel efficiency between dry-dockings. IWC is also recognized as beneficial for reducing fuel consumption, greenhouse gas emissions, and limiting the transport of non-native species.

IWC systems typically involve the use of diver or remotely operated cleaning units (i.e., cleaning carts) that remove various forms of biofouling from hull and niche areas of ships. IWC is generally described as either proactive or reactive. Proactive IWC is the periodic removal or reduction of biofilm growth (i.e., microfouling or slime layer) on ship surfaces. Proactive IWC also removes newly settled or attached microscopic stages of macrofouling organisms to minimize macrofouling growth. Reactive IWC is used to remove already established macrofouling organisms (e.g., barnacles, bivalves, tubeworms, sponges, and macroalgae) and often includes capture, treatment, and disposal of cleaning debris.

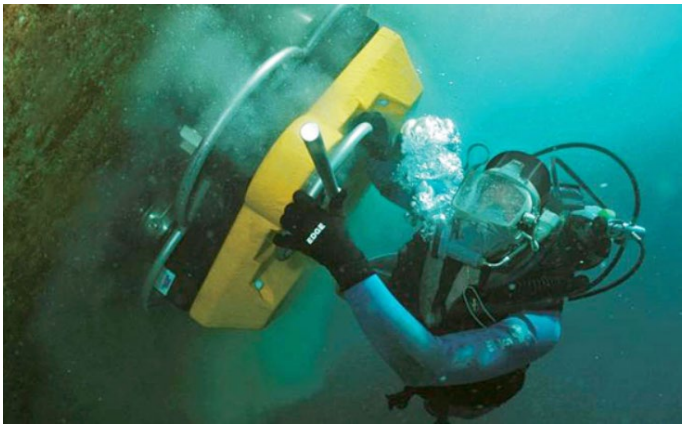

Figure 25. A diver cleaning the side of a ship. Source: Maritime Environmental Resource Center

Although IWC has the potential to provide significant ship operations and biosecurity benefits, there are two main IWC processes that may result in inadvertent environmental harm: (a) lack of, or incomplete, capture of dislodged debris by the cleaning unit; and (b) release of untreated, or incompletely treated, effluent from debris processing. Potential environmental impacts from these two IWC processes include:

- Increased discharge of coating biocides and microplastics to ambient waters;
- Release of live biofouling organisms, their propagules, or pathogens into local habitats; and
- Diminished coating condition (e.g., scuffs and chips) that reduces antifouling performance and longevity.

Given the potential for causing unintended environmental harm, testing of the efficacy and safety of both proactive and reactive IWC systems is needed. Such robust and standardized testing is critical for the

responsible use of IWC systems and the success of biofouling-related policy and regulations.

Goal

The goal of the project was to develop nationally and internationally accepted testing guidelines to provide standardized, science-based test procedures that produce the data (and level of confidence) needed by permitting or regulatory authorities when assessing applications for IWC systems. Testing guidelines would have to provide detailed and rigorous procedures for the independent performance testing of all forms of IWC systems (i.e., both proactive and reactive systems) for external ship surfaces. This includes the various components or options of multicomponent systems for fouling removal (e.g., cleaning unit for flat hull surfaces and smaller handheld tools for more complex niche areas) or effluent treatment (e.g., physical separation for captured solid material and treatment for dissolved biocides and/or live organisms).

Guidelines are being developed so that specific IWC systems could be tested in a standardized way that is appropriate to their design, operational requirements/limits, and their individual service providers' claims.

Methodology

International subject matter experts (from academia, agencies, and the private sector) were brought together to help establish draft comprehensive testing protocols. The initial IWC performance test protocols were then carried out for one reactive IWC system on one proactive IWC system to quantify their safety and efficacy and to validate and refine testing procedures.

A full IWC system should be tested on a minimum of three distinct ships. This level of replication was meant to provide fundamental information on system performance, environmental safety, and applicability across different conditions within the operational claims and parameters of the individual IWC system. A single test ship would not have been able to provide all relevant challenge conditions for predictive IWC system testing.

The test ships and conditions chosen captured as much relevant variability in the key parameters (ship, environmental, and IWC system parameters). While the overall IWC system test unit of replication is the number of test ships (i.e., $n \geq 3$), additional sample replication within individual test trials of biofouling removal/prevention, changes to water quality, debris capture/processing, and ship coatings impacts were identified.

All test trials should be conducted over at least a 90-minute cleaning event, with the IWC system operating in a normal, defined cleaning mode for the conditions presented. Sampling for the various performance measures took place in smaller designated subsections of the test ship's cleaned areas, or during a series of smaller time periods (minimum 90 minutes) of a full cleaning event. However, at least one test trial, on one test ship, involved a substantial cleaning area (e.g., at least 1/3 of the test ship) over a realistic timeframe (e.g., several hours), representative of the expected typical application of the IWC system being tested.

Research Findings

Several peer-reviewed publications have been produced from this work, and testing guidelines[24] were developed. During the course of the study, the relevant parameters and considerations were ascertained and verified. The IWC system testing guidelines provide a standardized method for verifying the claims of IWC technology manufacturers and produce the data (and level of confidence) needed to approve or permit IWC activities. Test results may then be used by port administrations, and other authorities, to determine whether a specific hull-cleaning technology is acceptable for use in a port.

Incorporation of Research

The guidelines will inform decisions made by the International Maritime Organization with regard to updates/revisions to the 2011 Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species. The Guidelines will also inform U.S. regulatory agencies with future rulemaking associated with discharges from vessels.

Relevant Links

ACT/ Maritime Environmental Resource Center (MERC) (2022b). Guidelines for Testing Ship Biofouling In-Water Cleaning Systems. Solomons, MD: ACT/MERC, TS-788-22, CBL/UMCES 2023-017.

International Maritime Organization (2011). Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species. International Maritime Organization: London.

Scianni, C., Georgiades, E., Mihaylova, R., and Tamburri, M.N., 2023. Balancing the Consequences of In-Water Cleaning of Biofouling to Improve Ship Efficiency and Reduce Biosecurity Risk. Front. Mar. Sci. 10:1197366.

Georgiades, E., Scianni, C., and Tamburri, M.N., 2023. Biofilms associated with ship submerged surfaces: implications for ship biofouling management and the environment. Front. Mar. Sci. 10:1197366. doi: 10.3389/fmars.2023.1197366.

Tamburri, M.N., Soon, Z.Y., Scianni, C., Øpstad, C.L., Oxtoby, N.S., Doran, S., and Drake, L.A., 2022. Understanding the potential release of microplastics from coatings used on commercial ships. Frontiers in Marine Science 9:1074654.

Tamburri, M.N., Georgiades, E.T., Scianni, C., First, M.R., Ruiz, G.M., and Junemann, C.E., 2021. Technical Considerations for Development of Policy and Approvals for In-Water Cleaning of Ship Biofouling. *Frontiers in Marine Science* 8:804766.

[24] ACT/MERC (2022b). Guidelines for testing ship biofouling in-water cleaning systems. Solomons, MD: ACT/MERC, TS-788-22, CBL/UMCES 2023-017.

Tamburri, M.N., Davidson, I.C., First, M.R., Scianni, C., Newcomer, K.A., Inglis, G.J., Georgiades, E.T., Barnes, J., and Ruiz, G.M., 2020. In-Water Cleaning and Capture System to Remove Ship Biofouling: An Initial Evaluation of Efficacy and Environmental Safety. *Frontiers in Marine Science* 7:437.

4.7.2 Energy Efficiency and Decarbonization Technical Guide

Project Description

Background

Research Sponsor: MARAD
Research Conducted by: Glosten Inc.
Project Completed: November 2022
Funding: $186K

Although maritime transportation is considered the most efficient way to move cargo, energy costs are still a massive part of the operating budget. Because of this, technical and operational measures that improve efficiency make great business sense while helping to buffer the effects of fluctuating energy prices. These kinds of measures are important when energy prices are high and will become crucial when carbon emissions from fossil fuels have a higher price.

MARAD sees energy efficiency as foundational to its other environmental efforts, particularly those that seek to prepare the industry to transition to low-carbon energy sources that may be substantially more costly. This project seeks to acknowledge the need, risk, and uncertainty associated with existing and emerging technologies and describe opportunities in terms that support informed business and policy decisions.

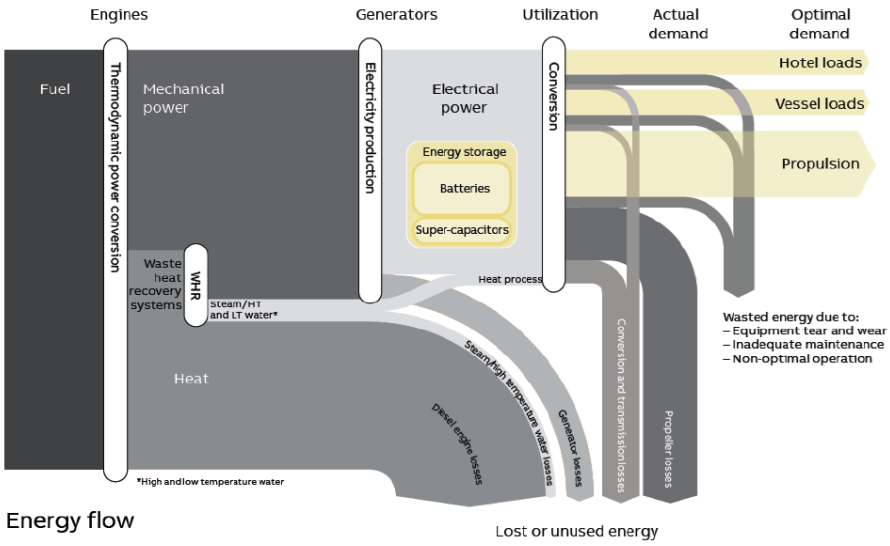

Figure 26. Energy breakdown for diesel-electric vessel. Source: ABB

This work expands on a 2016 investigation by Glosten Inc. that looked at opportunities to improve vessel energy efficiency through technical and operational measures. This project updated the 2016 study and went on to evaluate technologies and produce a technical guide aimed at supporting the maritime industry's energy transition.

Goal

This project was undertaken to produce a comprehensive report and guide describing emission reduction measures relevant to the U.S. maritime fleet. The guide focuses on the state of energy efficiency and fuel technologies. It further describes emerging technologies and operational measures that may contribute to improving efficiency and reducing greenhouse emissions in the long-term. The primary goal of the work is therefore to serve as a reference for U.S. and international owners/operators but is geared toward the vessel types that are characteristic of the U.S. flag merchant fleet. It is also relevant to developing policy that would support and balance the uptake of energy efficiency measures with other steps towards energy transition for the fleet.

Methodology

This report built on prior work, using additional research and outreach to update and expand the content to better support and inform the industry investment and MARAD policymaking. The final guide was developed according to the following steps:

- Reviewed the current state of energy efficiency technologies and determined which should be updated, added to, or removed from the previous report.
- Researched new content for incorporation into the Guide, including renewable fuels and related technology, the ability of vessel systems to adapt to new fuels, the availability of fuel, and the potential for onboard carbon capture.
- Performed outreach with key technology developers to obtain additional information on technology specifics, maturity, and any pilot projects.
- Developed reference lists for pilot projects and equipment developers.

Research Findings

This project produced a comprehensive and pragmatic compendium of the state of knowledge related to energy efficiency opportunities for the U.S. maritime fleet. Although it does not have the traditional "findings" of an academic study, as a practical work, it acknowledges the complexity and opportunity in the dynamic landscape of maritime energy efficiency technologies and decarbonization solutions. The guide provides both a snapshot of the current landscape and a view of which energy efficiency and decarbonization solutions could reach maturity and gain adoption in the near- and mid-term timelines.

Incorporation of Research

This guide serves as a starting point for owners/operators to consider the overall landscape of energy efficiency, fuel, and operational measures available, and how the emissions performance of their fleet, in singular or diverse trades, can be improved in the most effective manner.

For MARAD and the DOT, the guide is a comprehensive reference for measures that can be tracked, supported, and deployed either individually or as components of strategies and policies that support organization energy and emissions goals.

Relevant Links

Energy Efficiency and Decarbonization Technical Guide (November 2022). U.S. Department of

Transportation: Maritime Administration, Office of Environment and Innovation, Maritime Environmental & Technical Assistance (META) program.

4.8 NHTSA

4.8.1 Countermeasures That Work (10th Edition)

Project Description

Background

Research Sponsor: NHTSA

Research Conducted by: Battelle Memorial Institute

Project Duration: September 2015-September 2019; 9th Edition published in 2018; 10th Edition published in 2021

Funding: $551K

A significant part of highway safety program activities is devoted to behavioral countermeasures. NHTSA studies behaviors and attitudes in highway safety, focusing on road users such as drivers, passengers, pedestrians, and motorcyclists. NHTSA identifies and measures behaviors involved in crashes or associated with injuries, and then develops and refines countermeasures to deter unsafe behaviors and promote safe alternatives. NHTSA's extensive research on behavioral countermeasures is encapsulated in Countermeasures That Work (CMTW), a reference to assist State Highway Safety Offices (SHSOs) in selecting effective, science-based behavioral traffic safety countermeasures for major highway safety problem areas such as speeding and distracted driving.

CMTW describes major strategies and countermeasures relevant to SHSOs; summarizes their use, effectiveness, costs, and implementation time; and references important research summaries and individual studies. CMTW is not a guidance document, but rather it is a tool that provides an overview for readers to familiarize themselves with behavioral strategies and countermeasures in each topic area and provides resources for a deeper look at the topic.

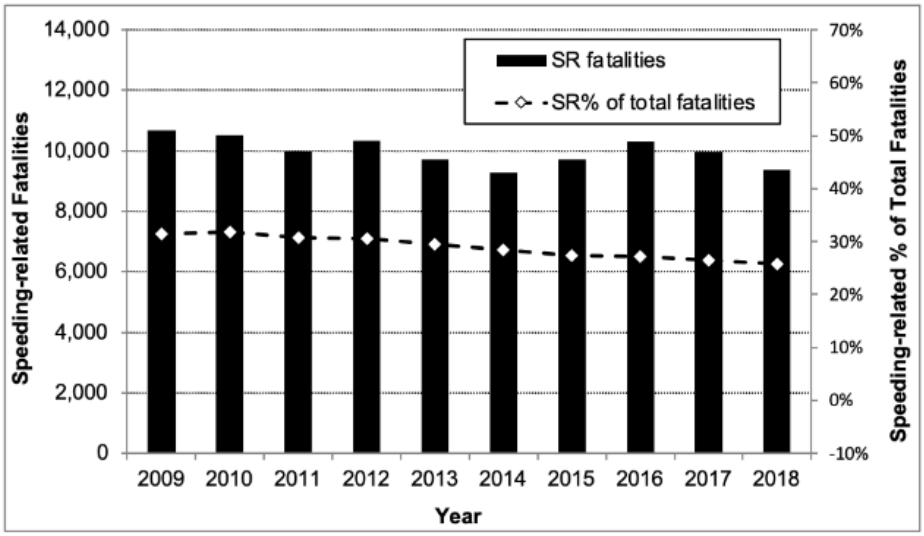

Figure 27. Speeding-related fatalities per year and speeding-related fatalities as a percentage of all fatalities. 2009-2018. Source: NHTSA

The evaluations summarized in this document allow SHSOs to benefit from the experience and knowledge gained by others and to select countermeasure strategies that have either been proven to be effective or that have shown promise. Within CMTW, effectiveness is rated using a one to five star-rating system with one- and two-star countermeasures having limited/no high-quality evidence or undetermined effectiveness and five-star countermeasures being effective in multiple high-quality evaluations with consistent results.

Goal

The research goal was to update CMTW with current research and trends and consider the inclusion of new countermeasures.

Methodology

The research team reviewed research studies and other information for each countermeasure and updated the CMTW as appropriate. Data were updated to include information from 2018 Fatality Analysis Reporting System.

Research Findings

The guide contains a topic chapter for each of ten problem areas. Each chapter begins with a brief overview of the problem area's size and characteristics, the main countermeasure strategies, a glossary of key terms, and a few general references. Next, a table lists specific countermeasures and summarizes their effectiveness, costs, use, and implementation time. Each countermeasure is then discussed in about a page. References are provided for each countermeasure. When possible, summaries of available research are cited with web links where available, so users can find most of the evaluation information in one place.

Incorporation of Research

One of the most widely distributed NHTSA publications, CMTW is used as a reference by many highway safety professionals, including NHTSA's Regional Offices and SHSOs. Most states use CMTW as a reference for details about effective countermeasures to include in their Section 402 Highway Safety Programs and Section 405 National Priority Safety Programs grant applications. When a State uses a countermeasure that is rated as three stars or higher in CMTW, it is not required to provide independent justification for purposes of NHTSA's formula grant program.

CMTW was traditionally offered as a static resource (hard copy or PDF file), but the tenth edition became available via an interactive website. The resource, now in its 11th edition, is available online. This allows readers to search important components such as keywords and star ratings, with the option to create a link to a personalized CMTW book that can be printed or shared.

NHTSA is developing a companion piece to CMTW called Countermeasures At Work. This project extension elaborates on some of the countermeasures contained in the guide by providing real-world

examples and details on localities where specific countermeasures were put into place. The countermeasure descriptions will include details about locality size, cost, stakeholders to involve, challenges, evaluation, and outcomes. Case studies and implementation considerations for each countermeasure will be provided.

Relevant Links

Kirley, B. B., Robison, K. L., Goodwin, A. H., Harmon, K. J. O'Brien, N. P., West, A., Harrell, S. S., Thomas, L., & Brookshire, K. (2023, November). Countermeasures that Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices, 11th edition, 2023, Report No. DOT HS 813 490. NHTSA.

Venkatraman, V., Richard, C. M., Magee, K., & Johnson, K. Countermeasures that Work: A Highway Safety Countermeasures Guide for State Highway Safety Offices, 10th edition, 2020, Report No. DOT HS 813 097. NHTSA.

4.8.2 Cybersecurity Best Practices for the Safety of Modern Vehicles

Project Description

Background

Research Sponsor: NHTSA
Research Conducted by: NHTSA
Project Duration: Approximately 3 years including public comment periods, review of public comments, and revisions to the updated version with Agency and departmental review.
Funding: n/a

Connectivity and modern vehicle technologies that intervene or provide sustained assistance to drivers (e.g., partial driving automation) also introduce new cybersecurity risks. Without proactive measures taken across the vehicle lifecycle, cybersecurity breaches could result in negative safety outcomes. Therefore, motor vehicle cybersecurity remains a top priority for NHTSA. NHTSA is engaged in research and industry outreach efforts to support enhanced reliability and resiliency of vehicle electronics, software, and related vehicle control systems. NHTSA's goals are to:

1. Mitigate safety risks associated with failure or potential cyber compromise of such systems, and
2. Ensure that affected parties take appropriate actions so that cybersecurity concerns do not pose safety risks or public acceptance barriers for proven safety technologies.

In October 2016, NHTSA issued its first guidance focusing on the cybersecurity of motor vehicles and motor vehicle equipment. Cybersecurity Best Practices for Modern Vehicles ("2016 Best Practices") was the culmination of years of extensive engagement with public and private stakeholders and NHTSA research on vehicle cybersecurity and methods of enhancing vehicle cybersecurity industry wide. The 2016 Best Practices leveraged existing automotive domain research, as well as non-automotive and IT-focused standards such as the NIST Cybersecurity Framework[25] and the Center for Internet Security's

[25] NHTSA, Cybersecurity Framework: Framework Documents, last updated September 28, 2023.

Critical Security Controls framework.[26]

Goal

The goal of the research effort was to support data-driven updates to the 2016 Best Practices with a focus on maintaining safety of vehicle operations that may be affected by cybersecurity hazards while taking into contemporary advances in reverse-engineering tools and knowledge-base.

Methodology

The Agency collected public comments after the publication of the 2016 Best Practices, continued research, and monitored progress in the automotive industry. NHTSA also reviewed voluntary standards and best practices developed by standards development organizations and members of the Automotive Information Sharing and Analysis Center (Auto-ISAC). The Auto-ISAC is an industry data sharing partnership committed to quickly identifying and responding to cybersecurity risks and threats in the nation's vehicle fleet, which NHTSA was instrumental in establishing

NHTSA published a draft update to its Best Practices in the Federal Register in January 2021. The Draft Best Practices touched on a wide array of issues associated with safety-related cybersecurity practices, and provided recommendations to industry on the following topics:

- General Cybersecurity Best Practices
- Education
- Aftermarket/User-Owned Devices
- Serviceability
- Technical Vehicle Cybersecurity Best Practices

A multidisciplinary team of NHTSA staff reviewed all public comments received in response to the publication of the Draft Best Practices. NHTSA made appropriate changes to the guidance, and a final document was published in September 2022, *Cybersecurity Best Practices for the Safety of Modern Vehicles*. A Federal Register notice accompanied the publication of the updated guidance; that notice details changes made to the Draft Best Practices and NHTSA's responses to the comments received.[27]

Research Findings

The updated Best Practices guidance incorporated changes in technology since 2016, as well as the development of industry standards. NHTSA believes the updated voluntary guidance document provides a solid foundation for developing a risk-based approach to the cybersecurity of safety-critical vehicle systems. The guidance also describes important processes that can be maintained and updated over time to serve the needs of the automotive industry.

Incorporation of Research

The 2022 Best Practices document is among a multitude of reference documents used by industry

[26] Center for Internet Security, Critical Security Controls.
[27] 87 FR 55459.

during design and development of vehicle electronics systems. Use of, and reference to, these Best Practices has been illustrated by the participation of industry in the development of the updated guidance. The updated guidance is expected to remain a highly utilized resource to secure safety-critical electronic systems in motor vehicles. The ultimate impact is the safety of the traveling public.

Relevant Links

NHTSA, Cybersecurity Best Practices for the Safety of Modern Vehicles, updated September 2022.

NHTSA, Cybersecurity Best Practices for the Safety of Modern Vehicles, Notice of Federal Guidelines, 87 FR 55459, September 9, 2022.

NHTSA, Cybersecurity Best Practices for the Safety of Modern Vehicles, Request for Comments, 86 FR 2481, January 12, 2021.

4.8.3 THOR-50M Crash Test Dummy

Project Description

Background

Research Sponsor: NHTSA
Research Conducted by: NHTSA
Project Duration: n/a
Funding: n/a

Crash test dummies, formally known as anthropomorphic test devices, are used to assess human injury potential in a crash. NHTSA's use of crash test dummies dates to the 1970s, when the first dummy was codified into the Federal Motor Vehicle Safety Standards (FMVSS) at 49 CFR Part 572. Since that time, NHTSA has regulated numerous other dummies that range in age, size, and sex, from children to small females to midsize males. Use of an expanded array of crash test dummies in NHTSA's crash tests has helped to reduce crash fatalities.

NHTSA has continually conducted research into advancements in crash safety, including the development of advanced dummies that better represent the interaction of vehicle occupants with modern restraint systems, such as force-limited three-point seat belts and air bags.

Goal

NHTSA sponsored multiple studies to test the performance of a new test dummy representing the 50th-percentile male: The Test Device for Human Occupant Restraint 50th-Percentile Adult Male Frontal Crash Test Dummy (THOR-50M). In comparison to the crash test dummy currently in use, the THOR-50M provides improved biofidelity (i.e., a measure of the dummy's ability to mimic a human-like response in a crash) in the thorax, shoulder, spine, knee-thigh-hip, lower leg, and abdomen, as well as improved kinematic response to a frontal crash. Additionally, the THOR-50M allows for multipoint deflection measurements in the thorax and abdomen, upper and lower tibia load cells, and acetabulum load cells, all of which allow for measurement of new injury criteria.

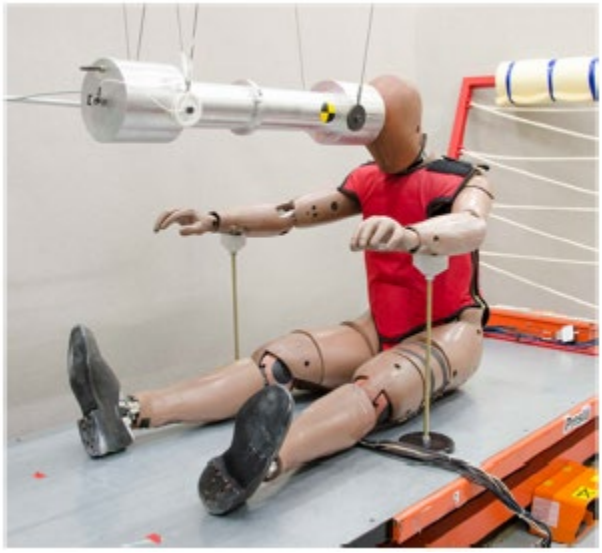

Figure 28. Head impact test setup. Source: NHTSA

Methodology

The THOR-50M Durability Report subjected the dummy to elevated energy qualification tests as described in the THOR-50M Qualification Procedures Manual. The THOR-50M Repeatability and Reproducibility of Qualification Tests evaluated the results of multiple qualification tests such as the one in the Durability Report.

Research Findings

The THOR-50M dummy was deemed suitable for use in compliance testing.

Incorporation of Research

NHTSA is pursuing two rulemakings to incorporate the THOR-50M test dummy into its regulations. One rulemaking will amend 49 CFR part 572 by adding design and performance specifications for the THOR-50M dummy. The second rulemaking will incorporate the THOR-50M dummy into FMVSS No. 208, which will allow manufacturers to use it instead of an older dummy design when doing belted and unbelted barrier crash testing.

Relevant Links

NHTSA NPRM: Anthropomorphic Test Devices; THOR-50M Incorporation by Reference, 88 FR 61896, September 7, 2023.

NHTSA pending rulemaking, FMVSS No. 208 THOR-50M Compliance Option, RIN: 2127-AM21, Spring 2023 Unified Regulatory Agenda.

Hagedorn, Alena, Martin, Peter, Millis, William, and Parent, Dan. THOR-50M Repeatability and Reproducibility of Qualification Tests, NHTSA Report No. DOT HS 813 258, October 2022.

Millis, William and Hagedorn, Alena V. and Murach, Michelle. THOR-50M Durability Report. NHTSA Report No. DOT HS 812 869, June 2020.

NHTSA, Interim Report to Congress — Crash Test Dummies, September 2022.

4.8.4 Pedestrian Automatic Emergency Braking

Project Description

Background

Research Sponsor: NHTSA
Research Conducted by: NHTSA Vehicle Research and Test Center
Project Duration: Various
Funding: Various

In 2021, 7,388 pedestrians were killed, and more than 60,000 pedestrians were injured in motor vehicle crashes. Those pedestrian deaths represented 17 percent of all motor vehicle fatalities.[28] This represents the continuation of the recent trend of increased pedestrian deaths on our nation's roadways. From 2012 to 2021, pedestrian fatalities increased by 53 percent.[29]

In the Bipartisan Infrastructure Law, Congress directed U.S. DOT to promulgate a rule requiring that all passenger motor vehicles for sale in the United States be equipped with a forward collision warning system and an automatic emergency braking (AEB) system.[30] An AEB system uses various sensor technologies and sub-systems that work together to detect when the vehicle is in an imminent crash situation, to automatically apply the vehicle brakes if the driver has not done so, or to apply more braking force to supplement the driver's braking.

A pedestrian automatic emergency braking (PAEB) system further provides automatic braking if the driver has not acted to avoid a crash with a pedestrian. Similar to AEB, PAEB systems typically use cameras to determine whether a pedestrian is in imminent danger of being struck by the vehicle, but some systems may use a combination of cameras, radar, lidar, and/or thermal imaging sensors.

In 2019, NHTSA published a draft test procedure that provides methods and specifications for collecting performance data on PAEB systems for light vehicles. Those test procedures were developed to assess the two most frequent crash scenarios involving pedestrians in the United States. They include the scenario in which the pedestrian crosses the road in front of the vehicle and the scenario in which the pedestrian walks along the road in the path of the vehicle.

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[28] NHTSA, Traffic Safety Facts 2021 Data: Pedestrians, DOT HS 813 458, June 2023.
[29] Ibid.
[30] Pub. L. 117-58, section 24208(a), codified at 49 USC § 30129.

Goal

In 2022, NHTSA performed test-track evaluations of PAEB systems. The main objective was to assess longitudinal crash avoidance capabilities for PAEB systems on 12 light vehicles in different lighting conditions.

Methodology

Tests were conducted following NHTSA's draft PAEB test procedure. Researchers used adult and child surrogate pedestrian mannequins that were developed specifically for testing vehicles equipped with PAEB technology. A low-profile robotic platform was used to support the mannequins in tests that required the mannequin to follow a path or be stationary during testing.

Research Findings

The testing showed that many model year 2020 vehicles were able to repeatedly avoid impacting the pedestrian mannequins at higher test speeds than those specified in the 2019 PAEB test procedure. In fact, several vehicles repeatably achieved full crash avoidance at speeds up to 37.3 miles per hour (60 kilometers per hour) or higher for the assessed test conditions.

Figure 29. Camera views filmed during tests (forward dashboard camera, dashboard, and external). Source: NHTSA

Incorporation of Research

In March 2022, NHTSA proposed expanding the New Car Assessment Program (NCAP) to include safety for people outside the vehicle – the first time this has been done. NCAP provides comparative information on the safety performance of new vehicles to assist consumers with vehicle purchasing decisions and to encourage safety improvements. In addition to star ratings for crash protection and rollover resistance, the NCAP program recommends particular advanced driver assistance systems technologies and identifies the vehicles in the marketplace that offer the systems that pass NCAP performance test criteria for those systems. At this time, NHTSA also proposed changes to its draft PAEB test procedures.

In June 2023, NHTSA published an NPRM to require AEB, including PAEB, systems on light vehicles. The Final rule was subsequently published in May 2024. This ruleadvances DOT's National Roadway Safety Strategy that identified requiring AEB, including PAEB technologies, on new passenger vehicles as a key departmental action to enable safer vehicles. This rule also responded to the mandate in the Bipartisan Infrastructure Law directing the Department to promulgate a rule to require that all passenger vehicles

be equipped with an AEB system.

Relevant Links

NHTSA Final Rule: Federal Motor Vehicle Safety Standards; Automatic Emergency Braking Systems for Light Vehicles, 89 FR 39686, May 9, 2024

NHTSA NPRM: Federal Motor Vehicle Safety Standards: Automatic Emergency Braking Systems for Light Vehicles, 88 FR 38632, June 13, 2023.

Request for Comments: New Car Assessment Program, 87 FR 13452, May 9, 2022.

NHTSA, 2022 Light Vehicle Pedestrian Automatic Emergency Braking Test Summary, March 2023.

4.9 PHMSA

4.9.1 Crack and Mechanical Damage Sensor for Unpiggable Natural Gas Transmission Pipelines

Project Description

Background

Research Sponsor: PHMSA

Research Conducted by: Northeast Gas Association with Pipetel Technologies

Project Timeline: 2013-2016

Funding: $840K

A pipeline inspection gauge, commonly referred to as a "pig," is a device used to clean and inspect pipelines. Unfortunately, not all pipelines are able to accommodate these devices, thus earning the label "unpiggable." In 2013, PHMSA awarded the Northeast Gas Association with a research project to develop a sensor for use during robotic inspections of unpiggable natural gas pipelines. The research supported the launch of a crack and mechanical damage deformation sensor, which allows the identification of cracks and any mechanical damage or ovality issues in a natural gas transmission pipeline that is unpiggable.

Unlike traditional caliper-based mechanical damage sensors found on other pigs, the crack and mechanical damage deformation sensor is very light, occupies very little space, and requires minimal power to operate —all of which are important attributes for effective operations in traditionally unpiggable systems. The crack and mechanical damage deformation sensor can identify mechanical damage or ovality issues at an accuracy level comparable to (or better than) traditional calipers.

Goal

The goal of this project was to complete the development of a sensor with the ability to detect mechanical damage and crack defects in complex, live pipeline environments and to carry out improvements on the design and sizing algorithms of the sensors under development.

Methodology

The project carried out field demonstrations of the combined mechanical sensor and crack sensor technologies in live natural gas pipelines using the Explorer 20/26 robotic system. (The Explorer line of robotic inspection tools resulted from an earlier collaboration of PHMSA and other development partners.)

Research Findings

The effort validated and improved the mechanical damage/ovality sensor and the crack sensor for the Explorer 20/26 robotic inspection system.

Incorporation of Research

The research supported the commercial launch of the laser deformation sensor on the Explorer line of robotic inspection tools. This commercialization has expanded inline inspection tool technologies and integrity management inspections using improved sensors within unpiggable pipelines.

Relevant Links

Final report: Development, Field Testing, and Commercialization of a Crack and Mechanical Damage Sensor for Unpiggable Natural Gas Transmission Pipelines, May 2016.

PHMSA project description: Development, Field Testing and Commercialization of a Crack and Mechanical Damage Sensor for Unpiggable Natural Gas Transmission Pipelines.

4.9.2 Improved Tools to Locate Buried Pipelines in a Congested Underground

Project Description

Background

Excavation damage continues to be a leading cause of pipeline incidents. Pipeline incidents caused by excavation damage can result in fatalities and injuries, as well as significant costs, property damages, environmental damages, and unintentional fire or explosions. A mapping technique was needed to identify the location of underground assets prior to construction activities or excavations.

Research Sponsor: PHMSA
Research Conducted by: Gas Technology Institute (GTI)
Project Timeline: 2018-2021
Funding: $502K

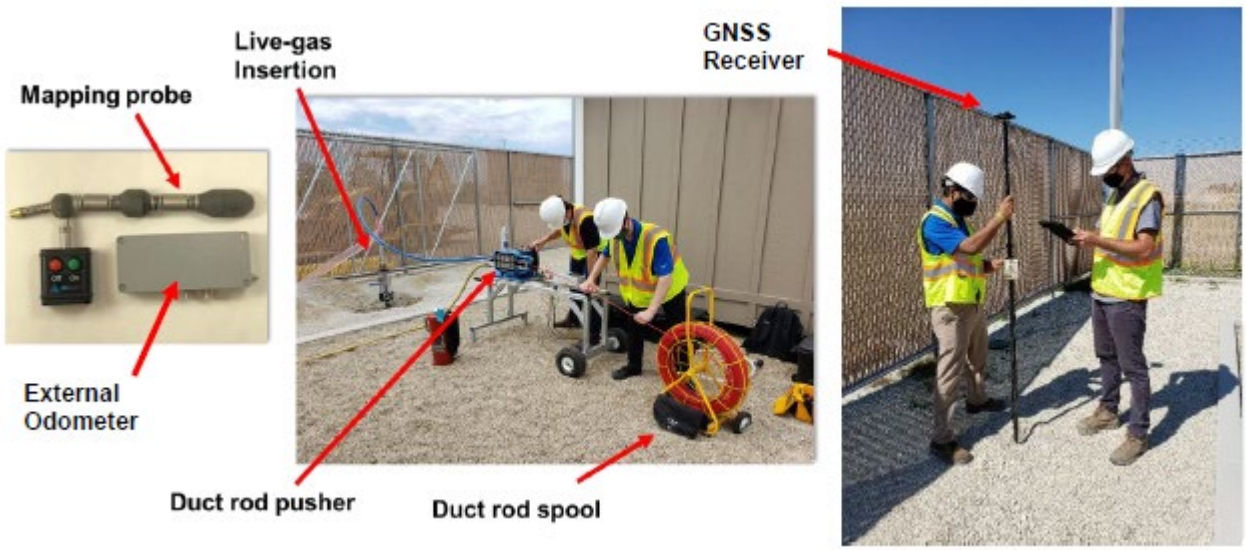

Figure 30. Example image of integrated mapping system operation. Source: GTI

Goal

The purpose of this project was to develop and commercialize a geospatial probe for mapping existing buried utilities through insertion into live gas pipelines without obstructing the flow of gas.

Methodology

Starting with preexisting mapping technology for non-pressurized pipelines, the project team designed a solution to map the location of live natural gas mains. A new access fitting was designed to allow the probe to enter live natural gas pipelines through a hot tap entry system. Once the initial prototype was created, researchers tested it with a mock setup at a GTI facility. When a fully functional field prototype was ready, the project team traveled to three different local utilities across the U.S. for field testing.

Research Findings

The project developed a geospatial probe to map existing buried utilities and validated it through live field demonstrations. The probe provided mapping of live underground pipes three-dimensionally and provided precise locations of utilities. A cloud-based data collection system was also created to collect, store, and view the mapping data—making it easily accessible to a utility's geographic information system.

Incorporation of Research

The resulting technology was commercialized as the Live Gas Mapper tool by REDUCT. The tool can map buried live gas pipelines within a 6-inch window of the centerline of the pipeline. From a single entry point, the technology can map up to 600 feet of live gas pipe. The probe provides location data from inside the pipe, meaning that it does not rely on acquiring location data from the surface to detail the coordinates of the pipe. The probe can enter two-inch and larger diameter pipes at an upright 90-degree angle, which enables two-way bi-directional travel.

Relevant Links

Final report: Improved Tools to Locate Buried Pipe in Congested Undergrounds, prepared for PHMSA by the Gas Technology Institute, December 15, 2020.

PHMSA project description: Improved Tools to Locate Buried Pipelines in a Congested Underground.

4.9.3 Full-Scale Tank Car Side-Impact Testing

Project Description

Background

Research Sponsor: PHMSA
Research Conducted by: FRA, U.S. DOT Volpe Center, and Transportation Technology Center, Inc.
Project Timeline: Began August 2020; ongoing
Funding: $1.75M on projects related to liquefied natural gas (LNG) by rail

The U.S. is today the world's largest natural gas producer thanks to production from shale and other unconventional formations. Transportation of natural gas, however, is constrained by the capacity of existing transportation infrastructure, which negatively affects regions with insufficient access to pipelines or ports. The limited access to pipeline infrastructure has generated interest in using rail transportation to help deliver natural gas to domestic and international markets.

For transportation by modes other than pipeline, natural gas can be cooled to a liquid state to produce a much denser liquefied natural gas (LNG). LNG has been transported in specialized cryogenic tanks by trucks on highways and by marine vessels for over 40 years in the United States, and over 50 years internationally. However, federal hazardous material regulations (HMR) do not authorize the bulk transport of LNG in rail tank cars. Instead, it is permitted only on an *ad hoc* basis as authorized by the conditions of a PHMSA special permit or in a portable tank secured to a rail car pursuant to the conditions of an FRA approval.

The expansion in U.S. natural gas production increased interest in a programmatic approach to using the nation's rail infrastructure to facilitate efficient transportation of LNG. In 2017, rail carriers petitioned PHMSA to authorize the transport LNG in bulk by rail tank car across the North American freight railroad network. In response, PHMSA and FRA established an interagency task force to conduct a multi-task initiative of research, data gathering, testing, modeling, and outreach.

Goal

PHMSA and FRA completed several tank car research projects that evaluated different aspects of the tank car and its components to determine puncture or non-puncture outcomes.

Methodology

Researchers conducted risk analysis research of hazardous materials moved on the tank cars by using finite element models and computer simulations to study derailments. FRA, in coordination with PHMSA, funded the development and continued refinement of finite element models for a variety of tank car specifications, as well as computer simulations of impacts and derailments. Component and full-scale test results were used to validate computer simulations and their assumptions and boundary conditions.

In November 2019, FRA conducted a full-scale impact test of a DOT-113C120W tank car at the Transportation Technology Center in Pueblo, CO. The test results were compared to simulation results, including the overall force-time or force-indentation histories, the puncture/non-puncture outcomes, the rigid body motions of the tank car, the internal pressures within the lading, and the energy absorbed

by the tank during the impact.

Research Findings

Results of tests and simulations demonstrated the potential improvement in crashworthiness from the outer tank enhancements set forth in the final rule.

Figure 31. Post-test tear in outer tank. Source: FRA

Incorporation of Research

PHMSA, in coordination with FRA, issued a final rule in July 2020 that amended the HMR to allow for the bulk transport of LNG by rail in DOT-113C120W specification rail tank cars with enhanced outer tank requirements, subject to all applicable requirements and certain additional operational controls. The final rule went into effect on August 24, 2020.

Relevant Links

Final rule: Hazardous Materials: Liquefied Natural Gas by Rail, 85 FR 44994, July 24, 2020.

FRA, Full-Scale Shell Impact Test of a DOT-113 Tank Car, Research Results 20-03, February 2020.

FRA, Side Impact Test and Analyses of a DOT-113 Surrogate Tank Car with Cryogenic Lading, DOT/FRA/ORD-22/33. September 2022.

4.9.4 Safety of Gas Transmission and Gathering Pipelines Rules

Project Description

Background

Research Sponsor: PHMSA
Research Conducted by: Multiple parties
Project Duration: Multiple projects spanning 2000-2017
Funding: $5.2M

PHMSA believes that the current regulatory requirements applicable to gas pipeline systems have increased the level of safety associated with the transportation of natural gas. Still, incidents continue to occur on gas pipeline systems, resulting in serious risks to life and property. For example, in 2010, a 30-inch-diameter natural gas transmission pipeline owned and operated by Pacific Gas and Electric (PG&E) ruptured in a residential neighborhood in San Bruno, CA. When the escaping gas ignited, the resulting fire killed 8 people, injured approximately 60 more, and destroyed or damaged more than 100 homes.

In its investigation of the incident, the National Transportation Safety Board determined that the

probable cause of the incident was PG&E's inadequate quality control and assurance when it relocated the line in 1956, as well as inadequacies in the utility's integrity management program. The National Transportation Safety Board determined that PG&E's integrity management program was deficient and ineffective because it:

- Was based on incomplete and inaccurate pipeline information,
- Did not consider how the pipeline's design and materials contributed to the risk of a pipeline failure, and
- Failed to consider the presence of previously identified welded seam cracks as part of its risk assessment.

Goal

PHMSA undertook a program of research projects to gain a better understanding of the causes of gas pipeline failures, such as mechanical damage (e.g., dents) or cracks in the welded seams connecting sections of pipeline. PHMSA also sponsored research to develop guidelines for the design of pressure tests so that pressure testing is carried out safely and effectively and that testing is performed to a consistent standard of quality.

Research Findings

This research increased understanding of gas pipeline failure mechanisms, safe operating parameters, and testing procedures required to safely operate pipelines.

Incorporation of Research

The knowledge gained from the research informed a set of three rulemakings designed to improve pipeline safety by reducing the frequency of failures of gas gathering and gas transmission pipelines. PHMSA published an Advance NPRM in 2011. Due in part to the breadth of the proposed changes, PHMSA subsequently decided to promulgate three separate rules, the first of which was finalized in October 2019. This first rule primarily concerned maximum operating pressure and integrity management for onshore gas transmission pipelines near populated areas designated as "high consequence areas."

The second rule, promulgated in November 2021, extended federal safety requirements to more than 355,000miles of onshore gas gathering pipelines with large diameters and high operating pressures. Gas gathering lines are pipelines used to transport natural gas from a current production facility to a transmission line or distribution main line. Generally, these pipelines are used to collect unprocessed gas from production facilities for transport to a gas treatment plant or other facility.

PHMSA expects the new requirements will reduce the frequency and consequences of failures and incidents from onshore natural gas pipelines through earlier detection of threats to pipeline integrity.

Relevant Links

Final rule, Pipeline Safety: Safety of Gas Transmission Pipelines: Maximum Allowable Operating Pressure Reconfirmation, Expansion of Assessment Requirements, and Other Related Amendments, 84 FR 52180, October 1, 2019.

Final rule, Pipeline Safety: Safety of Gas Gathering Pipelines: Extension of Reporting Requirements, Regulation of Large, High-Pressure Lines, and Other Related Amendments, 86 FR 63266, November 15, 2021.

PHMSA, Comprehensive Study to Understand Longitudinal Electric Resistance Welded Seam Failures, research performed by Battelle Memorial Institute, 2017.

PHMSA, Demonstration of External Corrosion Direct Assessment Applicability and Reliability for Demanding Situations, research performed by Gas Technology Institute, 2008.

PHMSA, Dent Fatigue Life Assessment - Development of Tools for Assessing the Severity and Life of Dent Features, research performed by BMT Fleet Technology Limited, 2011.

PHMSA, Development of Comprehensive Pressure Test Guidelines, research performed by Kiefner and Associates, 2017.

4.10 UTCs

4.10.1 Bridge Load Rating and Evaluation Using Digital Image Measurements

Project Description

Background

Research Sponsor: Center for Integrated Asset Management for Multimodal Transportation Infrastructure Systems (CIAMTIS) (UTC)

Research Conducted by: University of Delaware and George Mason University

Project Duration: 2019-2021

Funding: Federal $198K, match $198K

States must regularly inspect all public highway bridges in compliance with the national bridge inspection standards. Bridge load testing has historically involved mounting multiple discrete sensors to the structure and measuring the deformations as a load crosses the bridge. This type of testing typically involves bulky equipment, accessing hard-to-reach locations on the bridge, and time to set up and run the test.

Sensing technologies that employ vision-based techniques can save time by minimizing the need to physically access the structure, which is especially beneficial for bridges that traverse waterways. Sensing technologies also provide the ability to post-process data in real-time and re-analyze data from the video recording.

Goal

The objective of this study was to implement a procedure for load testing using non-contact, non-destructive sensing technologies to reliably determine the actual load-carrying capacity of a bridge.

Methodology

This research project utilized vision-based and three-dimensional point-cloud measurements to quantify deformations during full-scale, bridge load tests. Two sets of field experiments were performed on bridges in the state of Delaware. The recorded data were compared to data extracted from conventional (mounted) sensors to validate measurements, and in some cases, exceed the limitations of mounted sensors.

Figure 32. Loaded truck crossing a bridge during a load test. Source: CIAMATIS

Research Findings

The innovation of this research project allows end-users to monitor and evaluate a bridge without the

need for mounted sensors to capture deformations, saving time and resources when inspecting bridges.

Incorporation of Research

The broader impact of the sensing technologies used in this study could make load testing more routine to better understand the existing capacity of bridges to support inspection and maintenance strategies. Moreover, the anticipated results can aid decision makers on how best to invest infrastructure funds for repair and replacement, especially since almost 40 percent of the 614,387 bridges within the National Bridge Inventory are 50 years or older. With an increasingly more technological world, digital imaging has given end-users the ability to enhance data capture of multiple points of interest as well as a means for repeatable post-processing using vision-based measurement sensing technologies.

Relevant Links

CIAMTIS. Project Summary: Bridge Load Rating and Evaluation Using Digital Image Measurements. 2022.

Connely, Leslie. "Conducting Bridge Load Testing by Comparing Video Measurements." Civil Engineering Source, January 3, 2023.

4.10.2 Bridge Deck Overlays Using Ultra-High-Performance Concrete

Project Description

Research Sponsor: Transportation Consortium of South-Central States (Tran-SET) (UTC)

Research Conducted by: New Mexico State University (NMSU)

Project Duration: 2017–2018

Funding: $180K

Background

Bridge deck maintenance is expensive because of harsh exposure that shortens anticipated service life. The high cost of maintenance has led agencies to consider more durable materials for use as bridge deck overlays. This study focuses on assessing the possibility of using ultra-high-performance concrete (UHPC) produced with local materials to overlay existing concrete bridge decks. UHPC's exceptional mechanical and durability properties provide the potential to greatly improve the service life of existing bridge decks and their durability. The use of locally available materials also makes it more economical and sustainable compared to proprietary UHPC products.

Goal

The overall objective of this study was to evaluate the potential of using UHPC produced with local materials as an overlay material on existing concrete bridge decks.

Methodology

The research team tested the bond strength and thermal properties of the UHPC to evaluate its utility as an overlay material. They also subjected a UHPC overlay to full-scale structural testing with a pre-stressed channel girder.

Research Findings

The results indicated that the non-proprietary UHPC has the potential to serve as an overlay material as long as proper measures are used to prepare the substrate surface and ensure a high-quality bond with the existing deck. The incorporation of local materials can reduce the cost of materials by up to 70 percent compared to proprietary UHPC.

Incorporation of Research

Results from this project informed the use by New Mexico DOT of non-proprietary UHPC for a bridge deck overlay. The NMSU researchers actively collaborated with New Mexico DOT to generate practicable outputs for sustainable construction. In a follow-on technology transfer project funded by Tran-SET, the researchers provided necessary information during a pre-bid meeting to inform contractors, designers, and New Mexico DOT to successfully place an UHPC overlay. Multiple bids indicated the success and confidence provided through the training.

Figure 34. An acoustic emissions sensor attached to the overlay surface. Source: Tran-SET project final report

Relevant Links

Newtson, Craig, and Weldon, Brad. Deck Overlays using Ultra-High-Performance Concrete, Final Report. Tran-SET Project No. 17CNMS01, October 2018.

4.10.3 Testing, Monitoring, and Analysis of Fiber Reinforced Polymer Girder Bridge with Concrete Deck

Project Description

Background

Fiber-reinforced polymer (FRP) is a class of material that can be tailored and deployed in different ways to solve infrastructure problems. The FRP composites that are typically used in transportation infrastructure are composed of glass or carbon fibers embedded in a polymer resin such

Research Sponsor: Transportation Infrastructure Durability Center (TIDC) (UTC)

Research Conducted by: University of Maine (UMaine)

Project Duration: 2019-2021

Funding: $161K (U.S. DOT: $54K, UMaine: $109K)

as vinyl ester or epoxy.[31] FRP composite girders have the potential to replace conventional steel and concrete girders in highway bridge construction. Possible advantages of FRP composite girders are that they are lighter than concrete and steel girders, resist corrosion, require less maintenance, have longer lifespans, and are less carbon-intensive.

Goal

TIDC researchers worked with the Maine DOT, University of Maine licensed manufacturer AIT Composites, and a contractor to facilitate design and construction procedures for FRP composite girders.

Methodology

Due to the novelty of the composite-tub girder system and limited previous full-scale testing, more information on its in-service performance was desired. Although basic mechanics principals, design guidance for conventional materials, and design guidance for other FRP components allowed a reasonable, conservative design to be produced, the system's actual behavior and the accuracy of the assumptions made remained uncertain. Due to its hand in the development of the composite-tub girder system and experience in the spheres of research of FRP materials and bridge live-load behavior, UMaine was enlisted to help fill the knowledge gap between design and reality, and inform the design, manufacture, and construction of future bridges.

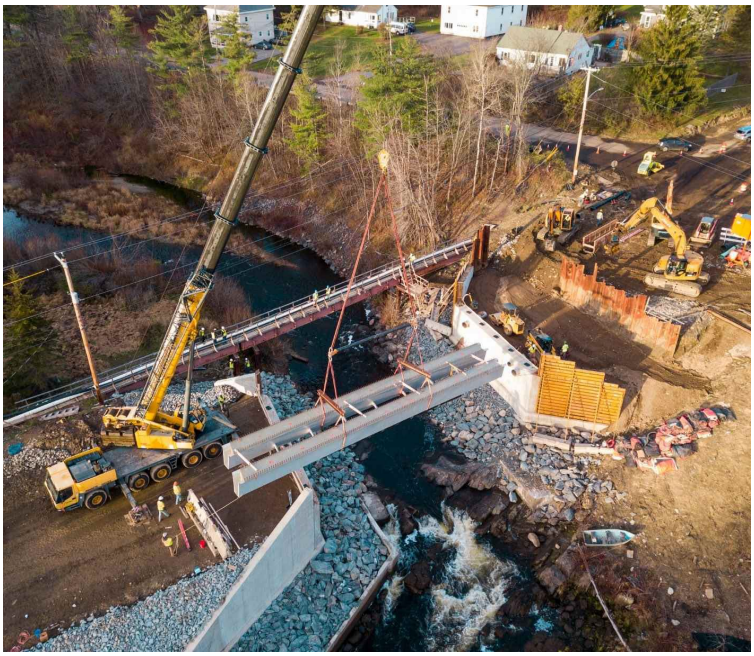

Figure 36. FRP girders being lowered into place at test site. Source: TIDC (project final report)

Four main tasks were given to UMaine to help improve understanding of the composite-tub girder system in general and the bridge in particular. First, UMaine facilitated the bridge's design using advanced numerical modeling of shear stress distribution, lateral-torsional buckling during construction, and effects of impact loading. This task was the subject of a previous project and will not be discussed here further. Once the final design of the bridge had been approved, the second task began. From first tests of composite-tub girder manufacturing procedures to pouring of the bridge's main deck, manufacture and construction of the bridge's superstructure was observed and documented. This served the purpose of informing subsequent tasks of the superstructure's structural history, and allowed the challenges encountered and

[31] Transportation Research Board, Advances in Fiber-Reinforced Polymer Composites In Transportation Infrastructure, National Cooperative Highway Research Program Project 20-68A, Scan 13-03, July 2015.

their proposed solutions to be documented to inform the design and construction of future structures.

Once substantial construction of the bridge had been completed and in parallel with readiness for bridge opening, the third UMaine task was conducted. Non-destructive live- load testing was conducted on the bridge in its near-virgin state under a high level of service loading. Four overloaded dump trucks were driven onto the bridge and positioned at several critical locations while the bridge's longitudinal strain response was simultaneously measured. The data collected during this testing was used to assess the bridge's actual stiffness and live-load distribution for comparison with original design assumptions, to update its capacity rating factor based on its actual response relative to theory, and as a benchmark for future behavior predictions, including those made as part of task 4. Task 4 itself involved creating high-fidelity, linear finite element models of the bridge, calibrating them based on the results of the non-destructive live- load testing, and using them to further understand the bridge and composite-tub girder system's service-level behavior. The results of these tasks were intended to be used to help avoid future challenges in design and construction, optimize design, inform future investigation, and increase knowledge of the structural behavior of this promising structural system.

Based on successful testing and supporting research conducted by UMaine on a new, hybrid FRP-concrete girder, a demonstration bridge using this technology in Hampden, Maine was planned for construction in 2020. This bridge has been designed in partnership with Advanced Infrastructure Technologies of Orono, Maine. This project provides a one-time opportunity to monitor and assess the performance of a novel in-service composite bridge. Data gathered from the testing, monitoring and advanced analyses proposed as part of this research will help drive acceptance of this novel FRP girder bridge system.

Research Findings

Field load testing and monitoring showed that girder performance was consistent with AASHTO requirements for traditional construction materials, and data gathered during field testing is also being used for comparison with future field assessment. The results of this research have contributed to the development of a draft FRP girder design guide suitable for use in future state and federally funded FRP girder bridge construction.

Incorporation of Research

This project laid the groundwork for additional TIDC research on the development of an FRP bridge girder design guide. Targeted for adoption by AASHTO, this design guide will accelerate the adoption of this transformational technology for highway bridge infrastructure across the US. To date, three additional FRP composite girder bridges have been installed in Maine, Rhode Island and Florida, all areas with corrosive environments that have been plagued for decades by high maintenance and frequent replacement of traditional steel and concrete bridge structures. Additional FRP girder bridges in Florida and Maine are currently in the design phase and scheduled for completion within the next few years.

Relevant Links

Schanck, Andrew, and Williams, David. Testing, Monitoring, and Analysis of FRP Girder Bridge with Concrete Deck: Final Project Report. Sponsored by TIDC. June 30, 2021.

4.10.4 Trajectory-Based Traffic Control with Low Penetration of Connected and Automated Vehicles/Real-time Distributed Optimization of Traffic Signal Timing

Project Description

Research Sponsor: UTC Program
Research Conducted by: University of Michigan
Project Completed: 2022
Funding: $150K

Background

This project aims at developing new science and technology of vehicle trajectory-based traffic control, especially under lower penetration of CAVs. Most of the existing models require at least a moderate penetration rate (e.g., 30 percent) to be effective. How to estimate real-time traffic condition and perform control under lower penetration rate (e.g., <10 percent) is still an open question. In addition, when the vehicle control is incorporated into signal control, usually a fully CAV environment is assumed. The interactions between CAVs and regular vehicles in a mixed-traffic condition are not thoroughly investigated.

Goal

This project aimed to propose new models for real-time traffic signal control under low penetration of CVs (i.e., ≤ 10 percent). It extends the previous study by combining both historical and real-time trajectory data to perform detector-free adaptive signal control. A probabilistic model is applied to estimate cycle-by-cycle vehicle arrival times and delays based on estimated average historical volume and a limited number of observed critical CV trajectories. Then a dynamic programming (DP) based adaptive signal control algorithm is applied to generate the optimal signal plan, using estimated vehicle delay as the objective function. The proposed model is tested in software-in-the-loop (SIL) simulation

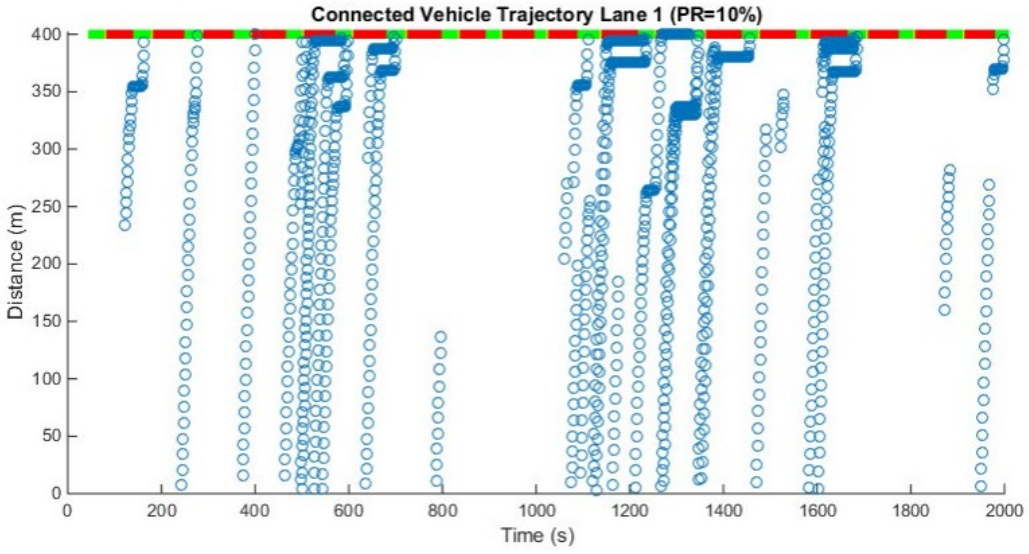

Figure 38. Illustration of CV trajectory under 10-percent penetration rate. Source: Univ. of Michigan

with various low penetration rates (10 percent, 5 percent, 2 percent, and 0 percent) and demand levels at a real-world intersection. Results are compared to well-tuned actuated signal control.

Methodology

Figure 37 shows the CV trajectories in one lane at a signalized intersection under 10 percent penetration rate with a demand level of 700 vehicles/hour/lane, which represents a typical scenario. The figure shows that some CVs passed the intersection without stopping while others stopped in the queue because of the red signal. Some of the vehicle trajectories are only partial because of lane changes. Note that during most of the cycles just one or two CVs were observed and during some cycles, there were no CVs.

Research Findings

This project (and others) led to the creation of the Optimizing Signal as a Service (OSaaS) which takes advantage of large-scale trajectory data from connected vehicles. Using this data, OSaaS is able to diagnose traffic signal performance, identify problems, and optimize signal timing.

Incorporation of Research

This OSaaS system has been deployed in Oakland County, MI, and has reduced average vehicle delay by 10 percent to 15 percent. The OSaaS system could immediately be deployed at any traffic signal in the U.S. to reduce congestion without the need for new instrumentation at infrastructure-based sensors.

Relevant Links

Feng, Y., & Liu, H.X. (2021). Trajectory Based Traffic Control with Low Penetration of Connected and Automated Vehicles. Final Report. UMTRI-2022-9. DOI: 10.7302/7021.

4.10.5 Contextual Guidance at Intersections for Protected Bicycle Lanes

Project Description

Background

Research Sponsor: National Institute for Transportation and Communities (UTC)

Research Conducted by: Portland State University and Toole Design Group

Project Duration: 2015–2019

Funding: $125K federal funding, $125K cash match

Safety and perceived comfort are the two key considerations for cities attempting to build connected low-stress networks, given the positive correlation between perceived comfort and ridership. Studies have consistently found that people prefer bike facilities that are separated from traffic, such as off-street paths and protected bike lanes, with physical separation such as a post or concrete curb. However, studies of bicyclists' sense of safety and comfort have generally focused on road segments, rather than the intersections of those roads.

Goal

Protected bike lanes are becoming increasingly common around the United States, yet there is little guidance for how to extend the protected lanes through one of their most dangerous links: the intersection. The objective was to come up with contextual guidance for the design of intersections that are safe and comfortable for cyclists.

Methodology

Using video microsimulations to estimate expected bicyclist and turning-vehicle interactions, researchers paired those results with in-person surveys to establish bicyclist comfort based on intersection design type and volumes.

Research Findings

The research results provide suggestions for designs that can improve the perception of safety and comfort for people biking. studies of bicyclists' sense of safety and comfort have generally focused on road segments, rather than the intersections of those roads. Using video microsimulations to estimate expected bicyclist and turning-vehicle interactions, researchers paired those results with in-person surveys to establish bicyclist comfort based on intersection design type and volumes.

Incorporation of Research

This study has been incorporated into design guidance for intersections by the National Association for City Transportation Officials (NACTO). This research is also featured in a May 2019 addendum to NACTO's Urban Bikeway Design Guide. These results can be incorporated into existing and future bicycle facility design guidelines developed by U.S. DOT.

Figure 39. Bicyclists crossing an intersection. Source: Adobe Stock

Relevant Links

Website. Biking Safely Through the Intersection: Guidance for Protected Bike Lanes. National Institute for Transportation and Communities.

Monsere, C., N. McNeil, Y. Wang, R. Sanders, R. Burchfield and W. Schultheiss. Contextual Guidance at Intersections for Protected Bicycle Lanes. Final Report. NITCRR-987. Portland, OR: Transportation Research and Education Center (TREC), November 2019.

Monsere, C., N. McNeil, Biking Safely Through the Intersection: Guidance for Protected Bike Lanes, National Institute for Transportation and Communities (NITC). Project Brief 987, December 2019.

National Institute for Transportation and Communities. Webinar: Contextual Guidance at Intersections for Protected Bicycle Lanes. Christopher Monsere and Nathan McNeil, Portland State University. October 8, 2019.

National Association of City Transportation Officials (NACTO). Don't Give Up at the Intersection. May 2019.

Interview with researcher Chris Monsere (YouTube, 4m 18s). Biking Safely Through the Intersection: Transportation Research at PSU. Transportation Research & Education Center at Portland State University.

4.10.6 Signal Timing Strategy for Displaced Left Turn Intersections

Project Description

Background

Research Sponsor: Center for Advanced Multimodal Mobility Solutions and Education (CAMMSE) (UTC)
Research Conducted by: Texas Southern University
Project Completed: September 2020
Funding: $81K

Conventional intersection design has met the challenges of increasing congestion and traffic delays. To solve this problem, transportation planners and engineers have proposed a variety of innovative intersection designs. Among these innovative intersection designs, the displaced left turn (DLT) intersection has been implemented in 12 states in the USA. Since DLT is relatively new and has been implemented in only a few states, there are few existing guidelines available for designing DLT intersections. One of the critical elements when designing a DLT intersection is the signal timing plan. An appropriate signal timing plan will maximize intersection capacity, reduce congestion, and improve safety. There are very limited existing studies on the signal timing design of DLT and the progression needs of vehicles have not been well considered in these studies.

Goal

The purpose of this research is to develop a comprehensive signal timing strategy for DLT intersections.

Methodology

To achieve this purpose, the research team first reviewed and summarized current guidelines and research findings on how to design and optimize signal timing for DLT intersections. Then, a new DLT signal time design methodology was proposed by considering various traffic conditions. The proposed DLT signal timing is evaluated by microscopic simulation. The results are compared with the signal timing provided by an existing signal timing optimization tool named Synchro, and the results show that the developed signal timing outperforms the one generated by Synchro regarding the average delay, travel time, and queue length.

The primary methodology of this research is to develop guidelines on the design of signal timing for DLT

intersections based on traffic flow progression. The specific objectives are to:

- Develop procedure and guideline for coordinating the major intersection signal with the minor intersection signals in DLT intersections,
- Develop a guideline for the signal timing for both major intersection and minor intersections in DLT intersections,
- Conduct a case study to evaluate the developed guideline and demonstrate its application.

Research Findings

This research identifies the importance of considering the DLT intersection as one system during signal design and timing. Existing studies developed the signal timing models based on inaccurate queuing delay assumption, which failed to provide enough considerations on re-acceleration and deceleration of vehicles when they meet multiple traffic lights. Besides, this research also provides an important reference for the geometric design of the DLT intersection. To ensure the ideal progression, the distance between the minor intersection and major intersection should be long enough so that travel-time based signal timing can accommodate for left-turn traffic demand. Future studies can be conducted on the DLT intersection with unbalanced traffic volumes. A field study in the real-world should also be conducted to evaluate the operational performance of developed signal timing.

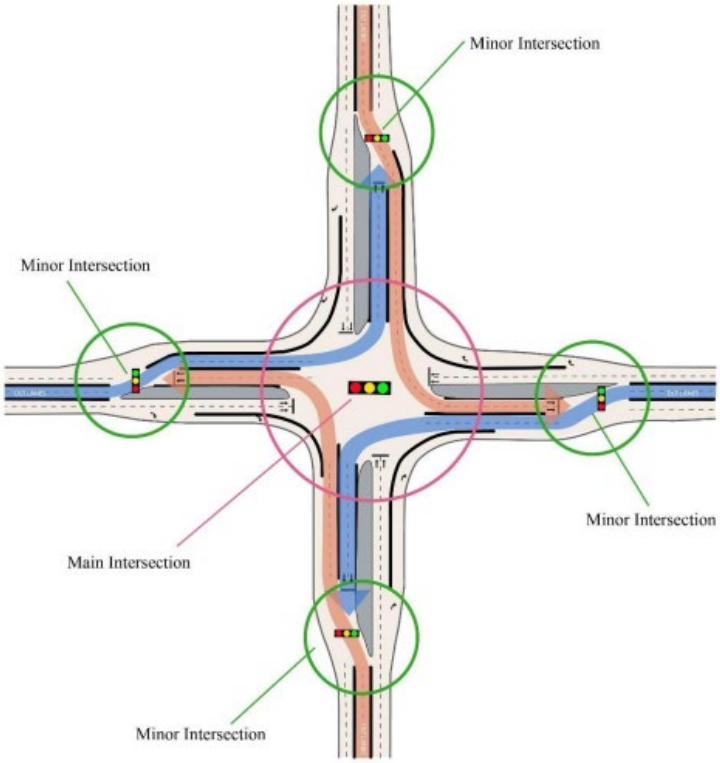

Figure 40. Typical full displaced left turn intersection design with four legs. Source: CAMMSE

Incorporation of Research

The results of this study could be incorporated into the U.S. DOT Highway Design Standards, and Traffic Signal Timing Manual to provide guidelines for the successful implementation of displaced left turn intersections.

Relevant Links

Qi, Yi, et al. Signal Timing Strategy for Displaced Left Turn Intersections, Final Report, Center for Advanced Multimodal Mobility Solutions and Education, August 2020.

4.10.7 Multiscale Model for Hurricane Evacuation and Fuel Shortage

Project Description

Background

Research Sponsor: Center for Advanced Transportation Mobility (UTC)
Research Conducted by: Embry Riddle Aeronautical University
Project Completed: 2020
Funding: $89K

Hurricanes are powerful agents of destruction with significant socioeconomic impacts. High-volume mass evacuations, disruptions to the supply chain, and fuel hoarding from non-evacuees have led to localized fuel shortages lasting several days during recent hurricanes. Those fuel shortages gave rise to various other issues such as an unpredictable increase in fuel prices that hinder evacuations from low-income areas, traffic congestion on the highways due to stranded vehicles, and difficulties with emergency and medical transportation.

News reports provide some information on the extent of fuel shortages during recent hurricanes, but the crowdsourcing platform Gasbuddy has quantitative data on the fuel shortages. The analysis of this fuel shortage data suggested fuel shortages exhibited characteristics of an epidemic. Fundamentally, as fueling stations are depleted, the latent demand spreads to neighboring stations and propagates throughout the community, similar to an epidemiological outbreak.

Goal

The research goal was to develop a susceptible-infected–recovered epidemic model to study the evolution of fuel shortage during a hurricane evacuation. Within this framework, an optimal control theory was applied to identify an effective intervention strategy.

Methodology

In this study, a predictive model formulation for the evolution of fuel shortages during hurricanes and an optimal control strategy to mitigate such shortages is developed. As fueling stations are depleted, their latent demand spreads to neighboring stations and throughout the community, similar to an epidemiological outbreak. This realization allows the application of well-established epidemiological research and models to be applied to fuel shortages and mitigation strategies. In addition, an epidemiological analogue for resource allocation based on vaccination models and optimal control theory is developed to address fuel shortages. The data analysis of the evacuation traffic and crowd sourced fuel shortage data suggests that there is a direct correlation between the two. The analysis suggests the evacuation from Hurricane Irma and related activities depleted over 60 percent of the fueling stations in Tampa, Miami/Fort Lauderdale, and Naples, while Jacksonville saw depletion rates as high as 56 percent.

Research Findings

The study found a linear correlation between traffic demand during the evacuation of Hurricane Irma and the resulting fuel shortage data from Gasbuddy. This correlation was used in conjunction with

survey data from the Statewide Regional Evacuation Study Program to estimate the evacuation traffic and fuel shortages for potential hurricanes affecting south Florida. The epidemiological dynamics and optimal control methodology were applied to analyze the fuel shortage predictions and to develop an effective refueling strategy.

Using epidemiological analogy, the fuel shortage epidemic is controlled when the basic reproduction number is less than 1. The predictive model suggests that there can be a fuel shortage in up to 90 percent of the refueling stations in Miami-Dade County, due to an evacuation from a Category 3 hurricane impacting Miami. The optimal control algorithm suggests the level and duration of intervention required to keep these fuel shortages from becoming an epidemic.

The model can also be used to predict the level of fuel shortage and the effect of intervention, by using limited data available during the early stages of a hurricane evacuation. Researchers demonstrated this approach using early data from Hurricane Irma for Naples-Fort Myers region.

Incorporation of Research

Lessons learned from this model and the codes developed through this project can be used to develop what-if scenarios to estimate fuel shortages during an ongoing hurricane or related large-scale evacuation. In addition, departments of transportation and other agencies can use the control algorithms for strategically allocating limited resources during such large-scale evacuations. Although the application focused on hurricanes impacting Florida, the model is generally applicable to similar resource shortages due to large-scale evacuations in any location.

Relevant Links

Sirish Nailae, Daha Liu, and Scott Parr. Multiscale Model for Hurricane Evacuation and Fuel Shortage, June 2020, Final Report.

Islam, S., Namilae, S., Prazenica, R., & Liu, D. (2020). Fuel Shortages During Hurricanes: Epidemiological Modeling and Optimal Control. *Plos one*, *15*(4), e0229957.

Islam, S., Parr, S., Prazenica, R., Liu, D., & Namilae, S. (2021). Predictive Modelling of Fuel Shortages During Hurricane Evacuation: An Epidemiological Approach. *IET Intelligent Transport Systems*, *15*(8), 1064-1075.

APPENDIX A: INFRASTRUCTURE INVESTMENT AND JOBS ACT (PUB. L. 117-58; NOV. 15, 2021; SEC. 25016

SEC. 25016. INCORPORATION OF DEPARTMENT OF TRANSPORTATION RESEARCH.

(a) IN GENERAL.—Chapter 65 of title 49, United States Code, is amended by adding at the end the following:

"§ 6504. Incorporation of Department of Transportation research

''(a) REVIEW.—Not later than December 31, 2021, and not less frequently than once every 5 years thereafter, in concurrence with the applicable strategic plan under section 6503, the Secretary of Transportation shall—

''(1) conduct a review of research conducted by the Department of Transportation; and

''(2) to the maximum extent practicable and appropriate, identify modifications to laws, regulations, guidance, and other policy documents to incorporate any innovations resulting from the research described in paragraph (1) that have the potential to improve the safety or efficiency of the United States transportation system.

''(b) REQUIREMENTS.—In conducting a review under subsection (a), the Secretary of Transportation shall—

''(1) identify any innovative practices, materials, or technologies that have demonstrable benefits to the transportation system;

''(2) determine whether the practices, materials, or technologies described in paragraph (1) require any statutory or regulatory modifications for adoption; and

''(3)(A) if modifications are determined to be required under paragraph (2), develop—

''(i) a proposal for those modifications; and

''(ii) a description of the manner in which any such regulatory modifications would be—

''(I) incorporated into the Unified Regulatory Agenda; or

''(II) adopted into existing regulations as soon as practicable; or

''(B) if modifications are determined not to be required under paragraph (2), develop a description of the means by which the practices, materials, or technologies described in paragraph

(1) will otherwise be incorporated into Department of Transportation or modal administration policy or guidance, including as part of the Technology Transfer Program of the

Office of the Assistant Secretary for Research and Technology.

''(c) REPORT.—On completion of each review under subsection (a), the Secretary of Transportation shall submit to the appropriate committees of Congress a report describing, with respect to the period covered by the report—

''(1) each new practice, material, or technology identified under subsection (b)(1); and

''(2) any statutory or regulatory modification for the adoption of such a practice, material,

or technology that—

''(A) is determined to be required under subsection (b)(2); or

''(B) was otherwise made during that period.''

(b) CLERICAL AMENDMENT.—The analysis for chapter 65 of title 49, United States Code, is amended by adding at the end the following:
''6504. Incorporation of Department of Transportation research.''.

APPENDIX B: SUMMARY OF PROJECTS REVIEWED FOR INCORPORATION OF RESEARCH FROM U.S. DOT RD&T PORTFOLIO, FY 2018-22

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
FAA	2020-2021	Benefits and Costs for Airport Noise and Operations Monitoring Systems	Provided airports with industry knowledge on the benefits and costs of noise and operations monitoring systems.	Airport Cooperative Research Program (ACRP) Research Report 237: Primer and Framework for Considering an Airport Noise and Operations Monitoring System
FAA	2020-2021	Best Practices for Implementing Effective Airport Biometrics	Provided a methodology to help airport leaders assess the value of biometrics for their facilities and a set of best practices to guide successful implementation of biometric solutions that increase overall security, unlock value/efficiencies, and enhance the airport experience.	ACRP Research Report 233: Airport Biometrics: A Primer
FAA	2019-2021	Blockchain Technology and Airports	Developed a primer to introduce airports to blockchain technology, describe potential use cases, and offer guidance to incorporating blockchain into airport operations.	ACRP Conference Proceedings on the Web 28: Introduction to Blockchain and Airport Operations in a COVID-19 Environment
FAA	2019-2021	Construction Safety and Phasing Plans	Developed a guide of best practices and a checklist to assist airport managers in creating construction safety and phasing plans suitable for airports of various sizes, activity levels, and geographic location.	ACRP WebResource 11: Construction Safety and Phasing Plans

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
FAA	2020-2021	Develop Runway Design Guidelines for Unmanned Aerial Vehicles	Developed guidelines for the design of runway infrastructure to meet the operational requirements of unmanned aerial vehicles of various sizes and configurations.	ACRP Research Report 238: Airfield Design for Large Unmanned Aircraft Systems
FAA	2020-2022	Effects of Cabin Seat Pitch and Alternative Seat Configurations on Evacuations	Determined the effect of changes to interior cabin configurations on egress, specifically seat pitch and width. Project informed response to section 577 of the FAA Reauthorization Act of 2018.	Egress rate and anthropological datasets were made publicly accessible for use by other researchers in evacuation and modeling endeavors.
FAA	2019-2021	Electric Aircraft – An Airport Planning Perspective	Described current and emerging technology requirements for electric aircraft at airports, which will be used to develop guidance for facility requirements.	ACRP Research Report 236: Preparing Your Airport for Electric Aircraft and Hydrogen Technologies
FAA	2021-2022	Extended Reality for Cabin Safety I: A Translational Study of Extended-Reality Technology in Training and Research	Assessed whether extended-reality equipment and software is mature enough for use in research, training, and aircraft certification activities.	Based on the findings from this study, FAA is researching other extended-reality software to (1) understand the efficacy of the technology when used in flight attendant training, (2) find a solution to reduce human subject injuries in aircraft evacuation studies, and (3) understand human cognitive processing and response to aircraft on-wing directional markings.
FAA	2019-2021	Integrated Domain Safety Risk Evaluation Tool	Developed a tool to ensure that proposed changes to the National Airspace System (NAS) do not increase risk associated with existing NAS systems by providing risk-based decision-making support for an air traffic safety oversight service in evaluating NAS	A comprehensive modeling methodology to identify the interactions between systems and air traffic procedures pertaining to separation minima in the NAS.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			system changes and changes to air traffic control procedures.	
FAA	2021-2022	Maintenance Safety Culture Survey	Developed and validated a scalable survey on maintenance safety culture that assisted operators and FAA in the identification of safety culture issues, gaps, and opportunities.	Human factors research data are being used to inform the improvement and effectiveness of risk-based decision-making and management of safety risks, particularly those that are human factors in nature.
FAA	2019-2020	Onboard Network Security and Integrity	Identified cyber vulnerabilities and risks in aircraft and provided recommendations for FAA safety risk assessment plans to be used in certification by aircraft and systems manufacturers.	A new methodology for cybersecurity safety risk assessment.
FAA	2019-2022	Human Factors Recommendations to Address the Flight Deck Impacts of Procedure-Based Concepts - Notional Airspace Geometries & Updates to Instrument Flight Procedures (Phase 1 of 3)	Research to anticipate, mitigate, and reduce potential pilot performance issues related to flying advanced human factors research that examined the impact of performance-based navigation procedures on flight deck operations, including pilot performance, flight deck procedures, and human-system interactions.	Human factors research data has informed FAA personnel who evaluate and approve pilot procedures and flight deck operations for performance-based navigation procedures.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
FAA	2021-2022	Risk-Based Decisionmaking in Aviation Maintenance Operations	Created human factors tools, job aids, checklists, and training data to help FAA operationalize risk-based decision-making in aviation maintenance operations.	The research informed recommendations to improve the effectiveness of processes and procedures in the aviation maintenance workplace.
FAA	2019-2021	Safety Oversight Management System	Developed safety data collection methods, advanced safety data and risk analysis techniques, and prototypes of risk-based decision-making capabilities to identify and analyze emerging safety issues in a cooperative nature with aviation stakeholders.	Concept of operations, model, and methodology for a system that provides an ability to analyze trends across the aviation community that is more effective than monitoring individual certificated entities.
FAA	2019-2020	Strategic Flightcrew Integration Needs in a Time-Based Control Environment, En Route Project (Phase 3 of 3)	Examined the human factors impact of trajectory adjustments issued to pilots via mixed communication modalities to complete an en route time-based flight .operation, including speed controls, time controls, and point-in-space operations.	Research data has informed evaluation criteria for the operational use of advanced communication, navigation, and surveillance capabilities for trajectory-based operations.
FAA	2019-2022	System-Level Crashworthiness Injury Criteria and Certification Methodology	Determined injury mechanisms and human impact tolerance levels specific to the aviation environment and the method to predict occupant injuries during a survivable crash. It developed techniques to use advanced occupant models to accurately simulate human response to impact and predict potential injuries for all impact vectors and occupant sizes.	List of occupant injury criteria and method to estimate fuselage and seat compliance.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
FAA	2020-2022	Understanding Coming Improvements and Transformations in Wireless Connectivity: Concepts for Smarter Airports	Provided aviation-specific information that better enables airport managers to make beneficial decisions and investments in the wireless services and capabilities that support their airport's operations and users.	ACRP Research Report 242: Transformation in Wireless Connectivity: Guide to Prepare Airports
FAA	2019-2021	Using Collaborative Decisionmaking to Enhance the Management of Adverse Conditions	Developed guidance for airports and their stakeholders for efficient use of airport collaborative decision-making as a tool for enhancing the management of irregular operations, emergencies, and crises.	ACRP Research Report 229: Airport Collaborative Decision Making to Manage Adverse Conditions
FHWA	2017-2019	2017 National Household Travel Data Analysis and Technical Assistance to Add-on Partners	Activities performed included post-2017 NHTS data analysis, trends extraction, non-response analysis, and broad technical assistance to add-on partners on data weighting and survey data applications.	Online data tools and downloadable codes for data analysis consistency. For the survey instrument, adoption of live geocoding during the survey significantly improved data quality.
FHWA	2018-2020	Advanced Geotechnical Modeling	Developed standard, open-graded structural backfill soil constitutive models for use in advanced geotechnical modeling.	Constitutive models and a journal publication.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
FHWA	2020-2022	Database of Major Projects Advanced via Alternative Contracting Mechanisms	Developed an open-source data platform on major project delivery to promote information exchange and performance tracking for various project delivery options.	In-depth database on major highway projects that can be used to assess project delivery options.
FHWA	2020-2021	Development of a Standardized Test Method for Durability of Ultra-High-Performance Concrete	Developed a standardized test method for the durability of ultra-high-performance concrete.	Test procedure is available to the community of practice.
FHWA	2014-2019	Enhanced Prediction of Vehicle Fuel Economy and Other Vehicle Operating Costs	Developed methods for predicting vehicle operating costs for a fleet of vehicles under different speeds, traffic conditions, roadway characteristics, and terrains.	Updated vehicle operating cost equations are used in the Highway Economic Requirement System (HERS) model, as well as for other purposes.
FHWA	2015-2018	Enhancing the National Highway Construction Cost Index and the Highway Revenue Forecasting Model	Developed a methodology to calculate and monitor the contribution of components to changes over time in the National Highway Construction Cost Index.	Improved methodology for calculating the National Highway Construction Cost Index.
FHWA	2020-2021	Evaluation Tool for Alternative	Developed a new tool for evaluating alternative contracting methods and offered workshops to State DOTs interested in testing it.	Processes and methods to consider alternative contracting methods for project delivery.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Contracting Methods		
FHWA	2020-2022	Freight Performance Management Analysis and Tools	Created a performance dashboard for freight mobility that uses travel time data from the National Performance Management Research Data Set to inform state freight planning and comply with statutory requirements to report using performance-based transportation metrics.	The dashboard is being used by states to write federally required freight plans. It also helps FHWA comply with statutory requirements related to freight transportation (e.g., freight highway bottleneck reporting).
FHWA	2020-2021	Mixture Performance Test Comparison "Rodeo"	Provided guidance regarding index-based performance tests; focus was on long-term aged materials.	Use of |E*|/sin delta as an aging index for possible balanced mix design implementation.
FHWA	2013-2019	Nation's Highways, Bridges, and Transit: Conditions and Performance Report to Congress	Performed trial test of online visualizations of key conditions and performance report data. This work also included development of software enhancements, maintenance, and analysis support for HERS and the National Bridge Investment Analysis System.	Information on future levels of infrastructure investment for pavement and bridge repairs based on current conditions; data are used to determine required investment levels for desired infrastructure improvements.
FHWA	2020-2021	Origin-Destination Forecast Data	Developed forecasts for each of the freight flows within the 2017 Freight Analysis Framework's origin-destination database for the years 2020 through 2050 (in five-year increments).	Freight commodity flow data for state and national freight planning. The Freight Analysis Framework has been a major data product for the transportation community since 1997.

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FHWA	2019-2020	Profiling Bridge Approach Transitions	Performed a statistical analysis of pavement profiler data collected at over 50 bridge approaches.	Datasets and research reports.
FHWA	2019-2021	Public-Private Partnership Intensive Training for Public Sponsors	Developed a series of training courses to provide information and tools to government officials who want to better understand how to evaluate proposals for public-private partnerships.	Processes and methods for evaluating project delivery via public-private partnership. Training offered via the National Highway Institute.
FHWA	2020-2021	Refinement and Delivery of a Standardized Test Method for Tensile Response of Strain-Hardening Fiber Reinforced Concretes	Refined and delivered a standardized test method for tensile response of strain-hardening fiber-reinforced concretes.	Publication of AASHTO Test Method: AASHTO T397.
FHWA	2016-2017	Shared Mobility and Transportation Equity	Produced a framework to categorize the equity barriers facing transportation system users. The 'STEPS to Transportation Equity' framework includes spatial, temporal, economic, physiological, and social barriers.	STEPS framework for assessing equity in access to transportation services.
FHWA	2020-2022	State and Metropolitan Planning Organization	Conducted assessments of state and MPO freight plans to document successful practices, areas of concern, and opportunities for training and technical assistance.	Processes and methods for state freight planning. These assessments are among FHWA's primary methods to understand freight transportation planning and program delivery activities.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		(MPO) Freight Assessment		
FHWA	2020-2021	Support Strut-and-Tie Concrete Design Concept Through Training Course Delivery	Created training course to support strut-and-tie concrete design concept.	Training course is available and being used by community to increase knowledge.
FHWA	2019-2020	The Transportation Future: Trends, Transportation, and Travel	Biennial report summarizing emerging demographic, socioeconomic, technological, geographic, and political or legislative trends affecting FHWA strategic priorities and goals, providing an overview of current and emerging trends impacting the transportation system.	Biennial Trends Report informs decision makers, practitioners, and the general public on future transportation needs, challenges, and opportunities.
FHWA	2016-2018	Transportation Scenario Planning for Connected and Automated Vehicles	Developed methods for the application of scenario planning and future scenario development to support planning, policy, and investments for AV/CV integration.	AV/CV scenarios and analysis tool to plan for future transportation investments and policy.
FHWA	2020-2022	U.S. Army Corps of Engineers Engineer Research and Development Center	Developed design aid charts and tables for selecting preliminary physical security protection measures for bridges.	Processes and methods for selecting preliminary physical security protection measures for bridges.

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		Interagency Agreement		
FMCSA	2017-2022	Accelerating SmartPark Deployment	Performed an assessment of ITS technology for truck parking, conducted a market analysis, and drafted a strategic plan for accelerated deployment of the technology.	A strategic plan to accelerate deployment of ITS for truck parking. Research results were also used to craft recommendations for the National Coalition for Truck Parking.
FMCSA	2018-2020	Advanced Fatigue Modeling for Individual Differences	This Phase III SBIR project continued work to develop the Trucking Fatigue Meter.	Fatigue models that incorporate individual differences to allow for improved driver scheduling and route planning.
FMCSA	2018-2021	Automated CMV Evaluation Program	This program addressed research questions related to truck platooning and the operation of automated CMVs. FMCSA took ownership of three Class 8 tractors from NHTSA and partnered with FHWA to research the potential benefits of cooperative automation through use of the Cooperative Automation Research Mobility Applications (CARMA) software.	Expanded industry and state knowledge base. Enhanced automated CMV and platooning systems. Updated state agency AV operating practices.
FMCSA	2020-2022	Automated CMV Evaluation Program: Volpe Testing and Evaluation Support	Tested and evaluated advanced driver assistance systems (ADAS), automated driving systems (ADS), and cooperative driving automation (CDA) for CMVs.	Evaluation reports inform future research.

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FMCSA	2020-2022	Brake-by-Wire (Electronically Controlled Brake) Systems	Conducted an in-depth literature search for data or modeling to determine the impact of brake-by-wire systems on safety (e.g., reduced crashes, injuries, and fatalities).	Final report detailing study findings.
FMCSA	2021-2022	Case Studies of Effective State CMV Crash-Reduction Strategies	Some states have implemented successful strategies to reduce CMV-related crashes in their jurisdiction. FMCSA will benefit in knowing strategies implemented across the states through both quantitative and qualitative analysis.	Case studies of strategies to reduce number of CMV crashes.
FMCSA	2017-2019	Civil Fines and Motor Carrier Safety	Used existing census data on carrier operation size, type, and commodity classification, and matched it with safety information and enforcement data to examine the most effective enforcement approaches for positive changes in safety.	Final report examining the most effective enforcement approaches for positive changes in safety.
FMCSA	2022-2023	Commercial Motor Vehicle Roadside Technology Corridor (CMVRTC) - Speed Camera Use	Assessed the deterrent effect of highly visible, CMV-only speed cameras in areas that experience regular high congestion. Assessed whether this technology should be used to directly populate FMCSA carrier risk profile data.	Understand how much highly visible speed cameras deter speeding and assess whether information gleaned from these cameras can and should be used to populate carrier risk profiles.
FMCSA	2022-2023	CMVRTC: System Validations and Duty Cycle Data Collections	Explored how often ADS-equipped CMVs will be engaged in automated operations. Identified and characterized key areas of failure for a commercial Class 8 tractor-trailer vehicle and quantified their severity, probability of occurrence, and how	A data set will be developed on when and where ADS is engaged, which will support future research to understand areas that may require further exploration/research. In addition, a failure mode and effects analysis

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			controllable the resulting situation is by an autonomous vehicle system.	will be conducted to identify areas on which the agency should focus.
FMCSA	2022-2023	CMVRTC: Electric Commercial Motor Vehicle Exploratory Research	Examined safety issues pertaining to electric CMVs to ensure their safe introduction to the national fleet.	A comprehensive list of potential safety issues will be developed to assess strategies for any necessary updates to the agency's recommendations for their safe use. Past work on electric CMVs resulted in a training course in safe inspection practices; the current effort will support similar outcomes.
FMCSA	2017-2022	Crime Prevention for Truckers	FMCSA currently does not provide materials or training to truckers, including minority and women truckers, on how to protect themselves from being stalked, harassed, assaulted, or robbed. Before any effective solutions can be developed and implemented, FMCSA needs an understanding of the prevalence, seriousness, and nature of the problem.	A final report on the prevalence and severity of harassment against minority and female truckers.
FMCSA	2018-2022	Crime Prevention for Truckers	Collected data on the prevalence of crimes involving threats and assaults against minority and female truckers. Surveyed a sample of the truck driver population, gathering data on how many female/minority drivers have been threatened or assaulted; the nature of the offenses; times and locations of the incidents; and characteristics of both perpetrators and victims.	Final report on the prevalence and severity of harassment against minority and female truckers. Findings will be used in future FMCSA outreach and education initiatives.

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FMCSA	2017-2018	Cybersecurity Study for Heavy Trucks (with NHTSA)	This project investigated cybersecurity aspects of medium-duty and heavy-duty trucks compared to passenger vehicles.	Final report, including findings from a market study, literature review, and recommendations for cybersecurity best practices.
FMCSA	2021-2026	Data Repository (Naturalistic Driving and Other Datasets)	FMCSA-sponsored research and technology studies often result in datasets that can be used for future analysis. In many instances, FMCSA requires research teams to provide a de-identified, public-use dataset upon completion of a study. To support future safety-driven data analysis, FMCSA is developing a data repository to house the data from these studies. This existing and expanding data library is considered to be very potent for future research.	A secure data repository to house research data collected by FMCSA. Data will be made available to researchers who follow established access and security procedures. In addition, the project developed procedures for external researchers to access the data.
FMCSA	2019-2021	Develop and Test New Inspection Tools for States to Support ADS-equipped CMV Pilot Testing	FMCSA collaborates with the Commercial Vehicle Safety Alliance in developing best practices for enforcement of CMVs at the federal and state levels. That collaboration now extends to an exploration and identification of processes, communication methods, and inspection technologies to facilitate electronic safety inspections of ADS-equipped CMV operations.	Processes, communication methods, and inspection technologies to facilitate electronic safety inspections of ADS-equipped CMV operations.
FMCSA	2020-2021	Effect of the Length of Medical Certification on Safety	This research investigated whether drivers who are medically certified for less than 2 years have an effect on safety performance.	Final report that describes the study findings on whether drivers who are medically certified for less than 2 years have an effect on safety performance.

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FMCSA	2017-2018	Effectiveness of Weigh Station Pre-Clearance/E-screening Systems	This project evaluated available weigh station pre-clearance/e-screening systems to determine their effectiveness related to roadside enforcement efforts, commercial vehicle safety, crash reduction, injuries avoided, and lives saved.	Final report.
FMCSA	2018-2021	Expert Support for Improving Motor Carrier Safety Measurement	An independent committee appointed by the president of the National Academies of Science assisted FMCSA in developing and testing an item response theory model to measure motor carrier safety. The standing committee reviewed FMCSA's progress in implementing its action plan and provided guidance and advice.	Formation of a committee of 10-12 experts to advise FMCSA on its improvements to the measurement of safety; committee meetings and summary notes/letter reports detailing recommendations.
FMCSA	2020-2021	FAST Act: Beyond Compliance and Safety and Enforcement Impacts	Section 5222 of the FAST Act requires FMCSA to allow recognition, including credit or an improved Safety Measurement System (SMS) percentile, for motor carriers that take certain proactive safety measures. The FAST Act also requires FMCSA to carry out the Beyond Compliance provisions by incorporating methodology into the Compliance, Safety, Accountability program or the BASIC categories of the SMS; developing a process for identifying elements of technology and safety programs as a basis for recognition; seeking input from stakeholders; considering a monitoring program; and disseminating information on the Beyond Compliance program.	Report on Section 5525 and Section 5222. Draft recommendation for a comprehensive Beyond Compliance program that allows carriers recognition for going above and beyond the minimum safety compliance.

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FMCSA	2017-2017	FMCSA Contribution to the Transportation Center for Climate Change and Environmental Forecasting	The center is the focal point of a departmental effort to contribute information and participate more forcefully in the nation's efforts to address the long-term challenge of global climate change.	The center supports research, conferences, speakers, and coordination activities.
FMCSA	2016-2017	Future Roadside Technology Requirements/ Integrated Inspection Management System Support project	The requests to the Agency were to review the present violations available in Aspen, modify the software to include smart logic to assist in the identification of the appropriate citations, and to provide integration of information from other systems, such as Query Central, the Commercial Driver's License Information System, the Motor Carrier Management Information System, the Inspection Selection System, Safety and Fitness Electronic Records, and Licensing and Insurance.	Identification, development, and delivery of flexible tools necessary to execute a motor carrier inspection. This includes, at a minimum: • Revised/improved enterprise data management of commercial motor vehicle and driver inspection data. • Streamlined processing of inspection data from selection criteria to data upload to risk analysis. • Software tools to facilitate better collection and management of the data. • Full training of the system deliverables to ensure proper understanding.
FMCSA	2016-2017	Multi-Modal Driver Distraction and Fatigue Detection and Warning System - Phase 2 (SBIR)	Fatigue and distraction are among the major risk factors associated with CMV crashes. The effects of fatigue on drivers include impaired performance, loss of attentiveness, slower reaction times, impaired judgment, and increased probability of falling asleep. This Phase 2 SBIR project developed a driver fatigue	A driver fatigue and distraction monitoring and warning system that provides reliable detection and warning of driver fatigue and distraction.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			and distraction monitoring and warning system for CMV drivers.	
FMCSA	2017-2020	NAS Standing Committee	The FAST Act requires FMCSA to allow recognition, including credit or an improved SMS percentile, for motor carriers that install advanced safety equipment; use enhanced driver fitness measures; adopt fleet safety management tools, technologies, and programs; and satisfy other standards determined appropriate by the Administrator.	Final report.
FMCSA	2017-2021	Naturalistic Data Driving Research	The Onboard Monitoring System Field Operational Test collected continuous naturalistic driving data for over 200 trucks and buses. This project analyzed the continuous naturalistic driving dataset to determine whether driving hour is related to increased crash risk and assess fatigue and distraction as it relates to crash risk.	Key findings documented in the final report provide needed insight into motorcoach and truck operations.
FMCSA	2018-2020	Pooled Research for Driver-Focused Studies	FMCSA currently contributes funding to the National Surface Transportation Safety Center for Excellence (NSTSCE) in support of driver-focused research. The NSTSCE is supported financially and guided by a group of stakeholders that includes FMCSA, General Motors, Travelers Insurance Company, the Virginia Department of Transportation (VDOT), the Virginia Center for Transportation Research, the National Safety Council and Virginia Tech Transportation Institute (VTTI).	3-4 research reports per year.

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FMCSA	2018-2021	Re-Assessment of Commercial Driver's License Holders' Traffic Violations, Convictions, and Suspensions	The primary objective of this project was to determine the rates at which drivers are convicted of disqualifying offenses after receiving a traffic violation and appropriately disqualified after conviction at the state driver's licensing agency, as well as determining rates of detection for disqualified drivers during roadside inspections in up to 9 states.	Better understanding of the disposition of violations.
FMCSA	2018-2021	Research and Testing to Accelerate the Adoption of Automatic Emergency Braking (AEB) Systems in CMVs	Research on effective deployment of AEB on commercial vehicles in all segments over 10,000 pounds to understand and overcome current technology and market barriers.	Final report and recommendations for accelerating the adoption of AEB systems. Strategic plan with specific steps that can be implemented to obtain voluntary commitments from OEMs to install AEB systems on 90 percent or more of all CMVs.
FMCSA	2017-2020	Sensor Performance Guidelines and Naturalistic Driving Data Analysis	This project involved outreach to vehicle automation companies for input regarding best practices for adequate safe performance of relevant sensors. Additionally, sensor manufacturers were contacted regarding sensor upkeep and optimum conditions. Researchers also reviewed current sensor technologies that support automation and current calibration processes.	Final report and best practices.
FMCSA	2017-2019	Study of Truck Side Guards to Reduce	Despite three decades of international experience, the operational, cost-benefit, and regulatory aspects of requiring truck side guards in the United States	Final report.

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		Pedestrian Fatalities	has not been studied. This research project addressed this gap.	
FMCSA	2019-2022	Testing of Anhydrous Ammonia Nurse Tanks	This research effort established the detailed crack map (location and penetration) for a small number of nurse tanks; applied hydrostatic testing to those tanks with the known crack map; used acoustic listening devices to triangulate any sounds from any part of the tank that resulted from the hydrostatically applied stresses; and then verified the phased-array ultrasonic angle-beam inspection whether any known cracks were exacerbated by application of the hydrostatic pressurization of the test nurse tank.	Detailed stress corrosion crack maps for sample population of nurse tanks; final report detailing study findings; data needed to support a PHMSA rulemaking to improve required periodic testing of nurse tanks.
FMCSA	2017-2020	The Role of Human Factors in Cargo Tank Rollovers	This research obtained opinions from a wide range of carrier experts (from carriers with excellent safety records) on best practices for preventing rollovers. This included discussion of topics such as a driver's behavior and health, carrier safety culture, dispatching practices, fatigue management, etc.	A report identifying best practices for addressing human factors in cargo tank rollovers and recommendations on how the Agency could proceed to develop an online training curriculum to promote these best practices for avoiding cargo tank rollovers.
FMCSA	2019-2021	Understanding Limitations for Drivers of ADS-Equipped CMVs	As FMCSA begins to consider the use of automation by commercial drivers, it will be critical to understand the parameters under which these systems can be used safely in light of human factors limitations.	Final report detailing study findings.
FMCSA	2020-2021	Using Systems Modeling to Identify Impacts to FMCSRs from	The project focuses on key causal relationships affecting technology providers, the motor carrier industry, and consumers of motor carrier services (e.g., shippers), in the context of automation and competition in the freight industry. The project	The end deliverables are a report on potential industry changes, and next steps for how FMCSA can prepare, especially for requests for regulatory exemptions and changes.

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		Emerging ADS business Cases	provides a framework to identify the potential changes to humans' roles under different Level 4 and Level 5 automation scenarios and how current regulation may or may not apply.	
FMCSA	2021-2022	Using Systems Modeling to Identify Impacts to the Federal Motor Carrier Safety Regulations from Emerging ADS Business Cases	Automation offers an opportunity to improve the safety and efficiency of the motor carrier industry. FMCSA needs to understand the opportunities and risks that automation may provide so that it can conduct appropriate research to support future policy decisions.	1. Technical memo on freight industry competitive pressures looking forward. 2. A customized diagram of motor carrier industry roles, with agreed scope for next steps. 3. Initial causal model and recommendations. 4. Short memo laying out at least one option for refining or expanding the model.
FMCSA	2021-2023	Using Systems Modeling to Identify Impacts to the Federal Motor Carrier Safety Regulations from Emerging ADS Business Cases	This study assessed how artificial intelligence-machine learning (AI-ML) tools can analyze CMV near-misses and crashes using camera data (from traffic operations and onboard safety monitoring systems) and recommend changes in driver training, road design, and other countermeasures.	Final report with recommendations on the utility of AI-ML tools in analyzing CMV near-misses and crashes.
FRA	2011-ongoing	Accessibility	Identify innovative solutions for improved communications on-board passenger trains for passengers with disabilities. Research will develop recommendations for improved accessibility on-board passenger trains, based on modern wheelchair designs.	• Improved safety and accessibility of passenger trains. • Recommendations for enhanced on-board maneuverability and access for passengers using wheeled mobility devices.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
				• Recommendations for improved communication on passenger trains for passengers with disabilities.
FRA	2015-ongoing	Accident Consequence Reduction	This research studied loading and unloading practices of hazardous material to improve the operating practices and securement of the package for safe transportation and reducing non-accident releases.	• Minimize the consequences and damages caused by train derailment involving hazardous materials. • Investigate accidents and service equipment failures and improve survivability and performance. • Evaluate the performance of different tank car types.
FRA	2015-ongoing	Automation, Operating Personnel Information Management and Control	The objective is to conduct user and human reliability research with automation to help ensure safe and productive integration of automation technologies as industry develops them.	• Resolve problems related to design and implementation of human interface with technology to reduce human error. • Resolve problems associated with the role of the operator in relation to access to information about vehicle performance, status of track operations, automation, and other operational information.
FRA	2015-2018	Bridges and Structures	This research area focused on improving safety and the state of good repair of bridges, structures, track design, and special track work. The scope of this research included collaborative projects with industry, including AAR.	• Eliminated the need for a fixed reference when estimating the displacement of bridge components under train loads. • Eliminated the need for fixed instruments to measure bridge performance. • Increased the inspection frequency of railroad bridges. • Developed a useful tool for FRA bridge inspectors.

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FRA	2017-ongoing	Cab Displays, Controls, & Environment	This project entailed improving cab/locomotive visibility at night, providing extra alerting for track workers and attempting trespassers, providing extra visibility/alerting when approaching grade crossings, unifying an optimized cab display across all railroad providers, increasing freight and passenger rail safety, and reducing operating and maintenance costs for locomotives.	• Ensure all LED lights can be used safely and effectively in freight and passenger trains. • Reduce operating and maintenance costs and increase railroad safety.
FRA	2012-ongoing	Emergency Preparedness Research	Federal passenger equipment safety standards require that emergency egress and rescue access systems "shall be designed to permit rapid and easy removal from each side of the door during an emergency situation." However, the federal regulations do not have a quantitative definition of what "rapid and easy" is. The goal of this research effort is to provide a scientifically defensible value for "rapid and easy" based on data from first responders and railroad employees during training exercises.	Understanding the dynamics of passenger interaction as evacuation ensues on a passenger train will provide the FRA with quantitative data to make decisions for improving the current standards.
FRA	2016-ongoing	Energy and Emissions Safety Research	In support of DOT strategic goals of safety and innovation and its research target of environmental stewardship, FRA undertakes research that investigates efficacy of alternative fuels to improve energy efficiency and reduce emissions of rail transportation. This research area focuses on supporting activities related to real-world demonstration of alternative fuels, technologies and improvements in standards for noise emissions to ensure implementation of rail across the nation.	• Reconcile inconsistencies between the current U.S. Environmental Protection Agency noise emissions limits and equipment performance. • Provide information to drive standards and requirements writing and enforcement in support of revisions to noise emissions limits for trains. • Develop public tools that can be used industry-wide for decision-making that will ensure the development of innovative

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
				strategies for locomotive and passenger rail equipment.
FRA	2012-ongoing	Facilities and Equipment - Transportation Technology Center (TTC)	The primary objectives of this funding are to maintain the one-of-a-kind infrastructure at the TTC to accommodate the testing and evaluation of intelligent railroad systems technologies and to provide FRA with the type and quality of facilities and equipment needed to meet its mission.	Provide a world-class testing facility for rail technologies and operating procedures, including facilities for track, rolling stock, train control and communication, and human factors research.
FRA	2013-ongoing	Fire Safety Research	The program focuses on improving current federal regulations and industry standards for crashworthiness of passenger locomotive fuel tanks, as well as the fire performance of materials and components used in passenger rail equipment.	• Address limitations associated with the current rules and standards for fire safety performance of materials used in passenger rail cars. • Allow for more realistic test methods and evaluation tools that will result in cost savings for the passenger rail industry. • Validate more cost-efficient modeling and testing methods.
FRA	2015-ongoing	Glazing Standards	The research in this area will comprehensively describe all the engineering requirements placed on glazing systems, survey existing glazing systems design strategies used throughout the world, and assess the effectiveness of these designs in meeting all of the engineering requirements.	Recommended strategies to balance the competing needs for glazing in a passenger car in the contexts of performance capabilities and functional expectations.

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FRA	2013-ongoing	Grade Crossing and Trespass Outreach and Education	This research is developing and disseminating educational tools to the public. The purpose of the tools is to provide awareness of the risk of accidents that may occur at grade crossings when appropriate behavior is not observed.	The projects are aimed to mitigate and possibly eliminate trespassing casualties by using innovative solutions for detection and education.
FRA	2018-ongoing	Grade Crossing Modeling and Simulation	States and local governments do not have traffic simulation modeling tools, access to freight data, or the technical staff required to address traffic management and safety problems at highway rail grade crossings. The U.S. Government Accountability Office has appealed to FRA to resolve non-clearing queues at grade crossings. The FRA Office of Safety and multiple state and local government agencies asked FRA to revise GradeDec.Net to include innovative highway signaling technologies to help them develop more effective and less costly solutions.	This project is evaluating scenarios of possible safety improvements at grade crossings without the actual need to perform field testing. Modeling consists of simulating traffic and pedestrian scenarios to understand what safety improvements can be effective at a grade crossing.
FRA	2013-ongoing	Grade Crossing Pedestrian Safety	This research will evaluate the effectiveness of technologies and infrastructure improvements that can mitigate the risk of accidents at grade crossings where pedestrians are involved.	Evaluation of the effectiveness of a particular type of pedestrian gate.
FRA	2012-ongoing	Grade Crossing Technology	This research area will investigate, analyze, and test new technologies to improve public safety at grade crossings.	• Further reduce grade crossing fatalities, with the goal of eliminating them completely.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
				• Utilize AI to automate detection of trespassers.
FRA	2017-ongoing	Highway-Rail Grade Crossings	Driver behavior accounts for up to 94 percent of vehicle crossing accidents for the U.S. railroad system. Thus, efforts to decrease human errors are critical.	This research studies grade crossings to understand the underlying causes and human behaviors that result in pedestrians and vehicles struck by oncoming trains at grade crossings. RD&T aims to reduce the risk of collisions and improve trespass detection and suicide prevention using AI.
FRA	2014-ongoing	Human Fatigue	Research related to human fatigue to better understand workload factors and their contribution to human fatigue and to create human fatigue prediction models to help personnel work scheduling.	The output of this project is to develop interventions or solutions to mitigate the effect of these factors and may include screening, diagnosis, and treatment of sleep disorders.
FRA	2014-ongoing	ITS	Facilitate multimodal collaboration between stakeholders to develop coordinated solutions for transportation systems. Accelerated development of connected/automated vehicles interaction with highway-rail grade crossing infrastructure.	• Requirements validation testing for rail crossing violation warning. • Developed draft autonomous vehicle requirements for grade-crossing interaction. • Developed conceptual architecture for passive grade crossing.

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FRA	2014-ongoing	LNG - Natural Gas Safety Research	LNG and compressed natural gas are viable alternatives to diesel fuel. There are prototype service utilizations of natural gas in the railroad industry. FRA provides support to the safe operation and use of such fuels through research focusing on the safety of fuel tenders and transportation containers.	• Determine fundamental knowledge on the performance of safety design features of natural gas fuel tenders and transportation tank cars and ISO tanks. • Identify and apply the risk criteria for review of applications for shipment of LNG. • Determine the crash environment and performance of industry-specified tenders will support the rail industry in the development of robust specifications.
FRA	2015-ongoing	Locomotive Crashworthiness and Occupant Protection	Research in this area is developing improved strategies and designs for rail rolling stock to reduce injuries and fatalities resulting from rail accidents (i.e., collisions and derailments).	• Prevent intrusion into the spaces occupied by passengers and crew in accidents. • Retrofit crashworthy components onto conventional locomotives and conduct full-scale dynamic impact tests to demonstrate the effectiveness of the crash energy management integrated system in a train-to-train collision. • Increase collaboration with the APTA. Plan and facilitate discussions with the rail industry, specifically members of the Construction and Structural Working Group to refresh safety standards. • Examine crashworthiness of various fuel tank designs to include conventional (i.e.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
				existing) equipment such as passenger locomotives and diesel multiple units. • Review results of testing of fuel tank specimens at the TTC and develop information on puncture characteristics.
FRA	2012-ongoing	Locomotive Engine Efficiency Safety Research	The goal of this research is to investigate innovative locomotive engine technologies to ensure the safe and efficient transportation of goods and people. Areas of focus for this research program include reduction in fuel consumption, improvement in engine component life, and improvement in the efficiency of older, less efficient locomotives. Research is conducted in collaboration with Class I railroads to demonstrate and develop prototype systems.	Improve the safety and efficiency of various locomotive technologies to: • Reduce fuel consumption • Improve engine component life • Reduce harmful exhaust gases • Improve the efficiency of older, less-efficient locomotives
FRA	2017-ongoing	Minimum Safety Requirements (consolidated to Vehicle & Track Performance)	This research addresses vehicle-track modeling with outcomes of knowledge and technologies to improve track-train safety and decrease derailments in the U.S. Improving the understanding of interaction and forces between vehicle and track in particular, influence of track geometry, vehicle suspension, and vehicle or track design on derailment risk. Provide recommendations for minimum standard to reduce derailment risk. Under this program, we work on all the areas related to requirements for:	FRA invests in technology that is innovative and has a lower technology readiness level than the private sector can justify. This FRA investment keeps the U.S. rail sector growing and improving to keep up with the efficiency and safety of the rest of the world. FRA is performing systematic, basic research in this area and the results will be used by industry and universities to make improvements to railroad safety.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			• Track geometry parameters for safe operation of trains • Measurement techniques and tools for measuring rail and maintaining proper rail shape • Measurement technique and requirements for measuring rail and maintaining proper rail shape • Finding safe track geometry for operation at lower speed	
FRA	2015-ongoing	On-Track Research & Testing (currently consolidated to FRA Research Assets)	This research improves track safety and decreases derailments on America's railways. The goal is to eliminate fatalities and serious injuries on heavy-axle-load mainlines by identifying and mitigating potential infrastructure-related risk factors.	• Prevent high-consequence derailments that result in the loss of human life and significant damage to property and communities. • Identify, understand, and mitigate track-related failure modes that pose significant risk to safe HAL operations due to higher loading conditions and changes in track designs and/or materials. • Ensure the safe and effective implementation of new and innovative technologies and maintenance strategies intended to mitigate adverse effects of heavy-axle-load operations on track infrastructure

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
FRA	2018-ongoing	Predictive Analytics	Predictive analytics refers to the application of large volumes of historical data to develop routines, numerical tools, and AI techniques to accurately predict adverse track structure/substructure conditions.	• Prediction of adverse conditions and safety-related issues in the track infrastructure long before they become problematic. • Understanding of how changes in track infrastructure condition, operations, and/or regulations can affect the potential risk for track-related derailments.
FRA	2012-ongoing	PTC Interoperability	Interoperability is a requirement of the Rail Safety Improvement Act of 2008, which requires all railroads to have the ability to operate any train on any railroad territory by any railroad qualified personnel. Interoperability will be the fundamental requirement for safety and efficiency within the railroad industry.	• Improved coordination between railroads to ensure PTC interoperability. • Maximize effective utilization of railroad-owned radio frequency spectrum. • Develop interoperability test plans and evaluation protocols.
FRA	2016-ongoing	PTC Next Generation	This research will identify and develop the methods, facilities, equipment, and capabilities required for providing future industry PTC development. Research will focus on providing additional functionality, improving reliability, and supporting integration with other technologies, all of which will support the objectives of improving safety and throughput.	• Increased rail network capacity. • Reduced delays associated with crew changeout. Increased safety through higher percent train location. • Limited deployment of positive train location by Class I railroads for evaluation.
FRA	2010-ongoing	PTC Technology	This research addresses issues associated with finalizing PTC development, deployment, and continued long-term evolution and maintenance. It supports the design and development of innovative systems to ensure PTC interoperability and reliability	• Investigation and enhancement of track circuit technologies to increase safety and throughput. • Development of technologies to safely increase the capacity of freight and

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			continue to evolve with the pace of technology development.	passenger trains through densely populated areas. • Development of improved PTC adaptive braking algorithms.
FRA	2015-ongoing	Rail Performance	FRA works with the railroads in committees, conferences, and the Rail Safety Advisory Committee (RSAC) to understand the current state of rail performance and integrity in the country and what can be done to improve it. This research built upon the FY 2019 first generation prototype with the second-generation prototype of flash thermography technology for detection of base defects.	• Upgrade inspection practices and technology. • Invest in technology that has a lower technology readiness level than the private sector can justify. • Keep the U.S. rail sector growing and improving to keep up with the efficiency and safety of the rest of the world.
FRA	2017-ongoing	Rail Safety Innovations Deserving Exploratory Analysis (IDEA)	The TRB initiated this effort in conjunction with FRA to address safety needs and advanced improvements within the railroad industry. The focus of this project is to solicit innovation, ideas, and advanced technology applications in railroad safety.	This project seeks to resolve all railroad safety problems. Outputs and innovations will change based on the selected project proposal.
FRA	2017-ongoing	Rail Trespass and Suicide Prevention (currently Highway-Railroad Grade Crossings, Railroad Trespass and Suicide Prevention)	This research seeks to better understand the two leading causes of rail-related death in the U.S. Hundreds of people lose their lives every year on train tracks due to trespassing or suicide. Human factors research on trespassing and suicide prevention should continue indefinitely.	• Solve two leading causes of rail-related death in the U.S. • Identify safety improvements to reduce grade-crossing and trespass deaths. • Identify and study the causal factors that lead to trespassing incidents on railroad property.
FRA	2017-ongoing	Railroad Systems Issues	This project conducts research focused on safety with secondary strategic alignment to innovation,	• High-speed rail should not be implemented without comprehensively

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			infrastructure, and accountability in the railroad industry.	considering the impact on existing equipment, infrastructure, passengers, and workers. • Designers and operators need to specifically address aerodynamic issues to accommodate varying interoperating train types and operational conditions specific to North America.
FRA	2015-2019	Research Equipment Management	This research area encompassed a diverse portfolio, resulting in increased knowledge and informed techniques to improve track safety and decrease derailments. The goal was to improve the safety and effectiveness of new technologies and maintenance strategies through evaluation and testing in real-world conditions.	• Reduced fatalities and serious injuries on heavy-axle-load mainlines. • Identified and mitigated potential infrastructure-related risk factors. • Increased understanding of the failure modes associated with heavier tonnage and higher-axle-load operations. • Increased safety and effectiveness of new technologies and maintenance strategies.
FRA	2018-ongoing	Research with Universities on Intelligent Railroad Systems	This project supported university research on intelligent railroad systems. FRA used a broad agency announcement to solicit applied technology research projects that will support DOT and FRA goals to advance automation and connected vehicle technology adoption in the rail industry.	The planned outputs for the future: • Focus on advanced technology, automation, and connected vehicle technologies. • Projects that advance these technologies for rural application. • Intelligent transportation systems. • Workforce development.
FRA	2017-ongoing	Rolling Stock Component Safety	This research investigates significant issues pertaining to safe operation of very long trains (150+ cars) as affected by use of air brakes. This research	The research reduces risks through the prevention of above-track equipment and component failures (e.g., situational hazard

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			investigates issues such as: the impact on application and release by increase of air brake signal propagation time.	prevention), and provides the analytical and technical basis to develop equipment safety standards while also improving safety, reliability, and respectability of rail equipment, technologies, and material.
FRA	2015-ongoing	Rolling Stock Maintenance & Inspection	The focus of this research is to evaluate and demonstrate the effectiveness and efficiency of automated inspection and maintenance procedures and equipment. This project will demonstrate the ability to develop, monitor, control, and evaluate integrated advanced components to detect defects in real-time, predict and prevent future failures, improve rolling stock capabilities and performance, and improve overall rail operational safety.	• Detect defects on rolling stock equipment and predict preventable future failures. • Develop a reliable EPSS for powering advanced detection devices on freight trains, increasing safety and security and improving the efficiency of freight railroad operations. • Understand the stress analysis of the wheel to improve its performance and mitigate wheel failure, a major cause for derailment.
FRA	1982-ongoing	SBIR	The SBIR program is a DOT-wide program that encourages domestic small businesses to engage in federal research with the potential for commercialization. The program encourages participation by minority and disadvantaged businesses in technological innovation and increases private-sector commercialization of innovations derived from federal RD&T directives.	• Improve the safety of freight and passenger railroad travel. • Develop new inspection methodologies and technologies for grade crossings.
FRA	2014-ongoing	Short Line Safety Institute	Since FY 2014, FRA has partnered with the SLSI to develop, pilot test, and implement an innovative safety culture assessment process. Small railroads do not have the budget or personnel to conduct	Recommendations resulting from the safety culture assessment process have provided Class II and III railroads—small railroads with limited resources to support safety training

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			safety culture assessments and training and education at their railroads. An organization's safety culture can impact safety outcomes.	and education—with information and actionable processes that can be implemented to operate at an increasingly high level of safety.
FRA	2016-ongoing	Structural Integrity	The goal of this project is to understand the performance and durability of safety equipment, and protective systems for tank cars and portable tanks.	• Identify and understand tank car behavior, acceptable manufacturing tolerances for tank car parts and components. • Define non-destructive testing performance and acceptance criteria. • Minimize the consequences of tank cars involved in accidents.
FRA	2016-ongoing	Tank Car Research	This research develops and improves the packages that carry hazardous materials, helping to reduce the release of material and minimize the consequences during rail accidents and incidents.	• Understand the puncture resistance and survivability of different tank car types. • Evaluate the performance of different tank car types. • Minimize the consequences of tank cars involved in accidents.
FRA	2011-ongoing	Tie & Fastener Performance and Integrity (currently consolidated to Track Stability)	This research serves to improve the industry state of knowledge regarding the design, manufacturing, and testing of reinforced concrete crossties used in freight and passenger track. The objective is to study the operating environment, manufacturing processes, and failure modes for concrete crossties to create and test recommended practices to improve performance. This research uses mechanistic design principles, experimental study, and collaboration with crosstie suppliers and users across the industry.	• Mechanistic design method for the design and construction of concrete crossties. ASTM 1096 standard for 5.32mm indented wire used in concrete tie manufacture. Freeze/thaw test as alternative to ASTM 666. Numerous updates and additions to AREMA Manual of Recommended Practices, Chapter 30. Alternative tie designs, including the use of weathered aggregates. Prism-based design performance qualification test.

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				• Dozens of journal articles, technical reports, presentations, and research results documents, presentations at TRB, AREMA, and JRC conferences. • Spike failure research: Identification of excessive longitudinal loading and plate uplift with elastic fasteners as contributing factors to spike fatigue failures in track with grade and curvature. Technical reports, research results, numerous presentations at industry conferences.
FRA	2013-ongoing	Track Buckling and Panel Shift (currently consolidated to Track Stability)	This research works to improve the detection of track buckling to improve track safety and decrease derailments in the US.	• Develop better infrastructure monitoring and maintenance practices to decrease the chances for track buckle and panel shift derailments. • Develop an innovative system that can accurately determine when a rail might buckle by measuring the rail stress levels without the railroads incurring significant monitoring costs (i.e. rail cuts, unfastening, uplift, welding, etc.). • Evaluate automated curve monitor technologies to detect track shift without incurring significant labor costs associated with manually staking out curves.

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FRA	2015-ongoing	Track Inspection	This research addresses inspection technology and processes to improve track safety and decrease derailments through technology research that yields effective methods to detect and mitigate track safety risks; development of data-driven technologies and innovations aimed at real-time decision-making; and development of automated track change detection technologies to enhance track inspection effectiveness.	• Development of a practical and accurate track condition change technology based on 3D laser scanning and processing using AI. • Demonstration of technology on Class 1 railways.
FRA	2015-ongoing	Track Support and Substructure (currently consolidated to Track Stability)	This research addresses track support and subgrade issues to improve track safety and decrease derailments through track support and substructure research to support higher loads, and track buckling and panel shift research to study rapid track failure. This research builds upon the FY2020 first and second-generation prototypes for measuring rail stress without a zero reference.	• Enhanced infrastructure monitoring and maintenance practices. • Design the portable track loading fixture. • Expand the failure mode detection for the gauge restraint measurement system, including research for detecting rail seat deterioration.
FRA	2018-ongoing	Train Handling & Operating Practices	This research will develop simulation scenarios to evaluate different network and capacity related parameters with electronically controlled pneumatic (ECP) brakes and PTC technologies and compare these to the conventional signaling and braking applications. Simulation scenarios include network topology, traffic type, ECP scenarios, and PTC scenarios (with and without ECP scenarios).	• Develop effective models for evaluating the economic benefits of improving railroad network velocity and capacity. • Enhance the economic benefits of improving railroad network velocity and capacity. • Reduce the cost of moving goods and passengers and increase the profits of the rail industry so they can continue to improve their service at higher safety and lower cost.

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FRA	2018-ongoing	Train Handling & Operating Practices	This research will develop simulation scenarios to evaluate different network and capacity related parameters with ECP brakes and PTC technologies and compare these to the conventional signaling and braking applications. Simulation scenarios include network topology, traffic type, ECP scenarios, and PTC scenarios (with and without ECP scenarios).	Develop methods for specifying and evaluating passenger rail vehicle suspension performance to ensure acceptable performance for a range of operating conditions.
FRA	Ongoing	Vehicle & Track Modeling (consolidated to Vehicle & Track Performance)	This research area aims to improve knowledge of interaction and forces between Vehicle and Track and in particular how to model and simulate different operating conditions, vehicle components is very critical to improve safety.	• Make accurate models and simulations of track and vehicle interaction to predict derailment. • Collect track or equipment data to use for modeling. • Model various equipment types and track conditions. • Perform simulations to understand railroad derailment risks. • Study the best way to model coil spring and other components in vehicle suspensions. • Provide guidelines and insights to the industry.
FRA	2015-ongoing	Vehicle & Track Performance (consolidated to Vehicle & Track Performance)	This research area focuses on all aspects of vehicle/track interaction safety. Many train derailments or accidents cannot be attributed to defects in either track or train alone. Rather, they result from the adverse dynamic interaction between the two or the existence of unsafe conditions at the wheel-to-rail interface, (i.e., improper lubrication or contact geometry). Research in this area presents	Outputs include: • Increasing the understanding of safe wheel/rail forces and safe vehicle and truck. • Improving how to keep the forces at a level to prevent damage to track structure.

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			an integral approach to understanding the behavior of the vehicle/track system to identify the safety implications arising from the dynamic interaction between track and train.	• Testing and simulating the performance of new equipment. • Supporting the Office of Safety in the implementation of the vehicle-track interaction rule.
FRA	Ongoing	Wheel-Rail Interface (consolidated to Vehicle & Track Performance)	This research area addresses vehicle-track modeling with outcomes of knowledge and technologies to improve track- train safety and decrease derailments.	• Increase understanding of the forces and wear mechanism at wheel-rail interface and mechanism for defect development to improve safety and reduce risk of derailment. • Provide guidelines on how and when to maintain the wheel-rail surface condition to provide maximum safety and life for the asset. • Increase understanding of how effective the wheel-rail friction modifiers are and how to measure it and its performance.
FTA	2016-2019	Accessible Transportation Technologies Research Initiative (ATTRI)	This project provided funding to support research, development, and testing of selected accessible transportation technologies.	Report with findings, lessons learned, and recommendations.
FTA	2017-2021	Accessing Rides to Community Healthcare	This project established a public health mobile clinic that provided health screenings at MetroLink public transportation stations.	Innovative partnerships.

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FTA	2019-2020	Applications of UAS for Public Transportation Facilities and Rail Rights-of-Way	This project assembled a group of technology and airspace experts to develop a scope of research and action plan for a UAS research project.	Report with findings, lessons learned, and recommendations.
FTA	2015-2021	Bus Propulsion Evaluation and Support	This project evaluated bus technology in real-world revenue service applications. It is focused on zero-emission bus technology and is conducted by the National Renewable Energy Laboratory.	Report with findings, lessons learned, and recommendations.
FTA	2017-2022	Comparative Analysis of Battery-Electric and Fuel-Cell-Electric Bus Propulsion Technologies	This project deployed five New Flyer battery-electric buses at the Alameda-Contra Costa Transit District.	Rolling stock.
FTA	2019-2021	Cost Allocation Technology for Non-Emergency Medical Transportation	This project developed a cost allocation technology to account for disparate Federal reporting requirements and maintain separation of funding sources by trip for non-emergency medical transportation.	Cost allocation technology.

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FTA	2019-2020	Creative Procurements to Improve Transit Cost and Effectiveness	This project assessed the state of procurement needs and transit agency's utilization of innovative lease agreements that deploy new technology. Researchers recommended ways to create a procurement environment that facilitates the adoption of promising new technologies.	Report with findings, lessons learned, and recommendations.
FTA	2017-2020	Enhanced Employee Protection Warning System Including Roadway Worker Protection	Sacramento Regional Transit District deployed and evaluated secondary worker protection system and work zone protection system to enhance track workers safety.	Communication and alert technology.
FTA	2017-2021	Fixed Location Train Detection and Worker Warning System	Maryland DOT, in partnership with the New York Metropolitan Transportation Authority, deployed and evaluated two secondary track worker safety protection systems.	Communication and alert technology.
FTA	2017-2021	FY 2015 5312 Low- or No-Emission Electric Buses	This project deployed five new flyer battery electric buses at the Utah Transit Authority.	Rolling stock.
FTA	2017-2021	GO Buffalo Mom	This project funded transportation to appointments for low-income users. It provided participants guidance on how to use the public transportation system for healthcare appointments.	Innovative partnerships.

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FTA	2015-2021	Information Dissemination and Evaluation Program	This program assisted FTA with communication, dissemination, and evaluation of research.	Report with findings, lessons learned, and recommendations.
FTA	2015-2020	Innovative Platform Track Intrusion Detection System Technology: A Demonstration	Los Angeles Metro deployed and evaluated a platform track intrusion detection system at station to potentially reduce injuries, fatalities, and other track intrusion incidents.	Communication and alert technology.
FTA	2015-2022	Lo-No Emissions Grant	The Duluth Transit Authority deployed six Proterra buses and three charging facilities. This project is a cold-weather demonstration of battery electric technology in transit revenue service.	Rolling stock.
FTA	2016-2021	MOD Performance Metrics	The project explored performance metrics as part of the MOD program. A focus of this research was to examine how transit agencies may need to reorient their approach to meeting MOD goals.	Report with findings, lessons learned, and recommendations.
FTA	2017-2020	MOD Sandbox: Adaptive Mobility with Reliability and Efficiency (Pima County, AZ)	This sandbox project explored integration of fixed-route, subscription-based ride-sharing and social carpooling services into an existing data platform to provide affordable, convenient, and flexible service.	Innovative partnerships.

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FTA	2017-2021	MOD Sandbox: Integrated Fare Systems – From Transit Fare to Bike Share (CTA, Illinois)	This project incorporated the local bike sharing company, Divvy, into CTA's existing transit trip planning app so users can identify the availability of bikes or docking stations near their transit stops and pay for bike rentals.	Travel planning and navigation technology.
FTA	2017-2020	MOD Sandbox: LA County and Puget Sound First/Last Mile Partnership with Lyft	The Sandbox project explored the viability of first/last mile solutions for trips originating and ending at select transit stops/stations. This project brought Via to L.A. County and the Puget Sound as a publicly supported ride-hailing option for customers connecting with transit at pilot locations.	Innovative partnerships.
FTA	2017-2020	MOD Sandbox: Limited Access Connections (Tacoma, WA)	This project connected Pierce Transit local service, Sound Transit/Sounder regional service, and local ride-share companies to increase regional transit use.	Innovative partnerships.
FTA	2017-2020	MOD Sandbox: Mobility Platform (Valley Metro, AZ)	The Sandbox project explored integration of mobile ticketing and multimodal trip planning in phases.	Trip payment technology.
FTA	2017-2020	MOD Sandbox: Paratransit MOD Demonstration (Pinellas Suncoast Transit Authority, FL)	The project aimed to develop an integrated platform that provided on-demand curb-to-curb paratransit service through partnerships with Lyft, United Taxi, Care Ride, Wheelchair Transport, and Goin Software.	Transportation coordination technology.

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FTA	2016-2020	Multi-Pedestrian Counting System Using Fusion of Stereo Camera and Laser Scanner	The project used infrared and LED technology to count multiple pedestrians walking in a large group, maintaining individual tracks even when some pedestrians walk in unpredictable patterns or leave the crosswalk prematurely.	Passenger counting technology.
FTA	2017-2020	Pedestrian and Cyclist Detection Devices for Buses	This SBIR project was for development of a detection and collision warning system that enables pedestrian and cyclist detection near transit buses in different environmental conditions.	Collision avoidance technology.
FTA	2017-2021	Pierce Transit Collision Avoidance and Warning Research and Demonstration Project	This project developed and deployed collision-warning technology with automated braking system to assist transit bus operators in avoiding collisions with pedestrians, cyclists, and other road vehicles.	Communication and alert technology.
FTA	2016-2019	Technology to Improve upon Automatic Passenger Counting Data	The project's purpose was to develop an integrated, multi-sensor passenger detection system for both automatic passenger counting and estimation of origin-destination traffic flows.	Passenger counting technology.
FTA	2016-2020	Transit Automation Analysis and Research Plan Development	This project developed the Strategic Transit Automation Research Plan, plan and executes knowledge transfer activities, and conducts transit automation related research, such as automation	Report with findings, lessons learned, and recommendations.

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			policy review, and transit applicability of light and commercial vehicle automation technologies.	
FTA	2017-2022	Transit Bus Mirror Configuration Research and Development	This project's goal was to design, develop, and evaluate prototype mirrors to reduce bus operator blind spot to avoid collisions with pedestrians at intersections.	Vehicle component technology.
FTA	2019-2022	Transit Data Research Project	This project provided FTA funding to the ITS JPO for Phase II of the Secure Date Commons. The Secure Data Commons is a common platform for innovative data analysis and sharing of results across the Department.	Report with findings, lessons learned, and recommendations.
FTA	2014-2017	Transit Safety	The goal of this SBIR project was to develop an antireflection technology that reduces the reflection of interior lighting on bus windshields, thus improving driver visibility and the safety of passengers and pedestrians.	Vehicle component technology.
FTA	2019-2020	Transit Vehicle Innovation Deployment Centers - CALSTART	The work was in support of creating an integrated, cohesive, public transportation innovation deployment network that is responsive to the needs of both transit agencies and U.S. transit vehicle manufacturers that will support ongoing efforts to test, deploy, and commercialize low- and no-emission vehicles and related components.	Report with findings, lessons learned, and recommendations.
FTA	2019-2021	Virtual and Augmented Reality to Aid	This SBIR project developed a guided augmented reality independence travel aid that will assist	Travel planning and navigation technology.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Transit Use by All Travelers	persons with disabilities to plan and execute a trip independently via a mobile device.	
FTA	2015-2020	Wayside Worker Protection Demonstration	This project's purpose was to develop, install, and demonstrate a wayside worker protection system developed by Bombardier to enhance track worker safety.	Communication and alert technology.
FTA	2017-2021	Zero-Emission Hydrogen Buses and Evaluation	This project deployed three additional fuel-cell buses at the Stark Area Regional Transit Authority in Canton, Ohio.	Rolling stock.
ITS JPO	2021-2021	ADS-Roadway Integration Collaboration Strategies	The project identified and developed institutional strategies and models within the context of the FHWA Highway Automation Concept of Operations to evolve and expand collaborative approaches to implement ADS-roadway operational integration at a national roadway network scale.	The scope of this project included the research, development, and assessment of organizational, institutional, and partnership models to facilitate ADS-roadway operational integration at a national roadway network scale.
ITS JPO	2021-2022	ADS-Roadway Test and Evaluation Framework Outreach	This project undertook the outreach plan development and execution to support the dissemination of the stakeholder-developed ADS-roadway test and evaluation framework.	Consistent ADS-roadway testing and assessment allowed for each deployment to build on one another and accelerate quality ADS deployments. The project also increased the awareness of and use of the ADS-roadway test and evaluation framework.

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ITS JPO	2020-2022	Advanced Transportation and Congestion Management Technologies Deployment Program	This program provides funding for eligible entities to develop model deployment sites for large-scale implementation and operation of a diverse set of technologies in various geographic regions.	The stated purpose was to reduce costs and improve return on investments; deliver environmental benefits through increased mobility; improve transportation system operations; improve safety; improve collection and dissemination of real-time information; monitor transportation assets; deliver economic benefits; and accelerate deployment of connected and autonomous vehicle technologies.
ITS JPO	2021-2021	AI Training Data – State of the Practice Assessment	Automated driving systems (ADS) have the potential to improve mobility and efficiency and reduce fatalities in our nation's transportation system. The machine learning discipline of AI enables many of the perception and object classification systems that are critical for enabling ADS to properly interpret the surrounding environment.	The project aimed to document the state of the practice and elevate the state-of-the-art by initiating conversations across industry on important factors to consider in minimizing bias in perception and object classification systems that affects the safe and equitable operation of ADS.
ITS JPO	2020-2022	ATC: Next Generation Wireless Communications Testing (U.S. Army Aberdeen)	The purpose of this project was for the U.S. Army to provide the ITS JPO with technical assistance and expertise for executing Phase II of the U.S. DOT-FCC-National Telecommunications and Information Administration (NTIA)'s spectrum-sharing test plan.	This project supported the testing of next-generation communication technologies, including testing occurring at other sites, by providing specialized equipment and expertise on an as-needed basis. It provided device characterization and baselining of V2X devices procured by U.S. DOT for testing and provided facilities for U.S. DOT researchers to test and rapidly evaluate new technologies under transportation scenarios.

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ITS JPO	2018-2018	Automated Vehicle Data Sharing	This project allowed data sharing and reduced redundancies in research. Review of shared research data allowed each mode to develop and perform a gap analysis on available research. Guidelines also included descriptions of how to check data quality before, during, and after data collection, and verify quality before transmitting for evaluation and sharing.	Establishment of data architectures and institutional capacity needed to address data exchange needs for AV integration across the modes of transportation.
ITS JPO	2018-2019	Automated Vehicle Impact Assessment	Automated vehicles continue to be an active area of research and development. To support AV policymaking, the JPO needs to keep abreast of research (including current automation projects), and to support selected AV modeling efforts to fill the gaps. In addition to keeping abreast of published literature, research coordination efforts included follow-on work for the DriveMe collaboration with Volvo Cars, as well as impact assessment activities with the EU-US-JPN Automation in Road Transportation working group.	This project focused on: • Maintaining awareness of other research in the U.S. and around the world, to improve insights and avoid duplication of effort. • Providing a strategic planning tool that state DOTs and MPOs can use to assess various C/AV scenarios. • Evaluating current publicly available plug-in modules used with traffic simulation tools. • Developing standards and evaluation criteria for tools various organizations are developing for estimating the impacts of automated and connected vehicles.

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ITS JPO	2017-2018	AV Intent and Status Communication with Other Road Users	AVs implement lateral and longitudinal control functions differently depending on the composition of the automated functions offered by the manufacturers. These differences between vehicles are anticipated to only increase as automation technologies become more prevalent. Additionally, each implementation of automation operates in relative proximity to the center of their intended operating envelope, particularly as roadway, traffic, and environmental conditions change en route.	This project added to human factors design guidance for the timing, sequence, and presentation of intent and status information to optimize the safe operation of automated, mixed-function vehicles.
ITS JPO	2018-2023	Automation Standards Development	This project (1) further developed details of near-term standards requirements for automation as informed by the Automation Standards Roadmap to be completed during FY17 and other factors, (2) identified candidate standards development organizations and partnerships, (3) identified cooperative options for harmonized standards, test/certification process development, and (4) conducted information-gathering and outreach.	Project scope included: (1) developing details of near-term standards requirements for automation, (2) identifying candidate SDOs and partnerships, (3) identifying cooperative options for harmonized standards, test/certification process development, and (4) conducting information gathering and outreach.
ITS JPO	2018-2020	Benefits Tool Prototyping	This project built on a fully working benefit-cost assessment model for one or two V2I applications. This research built upon prior work, including V2I Deployment Benefits Tool Framework Development, which developed a framework for a tool for benefit-cost assessment to help state and local agencies determine the best strategy for deploying V2I applications.	A benefit-cost assessment model for V2I applications. The developed model will help state and local agencies determine the best strategy for deploying V2I applications.

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ITS JPO	2018-2019	Business Model Analysis	Emerging shared-used modes have already impacted the traditional transit market and could conceivably disrupt current business and funding models. This activity aimed to explore the technical and institutional feasibility of innovative mobility-on-demand business models and document best practices.	Assessment of the technical and institutional feasibility of innovative mobility-on-demand business models and documenting best practices.
ITS JPO	2017-2018	CAMP Work Area 3 - Cooperative Adaptive Cruise Control (CACC) Small-Scale Test	This project performed the recommended research using a two-phase approach employing simulation tools and prototype evaluation to explore the feasibility and utility of providing CACC functionality as a DSRC-enabled evolutionary expansion of adaptive cruise control.	This project aimed to provide field test and analysis or empirical data, algorithm development, simulation and specification followed by CACC prototyping and testing. It also aimed to introduce the CACC feature as a commercial product.
ITS JPO	2020-2022	Collision Avoidance Metrics Partnership (CAMP)-OEM CV/CAV Stakeholder Engagement and Management	This project built upon the predecessor CAMP V2I Cooperative Agreement and 3-year extension supported by the Automated Vehicle Program and the V2I Program and supported new FY19 Automated Vehicle Program projects and stakeholder engagement by CAMP OEMs with operating agencies (state and local DOTs and the private sector).	In collaboration with state DOTs and local operating agencies, coordinated CV/CAV deployment readiness research activities to resolve barriers and issues that impede CV/CAV deployment and infrastructure readiness. Shared research needs and results with each other and DOT for future research planning and prioritization.
ITS JPO	2019-2022	CARMA Collaborative and Technology Transfer	FHWA developed the CARMA open-source cooperative automated driving technology reference platforms, CARMA platform and CARMA cloud, to accelerate innovation around automated driving technology and interaction with roadway infrastructure.	This project aimed to establish, facilitate, and support stakeholder forum and engagement to inform and educate on CARMA tools and use. Established national CARMA user base of research testbeds to advance cooperative automation transportation systems

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
				management and operations research leading to deployment.
ITS JPO	2019-2022	CARMA Integrated Highway Prototype	The objective of this project was to develop a Freeway Cooperative ADS use case concept of operations, requirements, proof of concept test, and a prototype plan. The CARMA platform and cloud were used to develop and prototype an Integrated Highway Prototype that bundles freeway operational strategies such as speed harmonization, lane change/merge, and platooning.	The scope of this project included the development of Freeway Cooperative ADS use case concept of operations, requirements, proof of concept test, and a prototype plan.
ITS JPO	2017-2018	Certification Governance Options	With the launch of the certification program's incentives to create sustainable certification labs with CV-oriented test procedures, the ITS Policy Program proposed to initiate research and multi-stakeholder engagement to lead to a governance structure for sustainable certification for the future.	This project aimed to incentivize industry to develop necessary policies and structures to ensure sustainable industry governance into the future.
ITS JPO	2017-2018	Certification Test Labs	This project provided the Policy Program and modal partners with an opportunity to ensure the evolving test procedures were in line with policy.	This project tested early versions of CV technology to ensure interoperability as well as proper instantiation of security and privacy before deployment.
ITS JPO	2018-2020	Certification Test Procedures	This project funded the development of information needed for developing additional certification test procedures for V2I technologies, devices, and systems. To date, only the most basic functionality	Certification test procedures for V2I technologies. Development of these V2I certification test procedures helps to provide certainty for deployers who typically do not

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			for V2I was represented in the CV test procedures, and deployers typically expect to be able to specify, in their procurements, that devices and technologies had to pass certification tests (for instance, for traffic signal controllers).	have the specialized equipment for performing such tests or staff with this type of expertise and helps mitigate risk for deployers.
ITS JPO	2018-2019	Connected Traveler	This project aimed to advance the CV Mobility work originally conducted for the Integrated Dynamic Transit Operations bundle. Since that bundle was tested, new advances in multimodal mobility and communications technologies advanced the state of the practice beyond what was originally tested.	Update of the concept of operations for the Integrated Dynamic Transit Operations bundle, development of initial requirements to support future potential prototype deployments and demonstrations, and the evaluation of standards-related gaps and identification of necessary modifications.
ITS JPO	2017-2018	Connected Vehicle Reference Implementation Architecture (CVRIA) and Infrastructure Architecture Integration	The purpose of this project was to ensure the infrastructure components are accurately addressed in the CVRIA. It is believed that the CVRIA had done a good job of accurately reflecting the vehicle side; however, it was time to analyze if the infrastructure side was adequately addressed and if there were areas that required attention. This effort required close coordination with the ITS Standards and Architecture program.	This project aimed to develop CVRIA to identify the key interfaces across the CV environment to support further analysis to identify/prioritize standards development activities.
ITS JPO	2017-2019	Connected Vehicle Traffic Control Systems (Multi-Modal Intelligent Traffic Signal Systems (MMITSS)	The proposed Connected Traffic Control System effort was a high-priority research area of the V2I Program designed to focus on the complexity and interaction of traffic, including CAVs and multimodal and other roadway users, as it moves on arterials and freeway interchanges.	This project aimed to improve traffic control systems which improved traffic safety, mobility, and reduced the environmental impact.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Enhancement & Field Test)		
ITS JPO	2018-2020	Cooperative Traffic Optimization for Signalized Corridors, Phase 1, Part 2	In 2015, FHWA validated the feasibility of Eco-approach and departure capabilities in the concept validation project. The first half of this project, Phase 1, Part 1, was funded by FHWA in FY17 for $1.9M and focused on the Signalized Intersection Approach and Departure modeling and analysis based on a variety of OEM test vehicles and two signalized corridors.	Project scope included technical research, development, and prototype field testing of Signalized Intersection Approach and Departure, leading to commercialization and deployment on instrumented arterial and urban corridors.
ITS JPO	2017-2019	Crash Avoidance Metrics Partnership (CAMP) Communications Research Project, Phase I Extension	Conducted the following core V2V communications research to support interoperability among V2V vehicles and devices: local misbehavior detection and reporting; global misbehavior analysis methods and processes; congestion control algorithm refinement and verification; and spectrum-related research to test and evaluate various spectrum-sharing technologies or proposals as they develop.	This project aimed to estimate the potential benefits of communication-based vehicle safety applications and define their communications requirements.
ITS JPO	2018-2020	CV Pilots Deployments - Independent Evaluation - Mobility - Environmental - Public Agency Efficiency	This project was the execution stage of evaluations of safety, mobility, environmental, and public agency efficiency impacts.	Identification of practical long-term sustainable financial and institutional models needed for CV technology deployment, assessment of potential national level benefits from CV technologies, and assessment of CV Pilot Program against program goals.

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ITS JPO	2018-2020	CV Pilots Deployments - National Level Evaluation	This project was the planning and execution of an evaluation assessing the potential national-level impacts associated with the deployment of the technologies and applications associated with the CV Pilot Deployment program.	Evaluation assessing the potential national-level impacts associated with the deployment of the technologies and applications associated with the CV Pilot Deployment program.
ITS JPO	2018-2020	CV Pilots Deployments - Program Level Evaluation	This project was to plan and conduct a program-level evaluation of the CV Pilot Deployment program.	This project aimed to identify practical program actions that enable for CV technology deployment, document the strengths and weaknesses of the program structure, procurement approach, management methods, and stakeholder engagement associated with the CV Pilots Program.
ITS JPO	2017-2018	CV-V2I Procurement Guide	This project funded the analysis of the differences between CV and ITS procurement methodologies and identified potential solutions to support CV project managers and their procurement staff.	This project aimed to analyze the differences associated with traditional ITS procurement methodologies with CV technologies; and to identify potential solutions to support a decision structure and guidelines for CV technologies procurements.
ITS JPO	2020-2021	Cybersecurity: Security Credential Management System (SCMS) Institutionalization/ Standardization	This project gathered research, analysis, and artifacts from the SCMS work and institutionalized and/or standardized key elements as a measure of providing state and local agencies who will deploy and operate CV technologies with a key component of cybersecurity for a cooperative ITS environment.	Support for the implementation and maturity of State, regional, and local agencies' cybersecurity capabilities and practices. Integration of the many modal projects related to cybersecurity research to ensure that the vast amount of research and information was disseminated to the fullest

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
				extent possible and helped prevent duplication of effort.
ITS JPO	2018-2022	Data Access and Retention	This project supported implementation of the ITS JPO Research Data Access and Retention Plan, which requires JPO-funded projects producing data to make it available to the public or authorized users in near-real-time according to standard procedures. The project also funded incubation of new capabilities to enable operational data exchange on a national scale through new approaches to local data harmonization and national data exchange.	Support for the implementation of the ITS JPO Research Data Access and Retention Plan. Technical assistance to internal and external stakeholders, development and maintenance of supporting artifacts, preparation of data for public access, data storage and processing costs, and promotion.
ITS JPO	2018-2020	Data Capacity Building	This project advanced the adoption of modern technology and product management best practices throughout the data program portfolio and with internal and external stakeholders.	Project scope included ensuring Data Access and Exchange Program product management development, procurement and delivery consistency and working with the PCB Program to expand the cadre of federal and non-federal personnel trained in these practices.
ITS JPO	2017-2018	Data Policy Playbook	This project created a concise online collection of existing policies, principles, and real-world examples of successful data management policies and practices. The intended audience was state and local agencies looking to transform how they collect, manage, and deliver transportation system data to meet the needs of emerging ITS technologies such as connected vehicles.	A concise and effective web-based playbook for state and local agencies on best practices for the procurement, enhancement, planning, and operations of transportation system-related data management.

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ITS JPO	2017-2019	Data Privacy and Management Tools	This project continued and expanded collaborative development, in the open, of modular data routing, validation, integration, sanitization, and aggregation functionality for deployers of connected-x devices.	Code and documentation that will build on the development framework and code-sharing platform established under the previous ODE projects. Project scope also included the provision of technical assistance to enable other federally funded projects to incorporate their code and development efforts under a single coordinated yet federated umbrella and prevent development of duplicative code.
ITS JPO	2020-2022	Delivery Timing and Modality of System State Information to Support Occupant Understanding of ADS Functionality	This project looked at embedded training that delivers knowledge and skill to the driver/occupant, exploring delivery timing and modality of system state and other information that can build the driver/occupant's understanding of ADS functionality, and also improve skill at performing supervisory tasks while remaining engaged.	Project scope included researching embedded training that delivered knowledge and skill to the driver/occupant, exploring delivery timing and modality of system state and other information that can build the driver/occupant's understanding of ADS functionality, and also improve skill at performing supervisory tasks while remaining engaged.
ITS JPO	2018-2019	MOD Demonstration Evaluation	The evaluation included an analysis of project impacts from performance measures provided by the project partners and identified in the MOD performance metrics task, as well as an assessment of the business models used and how existing FTA policies and regulations may support or impede these new service transportation models through evaluation of all project efforts.	Evaluation of MOD approaches and demonstrations aimed at validating the operational and implementation strategies of shared-use, on-demand transportation options, vehicle operations, and policies.

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ITS JPO	2018-2019	MOD Deployment and Implementation Guidance	The project developed guidance documentation for practitioners to assist with MOD concept development, planning, and implementation for agencies that would be responsible for a MOD deployment.	Guidance documentation for practitioners to assist with MOD concept development, planning, and implementation.
ITS JPO	2018-2020	Develop Prototype V2I/Infrastructure-to-Vehicle Query Advisory Applications	This project provided for the activities to develop the functional description and application requirements for a V2I/Infrastructure-to-Vehicle queue advisory application. It was expected that this work would be led by infrastructure owners/operators (IOOs) through the Connected Vehicle Pooled Fund Study and conducted in partnership with the Crash Avoidance Metrics Partners, LLC (CAMP).	Functional description and application requirements for a V2I/Infrastructure-to-Vehicle queue advisory application.
ITS JPO	2017-2022	Development and Delivery (Intramural)	This project tasked the Volpe Center with creating educational products either through its own professional staff or through contracting for the development and delivery of ITS training products by third-party subject matter experts.	Development and delivery of ITS training products.
ITS JPO	2018-2023	Development and Delivery (Industrial)	Multidisciplined training activities to assist internal and external audiences understand, prepare, and deploy Connected/Automated Vehicle and Smart Cities (i.e., V2I, V2V, V2X, Deployment Day Event, etc.).	Project scope included the development and/or maintenance of connected vehicle related training, e-learning courses, presentation material, webinars, and peer exchanges.

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ITS JPO	2020-2022	Development of a NIST Cybersecurity Profile for the ITS Ecosystem	This project developed a cybersecurity profile and guidelines for state and local DOT decision-making and activities to address cybersecurity issues for the ITS ecosystem.	State and local agencies implemented the Cybersecurity Framework Profile to understand their baseline cybersecurity posture and develop an understanding of the priority measures they should take to improve it.
ITS JPO	2019-2022	Development of Cooperative Automation Capabilities for Transit	This project built upon the success of the CARMA program, which has developed several tools to assist researchers in advancing cooperative driving automation strategies for new transportation systems management and operations use cases.	The scope of the project included the advancement of the CARMA platform powered by Autoware to support research on CDA strategies applied to transit operations, development of a concept of operations for CDA use cases supporting transit, and development of a simulation to demonstrate the application of CDA for transit operations.
ITS JPO	2019-2022	Development of Cooperative Automation Capabilities: CARMA Multimodal Development and Testing	Built upon FHWA's Open Source CARMA Platform and Cloud Prototype, enhanced and newly integrated Level 2/3 maneuvers and capabilities were developed for several cooperative dynamic driving task algorithms supporting arterial and freeway operational strategies.	The scope of the project included the development of cooperative automated driving applications and algorithms to support transportation systems management and operations use cases and capabilities (e.g., enhanced truck platooning and truck ADAS/ADS capabilities) leading towards deployment. This project also utilized a diverse team of national experts from both public and private sectors, through several established partnerships to accelerate the technology transfer and deployment of cooperative automated driving applications on state highways.

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ITS JPO	2018-2019	Development of Heavy Articulated Vehicle Basic Safety Message	This project further developed the concepts from the previous research project, "Heavy Vehicle V2V Basic Safety Message and Implementation Issues for Deployment," by building and testing a prototype tractor system to automatically determine the trailer characteristics and transmit a Basic Safety Message.	A prototype tractor system to automatically determine the trailer characteristics and transmit a Basic Safety Message. The prototype will be used for compliance test development and demonstrations.
ITS JPO	2018-2018	Disengagement Effects on Re-engagement in Levels 3 Automated Vehicles	For highly automated vehicles (Level 3), considerable research has focused on how to successfully bring drivers back into the control loop. The outcomes deal with both the minimum “take over request” time that human operators need to re-engage the driving task and reacquire adequate situation awareness to safely resume control of the vehicle, and the human-machine interface strategies to successfully alert human operators that they need to do so.	Project scope included the instigation of the effects of individual and combined disengagement factors on driver re-engagement time and success. The outcomes informed NHTSA’s guidance on Level 3 human-machine interfaces, and also informed Level 2 engagement strategies.
ITS JPO	2017-2018	Driver Expectations for Control Errors, Engagement, and Crash Avoidance in Automated Mixed Function	As automated mixed function vehicles were introduced for purchase in the marketplace, owners became familiar with the sensing and control functions of their vehicles. This study was the first of a series of studies to examine the role of driver expectations, their level of engagement, and their ability to avoid lateral and longitudinal crashes under a variety of traffic, roadway, and environmental conditions in a limited motion simulator setting.	This project aimed to improve the safety of automated mixed function vehicles (Level 2) by ensuring the compatibility of driver vehicle interfaces with human skills, abilities, state, and their expectations for system operation. The work produced design guidance for the timing, sequence, and presentation elements of the driver interface to optimize the safe operation of automated mixed function vehicles (Level 2).

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ITS JPO	2018-2018	Driver Vigilance Research for Level 2 and Level 3 Driving Automation Systems	Previous research has addressed driver engagement with Level 2 and Level 3 automated driving functions. Driver response times were observed as mediated by the timing, sequence and presentation of AV requests for the driver to take over control if necessary.	Review of foundational literature on human vigilance in the fields of experimental psychology and elsewhere.
ITS JPO	2017-2019	Early Deployer Cohort Program	The ITS Early Deployer Cohort Program enabled a community of practice among active early deployers who opted-in to work iteratively and collaboratively with each other and the U.S. DOT to make their projects successful while incrementally producing detailed documentation and shared software and data that the broader ITS community—activated by PCB program—could use to deploy their own state-of-the-practice, interoperable solutions.	Mechanism to engage early deployers as partners in problem solving to identify workable solutions more quickly with inherent buy in and incrementally produce detailed documentation and shared software and data to inform the broader ITS community.
ITS JPO	2018-2020	Early Deployer Technical & Equipment Assistance	This project continued to operate and maintain technical services (equipment loan program, a help desk/technical assistance service, and document management) to accelerate early deployer adoption and information sharing.	Facilitation of the provision of early deployer technical assistance.
ITS JPO	2020-2021	Eisenhower Transportation Fellowship Program	Graduate student provided the ITS JPO a detailed literature review on real-world implementation of AI focused on ITS.	Research results are helping the ITS JPO identify and assess practical implementation of AI in ITS for further investment.
ITS JPO	2018-2019	Event-Driven Configurable Messaging and	Activities in the first year of the program focused on: 1) rapid software prototype development of an event-driven dynamically configurable messaging capability	Software prototype development of an event-driven dynamically configurable message. The project developed and implemented a

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		Queue Warning - CAMP	of mature use cases with deployment ready partners, and 2) collaboration with ITS industry partners to develop a replicable methodology.	flexible message scheme able to dynamically adjust two-way data exchange between equipped vehicles and a traffic management center.
ITS JPO	2018-2019	Feasibility of Cloud-Based Real-Time Traffic Signal Applications	This project built off of FHWA-funded research that developed and simulated algorithms to use Basic Safety Messages to improve traditional signal timing.	Refinement of algorithms to produce vehicle trajectories from multiple data sources and the development of an open-source prototype system. The system produced real-time system performance measures.
ITS JPO	2017-2018	Federated Operational Data Environments (ODEs)	An ODE collects real-time data from connected vehicles, mobile devices, infrastructure devices, and emerging data sources, validates, integrates, de-identifies, and aggregates the data, and provides the data in real-time to subscribing traffic management and other applications. Two local ODEs are now in operation, and more are anticipated.	Use cases for sharing real-time data among ODEs as well as finding regional/national uses of the data, development of institutional, financial, and technical products useful to encouraging efficient data sharing across jurisdictions and functional boundaries in the surface transportation system.
ITS JPO	2020-2021	Guidance to Address Cybersecurity Risks Associated with Connected Truck Stop Technologies	To understand the cyber risks and impacts associated with modern truck stops and emerging truck-stop technologies, such as the potential to disrupt commerce, a technical scan was needed first to identify common technologies that are currently deployed at truck stops or may be deployed in the near future.	Best practice guidance for truck-stop operators and the motor freight industry.

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ITS JPO	2018-2019	Hazard and Safety Analysis of Automated Transit Bus Applications	The extension of automated vehicle (AV) technologies to transit buses has the potential to dramatically impact urban transportation. However, public acceptance of automated buses is contingent, in part, on the safe deployment of these technologies.	Application of hazard analysis techniques to identify high-level hazards associated with automated transit bus applications. The results of the hazard analysis were used to derive some generic top-level safety requirements, use cases, and safe states.
ITS JPO	2017-2018	Identifying Impediments to CV Infrastructure Deployment	Much was learned about CV deployment impediments from the V2I Deployment Coalition, the CV Planning analysis, and the CV Pilots Roundtable, among other efforts. A key lesson learned concerned a lack of information that was targeted to helping project managers prepare for, program funds for, procure equipment and systems, and design implementation projects associated with installing and operating CV infrastructure.	This project developed a series of V2I Deployment Impediments Reports, fact sheets, and FAQs to support project managers and offer deeper technical input to the FHWA V2I Guidance.
ITS JPO	2020-2022	Improving Analysis, Modeling, and Simulation for CAV Capabilities	This project improved current analysis, modeling, and simulation capabilities in assessing the performance of CAVs. Data sets generated from this project supported new CAV operations models that allowed for more realistic assessments of CAV impacts on traffic system performance.	This project focused on advancing the capabilities of analysis, modeling, and simulation to assess the impact of CAVs on transportation system performance. The models developed and associated data sets and documentation will allow state and local agencies to make more informed decisions on strategies that incorporate CAVs in their transportation systems management and operations.
ITS JPO	2017-2019	Infrastructure and V2X Mapping	The purpose of this project was to identify mapping and positioning needs specifically for V2X and	This project aimed to assess what map information was needed and how it was

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		Needs Assessment	integrate with broader digital infrastructure efforts being done by the Automation program.	communicated to V2X devices to support safety and mobility applications.
ITS JPO	2017-2022	Infrastructure Standards Maintenance	This project provided for no-cost public availability of ITS standards along with engineering and project management services to support the maintenance and updating of ITS infrastructure standards (e.g., National Transportation Communications for ITS Protocol (NTCIP) standards).	This project aimed to promote the distribution of all ITS standards approved for distribution, provide responses to inquiries concerning ITS standards, and provide monthly progress reports on ITS standards maintenance activities and website activities to ITS JPO.
ITS JPO	2018-2019	Integrated Data Exchange Hub for Modular ODE	This research produced data regarding vehicles, drivers and technology, and data that needed to be disseminated among all modes. This allowed data sharing and reduced redundancies in research. Review of shared research data allowed each mode to develop/perform a gap analysis on available research.	Establishment of an Integrated Data Exchange Hub for Modular ODE. This allowed data sharing and reduced redundancies in modal DOT research. Review of shared research data allowed each mode to develop/perform a gap analysis on available research.
ITS JPO	2018-2019	Integrated Modeling for Road Condition Prediction - Phase 3	The Integrated Modeling for Road Condition Prediction is a system that incorporates real-time and/or archived data and results from an ensemble of forecast and probabilistic models: atmospheric and road weather and hydrology, traffic, work zones and winter maintenance operations, incidents, special events, and demand then fuses them in order to predict the current and future overall road/travel conditions for travelers, transportation operators, and maintenance providers.	Expansion of the testbed for the Integrated Modeling for Road Condition Prediction.

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ITS JPO	2020-2022	ITS Deployment Evaluation Decision Support, Analytics, and Deployment Tracking Surveys	This work provided decision support for ITS deployment through the performance of strategic economic and related analyses.	This project aimed to provide high-quality information to enable improved ITS JPO and other stakeholder decision-making and improve the rate and nature of ITS deployment.
ITS JPO	2019-2022	ITS Deployment Tracking Surveys	Gathered information on the deployment of ITS technology nationally via surveys targeting transportation agencies involved with management of freeways, arterials, and transit, as well as surveys of other populations on a variety of topics as appropriate.	The surveys populate the only comprehensive national public sector database of its kind and contain deployment data covering almost 20 years. The data supports analysis of ITS deployment progress over time and can be used to assess the impact of interventions to stimulate deployment. The data also provides information for Congress and meets the congressionally mandated requirement to track ITS deployment.
ITS JPO	2020-2022	ITS Early Deployer Technical Support and Equipment Loan Program	This project continued to provide technical support to the ITS Early Deployer Program, which continued the Early Deployer Technical Assistance and Equipment Loan program and expanded it to include all CAV needs including CARMA.	This project aimed to support the CAV deployment community that was deploying CAV technology and ensure decisions were made from an overall system perspective and enhanced early deployer collaboration to promote nationwide interoperability during iterative state-of-the-practice evolution.
ITS JPO	2017-2018	Longer Driver Engagement with Mixed-Function	This project was a follow-on task to the Naturalistic Study of Mixed-Function Automated Vehicles (Level 2). The research continued to investigate driver engagement questions involving driver responses to	This project added to human factors design guidance for the timing, sequence, and presentation elements of the driver interface

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		Automated Vehicles (Level 2)	take-over requests on test tracks, engagement in natural driving, and engagement and recovery mediated by driver expectations of automated functions in a simulator.	to optimize the safe operation of automated mixed-function vehicles (Level 2).
ITS JPO	2017-2019	Mobility and Equity Impacts of Automated Vehicles	Building on the benefits model work of previous years, this project focused on the mobility and equity impacts of automated vehicle technologies.	This project aimed to advance the state-of-the-practice for understanding the impacts of AVs on congestion, personal mobility, and travel behavior.
ITS JPO	2017-2018	MMITSS Deployment Readiness	To make the MMITSS bundle and associated applications readily deployable, the goal of this project was to enhance the existing MMITSS prototypes that were developed and field-tested in Anthem, AZ, and Palo Alto, CA.	This project aimed to develop a comprehensive traffic signal system that services all modes of transportation.
ITS JPO	2017-2018	National SCMS Deployment Support	As outlined in NHTSA's recently released V2V NPRM, both trust and the appropriate protection of individual privacy are critical to ensuring successful messaging among vehicles. DOT and its industry partners addressed the need for trust and privacy through the design and development of a Public Key Infrastructure-based SCMS. To date, DOT and its industry partners have developed a proof-of concept SCMS that is expected to provide security certificate services to early V2X deployments.	This project aimed to ensure trusted and private CV communications. It also encouraged U.S. DOT and SCMS stakeholders to develop potential SCMS ownership and governance models to deploy a National SCMS.
ITS JPO	2018-2018	National SCMS Policy Development	The focus of this project was to assist U.S. DOT engage with a variety of V2X industry stakeholders to assess feasible National SCMS deployment models, and develop plans, strategies, and possible	Feasibility assessment of a national SCMS.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			pathways toward establishing a nationwide SCMS capability.	
ITS JPO	2018-2022	Next Generation Spectrum and Communications	The move toward the next generation of wireless communications will expand communication capacity for transportation-related activities. This project provided expert insight into these new communications capabilities and identified their relevance to transportation and their impact on DSRC.	Preliminary research on new communications capabilities, their relevance to transportation, and their impact on DSRC.
ITS JPO	2019-2022	Open-source Software Suite for Intelligent Transportation Systems	The Department had a number of development projects underway that used Agile Development practices to create open-source software with robust communities of practice. Development of the software-physical architecture enabled the government to provide the deployment community with software products that are interoperable, robust, flexible, extensible, and easier to implement and maintain.	The scope of this project included the integration of U.S. DOT-developed open-source software products. The software suite encouraged integration of open-source software into existing deployments and contributed back to the open software suite to accelerate future deployments.
ITS JPO	2017-2018	Operational Data Environment	The U.S. DOT's ODE is a product of the ITS JPO Data Program that receives real-time data from CVs, personal mobile devices, infrastructure sensors, and other sources as needed. The ODE then validates, integrates, sanitizes, and aggregates the data and distributes it to subscribers based on the subscribers' needs.	The objectives of this project were to productize and manage ODE software as a collaborative, open-source project; develop and test new ODE features; and test a regional ODE model that ingests and processes data from multiple local ODEs.

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ITS JPO	2018-2019	Performance Metrics and Evaluation	This project first developed accessible transportation performance metrics that could be used to evaluate ATTRI prototypes and other deployments. With the developed performance metrics, the project also assessed impacts resulting from the deployment of specific ATTRI prototypes in the ATTRI Wave 1 Application Development.	Project scope included the development of accessible transportation performance measures.
ITS JPO	2018-2019	Phase 2: Smart Phone Based Mid-Block Pedestrian Crossing In-Vehicle Warning	This project tested the application at mid-block crossings in Northern Virginia and Charlottesville, VA.	Demonstration and testing of the Phase 1: Smart Phone Based Mid-Block Pedestrian Crossing In-Vehicle Warning' application in an operational environment.
ITS JPO	2018-2019	Policy Impacts Assessment	This project identified and assessed policy impacts relevant to ATTRI Wave 1 applications.	Identification and assessment of ATTRI Wave 1 application policy impacts and recommendations on policies, guidelines, and rulemaking to support mobility and accessibility pertaining to Wave 1 applications.
ITS JPO	2017-2018	Pre-Deployment Guides	The contractor developed a set of written pre-deployment guidelines for four additional V2I applications using the input obtained from the project team and stakeholders.	This project aimed to develop pre-deployment guidelines for four additional V2I applications.
ITS JPO	2020-2022	Refining Real-World Case Studies for AI in Transportation	To determine where an appropriate federal investment or research project may provide needed positive impact, the ITS JPO first plays a role in identifying critical needs and challenges in the transportation system and finding technologies or	The scope of this project included the evaluation of real-world AI case studies and the further development and execution of a

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			approaches to address them. ITS JPO then partners with U.S. DOT modal administrations, state and local governments, industry, and academia to better understand the potential impacts of each identified innovation and how they can be applied to the transportation system.	deployment plan for a real-world AI scenario in transportation.
ITS JPO	2017-2022	Regional-National Strategy for Data Federation	This project conducted six national/regional workshops (and supporting virtual events/activities) to elicit stakeholder needs related to data sharing, identified potential approaches to the federation of data among operational data environments, and summarized findings.	National strategy with respect to the federation of emerging data sources.
ITS JPO	2020-2022	Research on the Usefulness of Text Analytics Techniques to Enhance Transportation Performance Management and Performance-based Planning Processes	This project explored text mining and analytical techniques that can be used to evaluate and interpret unstructured data.	This project focused on developing recommendations on how to use text analytics to help implement and manage statutory performance provisions as well as other future requirements.
ITS JPO	2019-2022	Roadside Unit (RSU) Standardization	The project evolved the FHWA-developed RSU Specification Version 4.1 with additional needs identified by the NTCIP 1218 RSU management	Voluntary technical standard for RSUs to enable secure, interoperable connectivity implementations nationwide.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			standard to allow publication as an ITS standard and associated hardware reference implementation.	
ITS JPO	2017-2019	SCMS Proof-of-Concept Operations	This line item funded the continuing operations of an initial, proof-of-concept security credential management system that supported the CV Pilots, Smart Cities, and other early adopters.	The purpose of the project was to establish an operational version of the SCMS proof of concept that would provide security credentials for V2V and V2I communication technology.
ITS JPO	2020-2022	Security Credential Management System (SCMS) Proof-of-Concept Governmental Management Support	The project provided a minimum viable misbehavior detection capability to support CV Pilots projects.	This project included the provision of a minimum viable misbehavior detection capability and included lessons learned and data analysis from collected misbehavior detection information that can be used to improve and develop national SCMS user needs, requirements, and designs.
ITS JPO	2019-2021	Security Evolution for NTCIP	The project provided the critical analysis necessary to develop candidate solutions to address evolving security needs across the NTCIP family of standards.	Identification of potential solutions to update security for the NTCIP family of standards to be suitable for use with shared communications networks and a roadmap to achieve desired longer-term benefit of appropriate security solutions for the NTCIP family of standards.
ITS JPO	2017-2020	SEMI Test Bed	This project continued to support the services for the Affiliated Test Bed program.	This project aimed to foster a deployment community that moves forward in a consistent manner, which is a significant basis for interoperability. In addition to creating "domestic harmonization," Canadian

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
				counterparts participated, which helped with cross-border harmonization.
ITS JPO	2017-2020	Situation Data Clearinghouse	This project maintained the prototype Situation Data Clearinghouse and Situation Data Warehouse to provide users with the ability to exchange connected-x data on a national scale.	This project aimed to support operational data exchange for the CV Pilots and increase understanding of the costs and approaches to support large-scale operational data exchange systems within the connected-x environment.
ITS JPO	2018-2019	Special Studies	MOD foundational work consolidated the ongoing work by the U.S. DOT and changing environment into a general concept, and summarized the key technical, operational, institutional, and policy challenges; and provided a framework for program and project activities. This project allowed us the ability to address specific enablers and challenges of MOD with investigative reports/primers.	MOD enablers and challenges.
ITS JPO	2017-2018	Spectrum Interference Modeling	Models for the propagation of wireless signals are just emerging, and NTIA's ITS Boulder has used previous funding from U.S. DOT to develop baseline models.	This project aimed to tailor wireless signal models to reflect the propagation of signals of industry-offered Unlicensed National Information Infrastructure (UNII) devices and to analyze their impact on DSRC signals.
ITS JPO	2017-2019	Spectrum Site Research and Measurements	Continued research on spectrum sharing with commercial unlicensed devices; to perform baseline interference testing and feed information into standards coordination and development.	This project aimed to explore the feasibility of spectrum sharing with commercial unlicensed devices; to perform baseline interference testing and feed information into standards coordination and development, standards policy development; to monitor and support a

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
				strategy for political, commercial, and stakeholder outreach on testing results and policy conclusions.
ITS JPO	2017-2022	Spectrum Use Modeling	The interference and signal propagation models to not illustrate how the band and its channels are being used—what is the usage rate based on different applications and the frequency, given geographic layout of devices and accounting for significant mobility of the devices. This project focused on the development of a simulation and/or modeling capability to illustrate usage from both a visual as well as quantitative perspective.	This project aims to develop a modeling capability to employ DSRC and other media that helps with deployment and implementation of CV technologies.
ITS JPO	2019-2020	Standards Test Procedure Generator Evolution	This project updated the current test procedure generator to make the tool media agnostic and to translate the generator into an open-source tool for community improvement via a resource such as GitHub.	The project delivered a new version of the test procedure generator that was technology-neutral and utilized an open-source development environment to allow the community to recommend and add new features and other improvements.
ITS JPO	2017-2018	Study on Automation Needs During Adverse Weather	Research was conducted to identify how vehicles and drivers interact during adverse weather and road weather conditions at different levels of automation.	This project analyzed the effects of weather and road conditions on AVs to highlight clear needs for future research and rulemaking, including the impact of weather/road conditions on safety and mobility for AVs.
ITS JPO	2018-2019	Surface Transportation Infrastructure Penetration	One of the things lacking was an ability for an operating agency to measure their resiliency. Step one was to perform penetration testing from the field systems into the operational centers and with back-	Penetration testing approaches.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Testing Approaches	end systems. It was important to ensure that there was an annual update capability for approaches.	
ITS JPO	2020-2022	Temporal Components of Warnings and Notifications for Safe Manual Re-engagement with the Driving Task in Automated Driving	Prior research with vehicle warnings examined various aspects of warning designs and how they impacted driver reaction times. Further, there was prior research that explored and modeled how and at what rate drivers lose information relevant to the driving task when they remove their attention and how and at what rate they regain information upon re-engagement relevant to the situational awareness. The current project intended to build off of this foundation.	This project aimed to review existing research on how the design of warnings impacts driver reaction time and provides design guidance for warning with Level 3 ADS vehicles.
ITS JPO	2017-2018	Testing of Market-Ready Products	This project continued the current vehicle-to-pedestrian (V2P) Phase 1 effort which developed a test protocol to assess the safety effectiveness of V2P technologies. In Phase 2, the V2P team tested market-ready V2P technologies on either the TFHRC intersection test bed or one of the connected vehicle test bed locations.	Test results published in a final report.
ITS JPO	2019-2021	Transit Standards Needs Identification	The task provided an assessment of standardization needs for multimodal and accessible travel options to increase the interoperability of services and data exchanges between regions and ease access to these services for customers.	The primary objective of this project was to identify suitable ITS-unique, related transportation-focused and information and communications technology standards, as well as gaps and emerging needs required to effectively support interoperable provision of multimodal and accessible transit options across jurisdictions.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
ITS JPO	2018-2023	Transit Standards Support	This project was designed to provide modal support (public transit) to support U.S. DOT's initiatives in Intelligent Transportation Systems (ITS) standards.	Project scope includes preparing and executing a transit-centric CV standards gap analysis.
ITS JPO	2017-2018	Transportation Cyber Security Framework Expansion to Address CV Implications	The purpose of this project was to establish a security framework that addressed all of the infrastructure and not limit it to traffic signal controls and RSUs. The deployment of CV exposed previously isolated infrastructure components to potential security risks associated with over-the-air data transmission.	A comprehensive infrastructure security framework that was expandable and included both legacy infrastructure equipment as well as CV equipment.
ITS JPO	2021-2022	TRB AV and Shared Mobility Services Forum	This forum identified and shared perspectives on current issues associated with incorporating automated vehicles and shared mobility services into the transportation system.	This forum brought together public, private, and research organizational partners to identify and facilitate fact-based research needed to deploy automated vehicles and shared mobility services in a manner and timeframe that informs policy to best meet long-term goals, and to share perspectives on these issues.
ITS JPO	2018-2020	Truck Platooning Field Test - Independent Evaluator	This project built upon the previous FHWA and JPO exploratory research to assess and study two and three truck platooning technologies and operations.	Development and validation of truck platooning deployment capabilities. Identification of the impacts on truck drivers, road users, operators, and fleet owners.
ITS JPO	2018-2020	Truck Platooning Impacts on Bridge Infrastructure, Phase I	This project conducted an initial analysis on how truck platooning applications impact traditional load factors for existing bridge infrastructure and whether platooning would result in loading greater than that anticipated by current design standards and how	Impact analysis of truck platooning on traditional load factors for existing bridges. Outputs will inform the development of new loading models.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Theoretical Analysis	potential impacts are related to bridge strength, service, and fatigue.	
ITS JPO	2019-2021	TFHRC Communications Media Testing for Transportation Infrastructure	The purpose of this project was two-fold: (1) to provide TFHRC with the ability to advance testing of the next generation of communications technologies for transportation infrastructure and cooperative and automated applications; (2) to provide funding to acquire a critical range of resources to support TFHRC testing as well as testing at other sites.	The scope of this project included the procurement of various resources needed to provide TFHRC with the ability to advance testing of the next generation of communications technologies for transportation infrastructure and cooperative and automated applications.
ITS JPO	2018-2019	Two Truck (Level 1) Platooning Deployment Readiness Test and Evaluation	This project built upon previous FHWA and JPO exploratory research to assess and study two and three truck platooning technologies and operations for upcoming commercial trucking industry plans to deploy CACC truck platooning.	Field testing of long-haul two-truck platooning in order to assess the impacts and benefits. Understanding of truck platooning impacts and benefits will accelerate deployment.
ITS JPO	2021-2022	US DOT Staff Training Plan for Automated Vehicles and Vehicle Connectivity	This project continued the work started to educate the staff of FHWA and Federal Lands by providing resources, materials, cohort or peer development and delivery, webinars, workshops, meetings, and development and delivery.	Execution and delivery of the U.S. DOT Staff Training Plan for AVs and Vehicle Connectivity.
ITS JPO	2018-2020	V2X Communications Large-Scale Field Preparations and Testing	U.S. DOT partnered with the FCC and NTIA for testing of DSRC and UNII devices (and potentially other emerging devices) with V2V and V2I safety applications employed.	Site selection and preparation for large-scale testing in a more naturalistic setting to ensure that no harmful interference occurs to DSRC-based applications under real deployment-scale conditions.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
ITS JPO	2020-2022	Work Zone Data Exchange Phase 2	Industry partners require a critical mass of active and consistent work zone data feeds from cities, counties, and states to justify substantial engagement in the Work Zone Data Exchange project. To rapidly increase the number of jurisdictions able to publish open work zone data feeds, the U.S. DOT is developing a fixed amount, simplified grant program to provide public roadway authorities financial resources and technical assistance to stand up data feeds and address common technical, institutional, and operational barriers.	This project aimed to accelerate safe roll-out of AVs through voluntary work zone data exchange and enabled infrastructure owners to increase quality and timeliness of data feeds. The project also aimed to establish institutional and technical models to sustain data exchange for market-driven implementations over a specified period of time.
NHTSA	2020-2025	ADAS Technology and Distracted Driving	This project will assess whether use of ADAS increases distracted driving behaviors, particularly engagement in non-driving related tasks. If so, the project will determine where and when the behaviors occur as well as the safety implications.	Results from innovative research addressing emerging issue to publish in technical report.
NHTSA	2021-2022	ADS - Lumbar spine response and injury risk	This research supports an evaluation of injury risk and development of injury criteria for the lumbar spine that can be applied towards use with the THOR dummies and has specific applications in ADS.	Human body models (HBMs) and anthropomorphic test devices (ATDs) for use in alternative seating arrangements associated with ADS-equipped vehicle designs.
NHTSA	2021-2021	ADS Occupant Kinematics - Rear Facing Upright and Reclined	These projects support the collection and/or application of new kinematic and injury data to support development/refinement of tools (ATDs, HBMs) that can be used to assess occupant safety in ADS alternative seating arrangements. Current	HBMs and ATDs for use in alternative seating arrangements associated with ADS-equipped vehicle designs.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			tools were not developed for highly reclined or high-speed rear-impact applications.	
NHTSA	-	Advanced 5th Percentile Female Crash Dummy (THOR-05F) Thorax Injury Criteria Development	Collect sled test data in realistic seat and restraint conditions with the THOR-05F crash dummy.	THOR-05F Advanced ATD
NHTSA	-	THOR-05F Testing, Evaluation and Documentation	Development/evaluation of newly designed parts based on initial evaluation; complete repeatability and reproducibility (R&R)/Durability testing and reports; biofidelity evaluation relative to Hybrid III 5th percentile female crash dummy; qualification manual/procedures for assembly, disassembly, and inspection/drawing package.	THOR-05F Advanced ATD
NHTSA	-	Advanced Frontal Child ATDs – 10-year-old Large Omnidirectional Child (LODC)	This project is developing a 10-year-old child dummy with improved biofidelity and comprehensive injury risk measurement capabilities in all loading directions common in real crashes, so that a child restraint's safety benefit can be more fully addressed.	10-year-old LODC.
NHTSA	-	Advanced Frontal Crash Dummies' Crashworthiness	Crashworthiness evaluation to support Rulemaking and NCAP initiatives for the THOR 50th male crash dummy, including support for frontal crash testing. Continue to support the development of the THOR 5th female and LODC 10-year-old child dummy,	Virtual (HBMs) and physical (ATDs) for use in alternative seating arrangements associated with ADS-equipped vehicle designs.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Performance Assessment	including refining seating procedures, assessing durability, and assessing performance in full frontal and/or frontal oblique crash tests (LODC child dummy in rear seat only).	
NHTSA	2021-2022	Alternative Glazing Performance Tests to Support FMVSS 205 and GTR Evaluations	Conduct an evaluation of certain tests specified in FMVSS 205 to support possible changes to that standard, including the use of glazing samples vs. production pieces and the requirements of the glazing GTR.	Test procedures.
NHTSA	-	Alternative Seating Configurations with Automated Driving Systems (ADS) - Forward Facing (includes reclined), Part 1 (50th Percentile)	Collection and/or application of new kinematic and injury data to support development/refinement of tools that can be used to assess occupant safety in ADS alternative seating arrangements. The focus of this task is on forward-facing and reclined 50th-percentile occupants.	Virtual (HBMs) and physical (ATDs) for use in alternative seating arrangements associated with ADS-equipped vehicle designs.
NHTSA	-	Alternative Seating Configurations with Automated Driving Systems (ADS) - Rear Facing Upright and Reclined	Collection and/or application of new kinematic and injury data to support development/refinement of tools (ATDs, human models) that can be used to assess occupant safety in ADS alternative seating arrangements. Current tools were not developed for rear-facing, (upright or reclined) high-speed impact applications.	Virtual (HBMs) and physical (ATDs) for use in alternative seating arrangements associated with ADS-equipped vehicle designs.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
NHTSA	-	Alternative Seating Configurations with Automated Driving Systems (ADS) - Lumbar spine response and injury risk FY22-126	This research supports an evaluation of injury risk and development of injury criteria for the lumbar spine that can be applied towards use with the THOR dummies and has specific applications in ADS enabled alternative vehicle designs. Base task (FY '21) involved literature review and assessment of current state of the art. Optional task(s) in FY '22 involves human body modeling and PMHS testing.	Virtual (HBMs) and physical (ATDs) for use in alternative seating arrangements associated with ADS-equipped vehicle designs.
NHTSA	-	Assessment of Alternative Glazing Performance Tests	Conduct an evaluation of certain tests specified in FMVSS 205 to support possible changes to that standard, including the use of glazing samples vs. production pieces and the requirements of the glazing GTR.	Data to support Agency decisions.
NHTSA	-	Buckle Up, Phone Down Evaluation	The state of Missouri developed a communications program designed to increase belt use and decrease distracted driving called "Buckle Up, Phone Down." NHTSA's Occupant Protection Division is funding demonstrations of the program in two additional states, and this project is to provide an evaluation of program implementation and of behavior change through observations.	Outcome and process evaluation of innovative program with results in a technical report.
NHTSA	-	Cellphone Blocking Technology to Reduce Distracted Driving	The base task will assess the feasibility of carrying out the project through a literature review, program scan, and development and pilot testing of data collection technology involving 9 participants.	Results from innovative research addressing emerging issue to publish in technical report.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
NHTSA	2020-2025	Characterizing High-Risk and Older Novice Drivers	This project will identify the personal characteristics and patterns of driving common to high- and low-risk novices during the first six months of independent driving and to examine the ways in which these factors, as well as trajectories of unsafe driving, differ between older (age 18) and younger (age 16) novices over the same time period.	Results from innovative research addressing emerging issue to publish in technical report.
NHTSA	2020-2024	Child passenger safety perceptions and practices in ridesharing and vehicles with ADS	This project will help us 1) understand how people choose to secure their children when in ride-sharing vehicles, 2) understand caregiver and driver perceptions of child restraint system (CRS) use in shared vehicles, and 3) generate practical ideas for improving CRS use in ride-share and vehicles with automated driving systems (ADS).	Results from innovative research addressing emerging issue to publish in technical report.
NHTSA	2021-2021	Child Restraint Frontal Fleet Testing at Contract Laboratories to Support FMVSS 213 Evaluation	Testing to support responses to comments on FMVSS 213 frontal NPRM.	Data to support Agency decisions.
NHTSA	2021-2023	Child Restraint Safety Research to Support FMVSS 213 and LATCH Evaluations	Provide support to address comments and other issues related to the FMVSS 213 frontal NPRM; provide support for the FMVSS 213 side and FMVSS 225 (LATCH) final rules; conduct FMVSS 213 frontal pulse variation analysis; develop FMVSS 213 sled test qualification procedures; evaluate booster seat metrics.	Data to support Agency decisions.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
NHTSA	-	Child Restraint Safety Research to Support Rulemaking Initiatives	Provide support to address comments and other issues related to the FMVSS 213 frontal NPRM; provide support for the FMVSS 213 side, Part 572 (Q3s), and FMVSS 225 (LATCH) final rules; continued evaluation of FMVSS 213 frontal pulse variation, seat foam characteristics, and surrogate retractor.	Data to support NHTSA decisions.
NHTSA	1900-1900	Crashworthiness Evaluation of the Biofidelic Rear Impact Dummy	Development of an initial seating procedure for use with a rear-impact dummy; possible initial assessment of durability in sled testing.	Seating procedure.
NHTSA	-	Crashworthiness Research on Pedestrian Protection - Advanced Legform Evaluation	The number of pedestrians killed (~5,000 annually) or injured on U.S. roads is both significant and increasing. Research and testing by both NHTSA and industry has demonstrated that cost-effective countermeasures integrated into a vehicle's front end can dramatically reduce injuries to the pedestrian through energy absorption. This project builds on this body of work by evaluating improved legforms that more fully assess upper leg/pelvis injuries due to impacts with high bumper vehicles. This project is also investigating whether countermeasures that are effective at reducing head/leg injuries are also effective at addressing thorax injuries.	Test procedures.
NHTSA	-	Develop and Test Impaired Driving Detection Cues	This project will follow previous studies such as the "DWI Detection Guide" by examining potential driving cues that may indicate drug-impaired driving based	Innovative project to develop and provide tools for law enforcement to better detect drug-impaired driving.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			upon observations of impaired driving validated by law enforcement.	
NHTSA	-	Development of Injury Criteria for the LODC 10-Year-old Child Dummy	Finalize thorax/abdomen/head/brain injury risk functions.	Data to support Agency decisions.
NHTSA	2013-2022	Driver Alcohol Detection System for Safety	Cooperative agreement between Automotive Coalition for Traffic Safety and NHTSA (begun February 2008) to develop and test prototypes that may be considered for vehicle integration. The goal is to develop noninvasive, seamless technologies to measure driver blood alcohol content and reduce incidence of drunk driving.	The goal of this effort is to develop a passive system to detect driver alcohol content. While the work has not yet been completed, a major milestone was reached. Licensing is now available for the zero-tolerance (<0.02 blood alcohol content) breath detection fleet derivative.
NHTSA	2019-2024	Driver Knowledge of Correct Use of New Technology Features in Vehicles	This project explores how drivers use ADAS and the extent to which such systems affect safety behaviors among drivers in their 40s compared to older drivers (70+). Additional optional tasks include adding young drivers (18-25) and developing training based upon the results.	Technical report.
NHTSA	2020-2023	Drivers' Internal Reasoning about Speeding Behavior	This project worked with a state to conduct a multi-methodological study of the internal reasoning drivers use to justify their speeding behavior through a self-report survey, examination of driving records, and focus group interviews.	Innovative data collection method to advance our understanding of how people think about alcohol- and drug-impaired driving.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
NHTSA	2020-2022	Drug and Alcohol Prevalence in Road Users in Severe and Fatal Crashes	This study examines the prevalence of legal and illegal drugs in the systems of seriously or fatally injured drivers and other crash-involved road users (e.g., pedestrians, bicyclists, scooter riders) presenting directly to selected trauma centers or morgues.	Innovative method of collecting information about impaired driving that will result in a data set, technical report, and draft journal article.
NHTSA	-	Dummy Management Laboratory	Management, calibration, testing, and deployment of NHTSA's fleet of crash test dummies, instrumentation, and spare parts.	Tools for safety evaluations.
NHTSA	2021-2022	Evaluate Test Procedure for Hydrogen Temperature Pressure Relief Devices	Conduct fire testing of temperature pressure relief devices for high-pressure hydrogen cylinders to evaluate suitability of draft test procedures for self-certification.	Test procedures.
NHTSA	2015-2020	Evaluation of Community-Oriented Enforcement Demonstrations	This modification will cover additional costs associated with the evaluation of two demonstration projects to increase public awareness and build community support for law enforcement efforts in seat belt and alcohol-impaired driving enforcement.	Outcome and process evaluation of innovative program with results in a technical report.
NHTSA	-	Evaluation of Rear Seat Belt Elongation Requirements	Conduct additional tensile tests on seat belt assemblies and sled tests with vehicle rear seat bucks to assess the safety implications of modifying the belt elongation requirements and test procedures for rear seat occupants.	Data to support Agency decisions.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
NHTSA	2021-2022	Evaluation of Seat Belt Elongation for Rear Seat Occupants	Conduct additional tensile tests on seat belt assemblies and sled tests to evaluate the relationship between belt elongation and rear seat occupant protection; compare U.S. and European standards.	Data to support Agency decisions.
NHTSA	-	Evaluation/ Documentation for the BioRID Rear Impact Dummy	Qualification test development and R&R; crash dummy/PMHS sled testing without head restraint.	Test procedures.
NHTSA	-	Evaluation/ Documentation for the LODC 10-Year-Old Child Dummy	Complete Part 572 documentation; assess relative to new pediatric thorax and shoulder response targets.	Data to support Agency decisions.
NHTSA	2021-2023	Examination of how the duration of secondary task engagement changes over time in lower levels of driving automation	Limited available evidence suggests that drivers may engage in secondary tasks both in Level 0 and Level 2 at approximately equal rates. However, anecdotal evidence suggests that the length of task engagement is longer with Level 2 systems activated. The goal of this study is to quantify both the number and length of secondary task engagement across levels of driving automation (i.e., Level 2 active vs. inactive) in a naturalistic setting.	Data to support Agency decisions.
NHTSA	2016-2022	Examine the Feasibility of a Standardized Field Test for Marijuana	This modification added additional participants to current laboratory testing of a potential standardized field test for marijuana impairment.	Development of innovative technology to identify cannabis-impaired driving.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Impairment Laboratory Evaluations		
NHTSA	2015-2020	Fatigue in Emergency Medical Services (EMS)	This modification will cover additional costs associated with refining and testing the learning modules, as well as to increase the incentives to participants in a study of the effectiveness of a training program on reducing fatigue in EMS personnel.	Innovative project to provide tools that the EMS community can use to reduce fatigue including evidence-based guidelines, a fatigue management training module, a web-based scheduling tool, several technical reports, and several journal articles.
NHTSA	2021-2022	Female-Specific Thorax Data Collection for Injury Risk Function Development	Collection of additional female-specific injury data for use in thorax injury criteria development for THOR-05F dummy.	THOR-05F Advanced ATD.
NHTSA	2022	Finite Element Model Development for the LODC 10-Year-old Child Dummy - FY22-110	Complete development and validation of the LODC child dummy finite-element model.	Tool for safety evaluation.
NHTSA	2021-2022	First Responder and EV Crash Investigation Safety	New research to augment and update existing first responder safety protocol recommendations including toxicity of Li-ion fires would be pursued to include expanding internal capabilities with charging and discharging equipment purchases as well as	Updated safety recommendations.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			personal protective equipment to safely supports more EV crash investigations.	
NHTSA	2021-2022	FY 2021 NCAP Load Cell Data Collection, Replacement, and Calibration	Continue to collect additional data during NCAP tests which allows NHTSA to indirectly monitor industry compliance with 2003 voluntary agreement on frontal crash compatibility.	Data to support Agency decisions.
NHTSA	2021-2022	Global Human Body Models Consortium - Year 3 of 5	FY21 activities focused on (1) validation of models in high-speed rear impact; (2) application of new female-specific experimental data in female model validation; (3) morphing of models to represent younger, middle-aged, and older occupants/pedestrians.	Human body models for government, industry, and academic use.
NHTSA	-	Global Human Body Models Consortium - NHTSA Co-funding for Year 4 of 5	FY '22 activities to focus on (1) development and validation of detailed/simplified 50th female occupant models; (2) model development/ enhancement for non-traditional seating (ADS); (3) ATD-like human model development (morphing of 5th/50th models to key anthropometry and matching segment masses/MOI).	Human body models for government, industry, and academic use.
NHTSA	2021-2024	Influences on Outcome of Proposed Graduated Driver Licensing Legislation	Examine factors predictive of the relative "success" of all bills related to graduated driver licensing introduced in the past 5 years. Based on factors associated with bills' "success," select 9 bills/states for in-depth study: interview members of various groups about the bills/states; synthesize interview results and archival/secondary data sources to	Final report.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			identify common influences on graduated driver licensing bills' success; document results of all analyses in a final report.	
NHTSA	-	Lay People's Understanding about Alcohol- and Drug-Related Impairment	Conduct a survey to examine: lay individuals' understanding and knowledge about alcohol- and drug-impairment and impaired driving; lay individuals' judgments about others' alcohol- and drug-impairment and impaired driving; how certain factors (e.g., situational, evidential) affect lay individuals' judgments about others' alcohol- and drug-impairment and impaired driving, and; the relationship between lay individuals' understanding, knowledge, and judgments regarding alcohol- and drug-impairment and impaired driving.	This is an innovative research study to examine how individuals think about alcohol and drug impairment and how this impacts their judgements and decisions related to impaired driving. Findings will inform development of impaired driving countermeasures.
NHTSA	2021-2022	Lower Interior Rear Seat Occupant Protection - Fleet and Countermeasure Assessment	Evaluate the head injury causing potential in recent model vehicles from rear seat occupant contacts with seat backs, head restraints, and lower B-pillars. This includes evaluation of possible countermeasures and refinement of test procedures.	Test procedures.
NHTSA	2020-2023	Maintaining Situational Awareness when Operating Automated Vehicles with Automated Driving	This project will document the current state of knowledge in driver/operator engagement relevant for motor vehicles including learning from other transportation modes such as rail and aviation.	Results from innovative research addressing emerging issue to publish in technical report.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Systems: Findings from Other Modes		
NHTSA	-	Material Flammability Test Procedure Development	Continue research to develop microcalorimetry testing as an upgrade for FMVSS 302.	Test procedures.
NHTSA	-	Motorcycle Helmet Research - Rotational Injury Prevention	Head injuries for motorcyclists continue to rise; This project involves evaluation of candidate rotational test configurations for distinguishing performance of helmets exposed to rotational loading; analysis of current linear acceleration criteria.	Data to support NHTSA decisions.
NHTSA	-	Motorcycle Helmet Research - Rotational Injury Prevention	Install/troubleshoot new drop tower; Develop/evaluate procedure for rotation testing.	Test procedures.
NHTSA	2021-2022	Motorcycle Helmet Test Procedures	Develop/refine test procedures for testing motorcycle helmet performance to improve objectivity and assess repeatability. This project is focused on short-term refinements to the existing FMVSS No. 218 test procedures based on previous testing experience and industry recommendations. This project does not explore the use possible new tests or performance criteria (such as rotational head criterion) for evaluating motorcycle helmet performance.	Test procedures.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
NHTSA	2016-2022	National Cooperative Research and Evaluation Program	This agreement provided support for administration of the National Cooperative Research and Evaluation Program, now termed the Behavioral Traffic Safety Cooperative Research Program, with research support from the TRB.	Cooperative research program provides opportunities for non-federal stakeholders to initiate innovative research projects to be funded through the program.
NHTSA	2018-2022	National Survey of Drowsy Driving Knowledge, Attitudes, and Behaviors	This project will conduct a nationally representative survey of a randomly selected sample of drivers on their attitudes, behavior, and awareness of drowsy driving.	Innovative method of collecting information about drowsy driving that will result in a data set, technical report, and draft journal article.
NHTSA	-	NPRM Support and Documentation for Worldwide Harmonized Side Impact Dummy (WorldSID-50M)	Rulemaking/NCAP support; procedures for assembly, disassembly, and inspection/drawing package, qualification manual with single arm test, finalize rest of documentation.	WorldSID-50M Advanced ATD
NHTSA	2021-2023	New York State Rear Seat Belt Law Evaluation	Beginning in November 2020, all passengers in rear seats in New York state aged 16 and older must wear seat belts. This project evaluated the effect of the new law on rear belt use by examining implementation and conducting observations of belt use.	Outcome and process evaluation of state law changes with results in a technical report.
NHTSA	2021-2022	Occupant Safety Performance Response and Parametric Study	Acquire scaled HBMs to match subjects in field trials.	Improved tools for safety evaluation.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		of Pre-Crash Vehicle Maneuvers		
NHTSA	-	Older Occupant Protection - Subdural Hematoma & Thorax	PMHS testing for subdural hematoma IRF; low-speed frontal crash test parameter development; small female side impact injury risk curve development (in conjunction with elderly side-impact group).	Data to support Agency decisions.
NHTSA	-	Pedestrian Protection Crashworthiness Research and NPRM/NCAP support	NPRM/NCAP support; aPLI (upper/lower legform test tool) evaluation; testing/analysis support for pedestrian case reviews.	Data to support Agency decisions.
NHTSA	2020-2024	Pilot Methodology for an Observational Survey of Motorcycle Personal Protective Equipment	This project followed up on a recently completed study that developed a methodology for observing protective helmets, gloves, pants, and jackets worn by motorcyclists by expanding the testing to two states.	Innovative method of data collection for motorcycle observation surveys to identify and collect information on protective gear used by observed motorcycle operators and riders.
NHTSA	2021-	Safety of Two-Wheeled Scooters	This project will systematically assess and compare ways to increase scooter visibility, specifically with high-visibility gear and headlight and tail light	Identification of factors and characteristics that improve conspicuity, which will inform recommendations for scooter operators and passengers.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
			configurations. The project will assess the effect of material type, placement, and motion on conspicuity.	
NHTSA	2020-2022	Strategic Highway Research Program (SHRP2) Speeding Data: Additional Analyses and Database Development	This project will follow-up on a previous analysis of speeding behavior among participants in the SHRP2 Naturalistic Driving Study by examining pre-crash factors in speeding-related crashes and by developing an algorithm that classifies lane-change behavior.	Innovative development of an algorithm to classify lane changing behavior in the SHRP2 naturalistic driving data, to be used in study of relationship of speed to crashes.
NHTSA	2021-2022	Side-Impact Test Procedure Development for Wheelchair Systems	Develop a standard side impact sled test procedure and assessment for manual and powered wheelchairs using standard and automated tie down and restraint configurations.	Test procedure(s).
NHTSA	2021-2021	Subdural Hematoma Injury Risk Curve Development for Older Occupants	Among older occupants, serious head and thorax injuries are the most frequent and life-threatening. This project addresses subdural hematoma, which becomes more frequent and more life-threatening with age.	Data to support Agency decisions.
NHTSA	2020-2023	Support for Research on Forensic Toxicological Laboratory Testing	This project provided support to the National Institute of Justice for collaborative research activities examining the feasibility and utility of laboratory testing guidelines related to drug-impaired driving investigations.	Innovative examination of toxicological data in drug-impaired driving cases.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		and Reporting Practices		
NHTSA	-	Test Procedure Development for Motorcycle Helmet Safety Performance	Development of test procedures for FMVSS No. 218 impact attenuation, penetration, retention, positional stability, rigid projection, chin bar impact, face shield penetration, and alternative retention tests.	Test procedure.
NHTSA	2021-2022	THOR Crash Testing at Contract Laboratories to Support FMVSS 208 Evaluation	Crash testing to support rulemaking initiatives for the THOR-50M ATD.	THOR-50M Advanced ATD.
NHTSA	2021-2021	THOR-05F Evaluation/ Documentation - Repeatability, Reproducibility, and Durability	The THOR-05F ATD is being developed to enable the possibility to address occupant protection concerns for small-sized occupants involved in frontal crashes. It is designed to have improved biofidelity and instrumentation as compared to existing small female frontal ATDs. The increased capability of this dummy may also allow it to be used to assess injuries to older occupants and makes it a prime candidate for being the most appropriate tool for assessing 5th-percentile female occupant safety in ADS alternative seating arrangements.	THOR-05F Advanced ATD.
NHTSA	2021-2022	THOR-05F Finite Element Model	Development and validation of a THOR-05F finite element model.	THOR-05F Advanced ATD.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
NHTSA	2021-2021	THOR-05F Knee-Thigh-Hip testing for injury criteria development	Female-specific, knee-thigh-hip PMHS testing and computational modeling to support THOR-05F injury criteria development.	THOR-05F Advanced ATD.
NHTSA	-	THOR-50M Advanced Crash Dummy Modifications for Reclined Seating	Optional task to order hardware for application on a highly reclined version of the THOR-50M crash dummy to be used in ADS-related seating studies.	THOR-50M Advanced ATD - Reclined/AV.
NHTSA	-	THOR-50M Advanced Crash Dummy Modifications for Reclined Seating (additional design iteration)	Further improve usability, durability, repeatability, and/or biofidelity of a highly reclined version of the THOR-50M dummy to be used in ADS-related seating studies.	THOR-50M Advanced ATD - Reclined/AV.
NHTSA	-	THOR-50M Advanced Crash Dummy Rulemaking/NCAP Support/ Enhancements	Rulemaking/NCAP support; evaluation of alternative components (face insert, internal Data Acquisition System, pressure measuring abdomen, components/instrumentation from alternative vendors).	THOR-50M Advanced ATD.
NHTSA	2021-2021	THOR-50M Enhancements	Evaluate potential enhancements (e.g., face insert, pressure-sensing abdomen).	THOR-50M Advanced ATD.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
NHTSA	2021-2022	THOR-50M Reclined Matched-Pair Testing	Evaluate the biofidelity of the THOR-50M with modifications to allow reclined seating postures; make any necessary modifications; and re-test.	Data to support Agency decisions.
NHTSA	2020-2021	Unattended Child Reminder Systems Evaluation and Test Development	Finalize development of assessment tests for vehicle-based system and aftermarket vehicle systems.	Test procedures.
NHTSA	2020-2023	WorldSID Fleet Testing and Evaluation	Crashworthiness evaluation to support rulemaking initiatives for the WorldSID-50M ATD, as well as continued support for the development of the WorldSID 5th-percentile female ATD (WorldSID-05F). This involves crash testing to evaluate vehicle and ATD performance and ATD durability.	WorldSID-50M and WorldSID-05F Advanced ATDs.
NHTSA	-	WorldSID Side Impact Dummy Crashworthiness Performance Assessment and Fleet Testing	Crashworthiness evaluation to support rulemaking and NCAP initiatives for the WorldSID-50M ATD, as well as continued support for the development of the WorldSID-05F ATD. This involves additional crash testing to evaluate vehicle and ATD performance and ATD durability.	WorldSID-50M and WorldSID-05F ATD Advanced ATDs.
NHTSA	2021-2021	WorldSID-50M Rulemaking Documentation	Produce documentation needed for potential inclusion of WorldSID-50M ATD as an option in FMVSS 214 and future inclusion in NCAP.	WorldSID-50M Advanced ATD.
PHMSA	2018-2020	A Novel Structured Light-Based Sensing and	Project purpose was to design and integrate an inline inspection tool based on novel structured light phase	Development and testing of a comprehensive corrosion damage detection framework based on enhanced structured light three-

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Probabilistic Diagnostic Technique for Pipe Internal Corrosion Detection and Localization	measuring profilometry to detect and characterize corroded surfaces in pipeline internal walls.	dimensional profiling with tailored algorithms for inline inspection from the pipe internal surfaces.
PHMSA	2018-2020	Consistency Review of Methodologies for Quantitative Risk Assessment	**The project developed a methodology and guideline to establish consistency, guidance, Background knowledge, and best practices to perform quantitative risk assessments of LNG facilities and demonstrate it on two representative generic LNG facilities.**	Standard methodology and guidelines for performing qualitative risk assessments for LNG facilities. Potential clarifications to the proposed 2019 edition of National Fire Protection Association 59A will be identified for PHMSA's consideration if it considers incorporating it by reference in 49 CFR 193.
PHMSA	2018-2019	Cost-Benefit Analysis of Deploying or Retrofitting External Based Leak Detection Sensors	The project delivered new knowledge outlining a methodology for performing cost-benefit analysis on external leak detection systems intended for use on hazardous liquid and natural gas transmission pipelines.	A cost-benefit analysis framework that can be used to objectively compare different deployment alternatives for external leak detection.
PHMSA	2019-2021	Data Collection, Normalization, and Integration	This project investigated the challenges of managing terabytes of data coming from multiple threat and infrastructure types on real pipelines. Researchers	Framework that can effectively factor large volumes of data resulting from technological

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Methods to Enhance Risk-assessment Tools for Decision-making	applied machine learning, causal modeling, Bayesian networks, and decision-science methods to the challenge of data normalization, data analytics, and data synthesis. The data must be screened, normalized, and integrated into assessment tools for actionable decision-making.	advancements in remote sensing and inspection tools.
PHMSA	2019-2021	Develop a Risk-Based Approach and Criteria for Hazard Detection Layout	This project developed a risk-based approach to (and criteria for) hazard-detection layouts at LNG facilities. The project identified the types of detectors best suited to serve the various areas that are common to most LNG facilities.	Methodology can be utilized to develop a hazard detector layout as well as to evaluate existing layouts.
PHMSA	2019-2021	Develop Remote-sensing and Leak-detection Platform That Can Deploy Multiple Sensor Types	The project developed and validated performance of a UAS with multiple sensors to improve pipeline right of way and leak detection monitoring. The UAS will be designed to provide automated multi-threat monitoring and surveillance through remote sensing systems.	The technologies in development for this program — the InstiMaps Automated Threat Detection System and AiRanger BVLOS UAS — have the potential to surpass the detection capabilities currently employed during routine patrol, to contribute to operator Leak Detection Programs, to make routine patrol safer, more effective, more automated, with reduced carbon footprint. With continued focus on FAA-type certification of the aircraft for pipeline patrol, commercial operations may commence as soon as early 2023.
PHMSA	2018-2022	Development of a Prediction Model for Pipeline Failure Probability Based on Learnings from	Developed a knowledge-based predictive model to assess pipeline failure through:	The project produced a high potential in turning incident text data into valuable knowledge because the structure of network may lead to a hierarchy of causation.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Past Incidents and Pipeline Specific Data using Artificial Neural Network	conducting root cause analysis of past incidents to identify those factors that have the potential to contribute to failure; utilizing the learnings about contributing factors behind pipeline failure to develop a predictive model based on artificial neural networks that monitors current existing conditions to determine dynamic failure probability of a pipeline.	
PHMSA	2016-2019	Development of Electromagnetic Acoustic Transducer (EMAT) Sensors for Corrosion Mapping of Unpiggable Natural Gas Pipelines Using Inline Inspection Tools	The project developed a bench-scale EMAT sensor that can be used to assess small diameter unpiggable pipelines containing reduced diameter fittings and other restricting features. The EMAT was specifically designed to directly measure the remaining wall thickness.	Successful integration and field demonstration of the new sensor, electronics, and robotic platform. The project developed an EMAT sensor independent of any specific platform to allow integration with multiple piggable and unpiggable pipe inspection platforms.
PHMSA	2016-2019	Development of High-Performance Gas-Coupled Ultrasonic Transducers for Inspection of Unpiggable	The project developed new dry-coupled ultrasonic transducer techniques will be investigated to determine feasibility for in-line inspection in unpiggable gas pipelines, especially for wall loss measurements. This novel technology will produce more accurate, higher-temperature resistant UT	A bench-scale non-contact gas coupled single crystal ultrasonic transducer for measuring remaining wall thickness down to 0.25 inch (6 mm) at a reasonable standoff in traditionally unpiggable or difficult to inspect distribution pipelines.

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Natural Gas Pipelines	probes and have additional uses in inspection for wall loss and cracks in liquid pipelines.	
PHMSA	2018-2021	Development of Low-Power Wireless Sensor Network of Conductivity Probes for Detection of Corrosive Fluids Inside Pressure Vessels and Piping	The project purpose was to develop conductivity probes that can be easily integrated into existing internal corrosion monitoring infrastructure (access fittings) and connected via a low-power wireless sensor network.	This project has developed the technology required to integrate on-line conductivity probes into a low-power wireless sensor network. These nodes are able to be deployed in isolated locations without grid power or communications support by utilizing solar energy harvesting elements.
PHMSA	2016-2020	Development of New Multifunctional Composite Coatings for Preventing and Mitigating Internal Pipeline Corrosion	The project developed and implemented new multifunctional composite coatings for newly constructed or existing pipelines to achieve an acceptable and economical design with multiple performance/functionality levels.	This project provided a comprehensive investigation of the new high-performance coatings, from fabrication, characterization, to overall performance, striving for superior protective coatings for internal corrosion mitigation of oil/gas pipelines.
PHMSA	2016-2019	Electromagnetic Strategies for Locatable Plastic Pipe	The project developed and validated two approaches for producing pipe that is locatable using electromagnetic sensing.	The approach to incorporate microencapsulated magnetic nanoparticles into the plastic pipe materials failed. The approach to add an antenna resulted in the selection of two viable designs: a delay line-type antenna and a simple bowtie antenna.

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PHMSA	2019-2021	Evaluation of the Efficacy and Treatment of Hazard Mitigation Measures for LNG Facilities	The project developed a standardized, consistent, robust, and detailed methodology for determining effective hazard mitigation measures that will utilize the thermal radiation and vapor dispersion computational models currently approved by PHMSA. This research identified and described how each of the mitigation measures can be consistently incorporated into hazard modeling.	Methodology for determining effective hazard mitigation measures for LNG facilities.
PHMSA	2018-2021	Evaluation of Well Casing Integrity Management for Underground Storage Wells	The project provided a better understanding of the methodologies used to predict the remaining casing burst capacity for underground natural gas storage wells, including casing logging technologies and burst capacity prediction models.	Framework for using casing inspection data obtained from high-resolution downhole integrity logs to estimate casing reliability and predict how the reliability will change with time due to corrosion feature growth.
PHMSA	2018-2021	External Leak Detection Body of Knowledge	The project developed a recommended practice for external-based leak detection on natural gas transmission lines. The recommended practice will increase the safe operation of the U.S. natural gas transmission pipeline network by standardizing practices across operators and increasing the likelihood that a leak is found before becoming a safety hazard.	The research results could be used by an independent certification organization to develop specific certifications for leak detection systems used on transmission pipelines.
PHMSA	2016-2019	Fundamental Mechanochemistry-based Detection of Early-Stage Corrosion	Model guided development of advanced detection methods to quantify the physical and mechanical changes associated with early-stage stress corrosion cracking in high-strength pipeline steel.	A systematic framework was created to monitor changes in parameters germane to corrosion prevention, while mitigating the corrosion impact on the pipeline infrastructure.

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		Degradation of Pipeline Steels		
PHMSA	2019-2022	Improve Dent/Cracking Assessment Methods	This project considered the variability of assessment models when defining appropriate fatigue life safety factors. It builds on mechanical damage assessment and management tools that were developed by the pipeline industry and other research organizations and that are being considered in America Petroleum Institute Recommended Practice 1183: Assessment and Management of Dents in Pipelines.	The following areas for improvement considered in this project were identified: 1) Improvement of indentation crack formation strain estimation, 2) assessment safety definition and 3) ILI dent and coincident feature sizing variation impact.
PHMSA	2018-2020	Improved Tools to Locate Buried Pipelines in a Congested Underground	The project improved upon the existing Geospatial's Smart Probe® technology, which currently has the capability to accurately determine the three-dimensional position of a non-pressurized pipeline in order to accurately map the location of live natural gas mains.	The project developed and validated a geospatial probe to map existing buried utilities through insertion into live gas pipelines. The resulting technology transfer led to the Live Gas Mapper (LGM-2) tool by REDUCT.
PHMSA	2018-2021	Improvements to Pipeline Assessment Methods and Models to Reduce Variance	The project developed, validated, and demonstrated improved assessment methods and models to lower the variance of model outputs when assessing the impact of interactive threats.	A mathematical model was developed for analysis of depth propagation.

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PHMSA	2019-2021	Improving Subsurface Non-metallic Utility Locating Using Self-Aligning Robotic Ground-penetrating Radar	The project developed a pre-commercial prototype robotic locating system. This system uses GPS and adaptive ground probing radar sensors to improve the quality of image and location data.	The robotic platform was field-tested to improve the quality of image and location data using self-adapting antenna configurations that increase the probability of detection.
PHMSA	2019-2021	Improving the Reliability, Detection, and Accuracy Capabilities of Existing Leak Detection Systems Using Machine Learning	The project used machine learning to address three primary leak detection systems gaps: the ability to find smaller leaks, find leaks faster, and find leaks more reliably than is possible with conventional computational pipeline monitoring systems.	The project's main success was development of the algorithm and framework that describes how pipeline operators can integrate machine learning algorithms with computational pipeline monitoring data.
PHMSA	2018-2020	Low-Variance Deep Graph Learning for Predictive Pipeline Assessment with Interacting Threats	Develop new, low-variance data-driven models and approaches for interacting threat characterization, simulation, diagnosis, and prognosis, which integrate deep learning and graph theory to enable interacting threat assessment and variance reduction.	A hybrid and heterogeneous simulation and data-driven model of individual and interacting threats.
PHMSA	2019-2021	Mapping Indication Severity Using Bayesian Machine Learning from Indirect Inspection Data into	The project developed a fast, reliable, and accurate tool that extracts corrosion severity and real corrosion rates by adapting current direct assessment practices.	Project results are promoting a deeper understanding of the uncertainty of the external corrosion indirect inspection data through utilizing Bayesian machine learning techniques. The outcome of this research project could be adapted to the existing

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		Corrosion Severity for Decision-making in Pipeline Maintenance		industry standards for external corrosion direct assessment.
PHMSA	2018-2022	Modernize the Assessment of River Crossings	The project supplemented guidance from American Petroleum Institute Recommended Practice 1133, and expanded and improved the capabilities of existing tools available to assess and monitor pipeline riverine crossings. The project also developed and adapted risk screening tools through advances in engineering analysis that are field-validated.	Information on the capabilities of existing tools available to assess and monitor pipeline river crossings.
PHMSA	2018-2021	On-Board Power and Thrust Generation for the Explorer Family of Robots for the Inspection of Undiggable Natural Gas Pipelines	The project developed an on-board electric power generation and thrust generation system in order to extend battery life and increase the inspection distance of robotic inspection tools.	A module was integrated on the Explorer 20/26 robot that harvests pipe flow energy to generate a tow force on the robot and electric power to run the robot and store in its batteries for future use.
PHMSA	2018-2020	Performance Gap Comparison of Process Safety Management Consensus Standards and	The project evaluated consensus standards, best practices, and regulatory requirements for process safety management to support PHMSA's strategy to update regulatory requirements for safety management systems for LNG facilities.	A line-by-line comparison of requirements using 29 CFR 1910.119 as a baseline reference and as the structure to organize information in a detailed comparison table. In total, the analysis identified 156 individual process safety management items, of which

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		Regulatory Requirements for LNG Facilities		approximately 85 potential gaps were identified for consideration.
PHMSA	2020-2021	Procedures for Retrofitting Indoor Gas Service Regulators	The project developed recommendations on how to retrofit ventless regulators, or externally venting regulators.	Reduced risk when gas service regulators and associated higher pressure piping were installed inside to maintain the same level of safety as the one for regulators installed outside.
PHMSA	2019-2021	Procedures for Selecting Locating and Excavation Technologies	The project developed a web-based database of relevant technologies, regulations, and best practices to improve asset location decision-making.	The research project investigated underground locating technologies and provided decision-making tools for reducing the probability of excavation damage to utility lines.
PHMSA	2019-2021	Program to Advance Computed Tomography for the Development of Reference Standards for Pipeline Anomaly Detection and Characterization	The project developed an inspection process and validated the data produced through the use of computed tomography as a non-destructive evaluation technology system for measuring crack and seam anomalies in pipe steel.	Project results are a validated data set and process that confirms the use of computed tomography as a non-destructive evaluation technology system that can be used for measuring crack and seam anomalies in pipe steel.

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PHMSA	2018-2020	Reliability of Subsurface Safety Valves	The project assessed the role that subsurface safety valves can have in improving underground gas storage safety. Reviews of relevant literature, interviews with subject matter experts, individual occurrence reports, and available databases were used to quantify the performance of subsurface safety valves across a range of deployments.	A model that can stochastically calculate the summation of independent and dependent random variables to estimate consequence potentials of well designs in natural gas storage operations.
PHMSA	2019-2021	Review the Intent and Safety Impact of Hoop Stress and Percentage of Specified Minimum Yield Stress Boundaries on Natural Gas Transmission and Distribution Pipelines	The project studied the definitions of natural gas transmission and distribution lines in 49 CFR Part 192, completed a literature review, and established safety considerations for new versus existing systems related to gas transmission and distribution integrity management.	The report data plots provide pipeline operators a new ability to calculate leak vs rupture boundary vs make predictions based from historical information about their system.
PHMSA	2018-2020	Risk Assessment and Treatment of Wells	The project developed relative, quantitative, and probabilistic risk assessment guidelines to assess the risks of well entry, based on type of entry.	Guidelines that provide underground gas storage well operators with information to support the development, selection, and application of risk-based models that will facilitate decision-making with regard to well entry activities.

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PHMSA	2018-2021	River Scour Monitoring System for Pipeline Threat Prevention	The project developed a river scour monitoring system capable of determining the degree of scour in a riverbed, thereby alerting pipeline operators should the amount of cover of the pipeline become reduced.	Development of a river scour monitoring system that provides active monitoring of pipeline crossings to detect the presence of pipe exposure resulting from river scour.
PHMSA	2020-2021	SBIR Phase 1 - Inline-Inspection for Both Circumferential Cracking and Axial Stress Using EMAT Guided Wave	This project evaluated the use of guided wave EMAT to detect circumferential cracks and measure axial stress.	This SBIR Phase 1 Project was not further funded with a Phase 2 award.
PHMSA	2020-2021	SBIR Phase I - Fiber Optic Sensors for Direct Pipeline Monitoring Under Geohazard Conditions	This SBIR project demonstrated that distributed fiber-optic sensing was a viable and cost-effective means to monitor natural gas pipelines.	This SBIR Phase 1 Project was further funded with a Phase 2 award.
PHMSA	2020-2021	SBIR Phase I - Magneto-Acoustic Bending Stress and Anomaly Detection Inline Inspection Tool	This project developed, demonstrated, and commercialized a robust, field-ready inline-inspection tool for the accurate detection of cracks, other anomalies, and quantification of bending stress.	This SBIR Phase 1 Project was further funded with a Phase 2 award.

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PHMSA	2020-2021	SBIR Phase I - Managing Geohazards Quantitative Risk Assessment for Pipelines	This Phase I SBIR project addressed risk from both isolated and cascading hazards (e.g., earthquake followed by landslide), supported economic analysis of proposed mitigation to reduce risk at both the asset management level and project level, and outlined the requirements for a data collection tool to close the gap on pipeline asset inventory and natural hazards.	This SBIR Phase 1 Project was not further funded with a Phase 2 award.
PHMSA	2020-2021	SBIR Phase I - Meandering Winding Magnetometer-Arrays Bending Stress and Crack Detection In-Line Inspection Module	This project established the feasibility and methodology for using Meandering Winding Magnetometer-Arrays formatted for inline inspection for the characterization of circumferential anomalies and bending stresses.	This SBIR Phase 1 Project was further funded with a Phase 2 award.
PHMSA	2020-2020	SBIR Phase I - No-Dig Point Repair Technology for Steel Oil and Gas Pipelines	This project further proved and improved innovative repair solutions that expand the capability of rehabilitating larger diameter steel transmission oil and gas pipelines.	This SBIR Phase 1 Project was further funded into a Phase 2 entitled "No-Dig Point Repair Technology for Steel Oil & Gas Pipelines."
PHMSA	2019-2022	SBIR Phase II: Combined Cleaning and Guided Wave Inspection System	The overall objective of Phase II was to develop a low-cost and lightweight, combined, inspection and cleaning, prototype dual-purpose pigging tool that can be used in as many current hazardous liquid pipe cleaning applications as possible.	Construction and testing of prototypes of dual-purpose cleaning/inspection tool.

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		for Hazardous Liquid Pipelines		
PHMSA	2019-2022	SBIR Phase II: Non-Destructive Testing of Fracture Toughness for Pipeline Steels	The primary objective of the Phase II project is to develop the sensitivity of the nonlinear guided wave system to the fracture appearance transition temperature of API 5L pipe steels in a laboratory environment and to show how the fracture appearance transition temperature is connected to the fracture toughness.	The Phase 1 project successfully demonstrated sensitivity of the nonlinear guided wave system to the fracture appearance transition temperature of API 5L pipe steels in a laboratory environment showed how the fracture appearance transition temperature is connected to fracture toughness.
PHMSA	2019-2022	Systematize 20 Years of Mechanical Damage Research	This project summarized the current state of knowledge related to mechanical damage, including formation and behavior, detection and characterization, assessment and management, remediation and repair, and recommended practices and standards.	This comprehensive report documents 20 years of mechanical damage research and knowledge and can be a guide to regulators, pipeline operators, researchers, and engineering consultants or analysts.
PHMSA	2018-2021	Tools for Predicting Gas Migration and Mitigating its Occurrence/ Consequence	The project developed an analytic method to predict the conditions needed for gas migration to occur and establish a recommended practice to improve response to gas migration incidents, specifically addressing how to work with states to improve the efficiency of finding and fixing natural gas leaks.	The project established a more comprehensive understanding of leak response operational practices, specifically in regard to gas migration from underground pipeline leakage.
PHMSA	2018-2020	Tubing and Packers Life-Cycle Analysis for Underground Gas	The project developed a lifecycle analysis for tubing and packing well-entry impacts and recommendations for improvements to alternative	A model that can stochastically calculate the summation of independent and dependent random variables to estimate consequence

OA or JPO	Project Duration	Project Title	Project Abstract	Research Outcome and Incorporation
		Storage Applications	coatings and designs of tubing and packing assemblies.	potentials of tubing and packing operations risk in natural gas storage operations.
PHMSA	2018-2021	Validating Non-Destructive Tools for Surface to Bulk Correlations of Yield Strength, Toughness, and Chemistry	The project used non-destructive surface testing: micro-indentation, micro-machining, in situ chemistry, and replicate microscopy analysis as accurate, efficient, and cost-effective tools for material property confirmation.	The results objectively provided understanding of the variance of material properties between outer surfaces of the pipe wall and the bulk as a function of steel type, seamless, and weld types.
PHMSA	2019-2021	Validation of Remote-sensing and Leak-detection Technologies Under Realistic and Differing Conditions	The project advanced UAS-mounted remote sensing technologies for 1) identifying pipeline right-of-way integrity threats, and for 2) detecting natural gas leaks under operational conditions within natural gas transmission and distribution pipeline systems.	The project results established a validation testing framework that was proven during field testing. It also documented a probabilistic understanding of uncertainties for each technology tested.
PHMSA	2020-2020	Vapor Cloud Explosion at Nil Wind	This project reviewed available weather data for the U.S. to determine which criteria could define "nil wind" conditions, as opposed to "low wind" conditions as already included in LNG facility siting studies, and their historical frequency of occurrence.	The weather data and consequence modeling results will be used to inform a recommendation on whether nil wind conditions should be included in facility siting requirements.

U.S. Department of Transportation