2024 Program Report

Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Program

October 2024

U.S. Department of Transportation

Federal Highway Administration

FOREWORD

The Fixing America's Surface Transportation Act, or "FAST Act," (Pub. L. No. 114-94) (2018) established the Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Program to make competitive grants for the deployment of advanced transportation technologies. This report fulfills the requirement of Section 503(c)(4)(G) of Title 23, United States Code, to make available to the public information that describes the effectiveness of grant recipients in meeting their ATCMTD projected deployment plans by posting an annual report on the U.S. Department of Transportation website. The report describes the effectiveness of grantees in meeting their projected deployment plans and presents findings on the safety, mobility, environmental, operational efficiency, and other effects of the technology deployments. It overviews fiscal year (FY) 2016, FY 2017, FY 2018, FY 2019, FY 2020, and FY 2021 ATCMTD projects with information as of March 31, 2024, including key technologies grantees are planning to deploy. The report also highlights performance measures grantees are using, as well as grantee insights and lessons learned regarding their technology deployments.

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16. Abstract
The Fixing America's Surface Transportation Act (Pub. L. No. 114-94) (2018) established the Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Program to make competitive grants for the deployment of advanced transportation technologies. The law directs that beginning 3 years after the first grant award and annually thereafter, the Secretary of Transportation shall post a report about the ATCMTD Program (23 United States Code § 503(c)(4)(G)) on the U.S. Department of Transportation website. The report should provide credible, useful information on the effectiveness of grantees in meeting their projected deployment plans, as well as findings on the safety, mobility, environmental impacts, operational efficiency, and other impacts of the technology deployments. This report represents the fifth report. It provides overviews of fiscal years 2016–2021 ATCMTD projects and describes the findings from one completed project. This report also highlights performance measures grantees are using, as well as grantee insights and lessons learned regarding their technology deployments.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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LIST OF ABBREVIATIONS

Abbreviation	Definition
ACTION	Advanced Connected Transportation Infrastructure and Operations Network
ADOT	Arizona Department of Transportation
ADS	automated driving system
AI	artificial intelligence
AI-ITMS	Artificial Intelligence-Enhanced Integrated Transportation Management System
AI-TOMS	Artificial Intelligence-Based Transportation Operations Management System
ALDOT	Alabama Department of Transportation
ATCMTD	Advanced Transportation and Congestion Management Technologies Deployment
ATMS	advanced traffic management system
AV	automated vehicle
AVL	automatic vehicle location
BSM	basic safety message
CAD	computer-aided dispatch
CAV	connected and automated vehicle
CCTSP	Chicago Centralized Transit Signal Priority Project
CCTV	closed-circuit television
CDOT	Colorado Department of Transportation
COG	Council of Governments
ConOps	concept of operations
CSW	curve speed warning
CV	connected vehicle
C-V2X	cellular vehicle-to-everything
DelDOT	Delaware Department of Transportation
DMS	dynamic message sign
DOT	department of transportation
DSRC	dedicated short-range communication
DSS	decision support system
EV	electric vehicle
FAST Act	Fixing America’s Surface Transportation Act
FCC	Federal Communications Commission
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FRAME	Florida’s Regional Advanced Mobility Elements
FRATIS	Freight Advanced Traveler Information System
FY	fiscal year
GDOT	Georgia Department of Transportation
GPS	Global Positioning System
HDOT	Hawaii Department of Transportation
HMI	human-machine interface
HOV	high-occupancy vehicle
ICM	integrated corridor management

ITS	intelligent transportation system
IPv	Internet Protocol version
KDOT	Kansas Department of Transportation
LADOT	Los Angeles Department of Transportation
LRS	lane reservation system
LED	light-emitting diode
MaineDOT	Maine Department of Transportation
MAST	Maine Advanced Signal Control and Connected Vehicle System for Safe, Efficient, and Equitable Rural Transportation
MDOT	Michigan Department of Transportation
ML	machine learning
MOD	mobility-on-demand
MoDOT	Missouri Department of Transportation
MWCOG	Metropolitan Washington Council of Governments
MMITSS	multimodal intelligent traffic signal system
NCDOT	North Carolina Department of Transportation
NDDOT	North Dakota Department of Transportation
NDOT	Nebraska Department of Transportation
NFTA	Niagara Frontier Transportation Authority
NITTEC	Niagara International Transportation Technology Coalition
OBU	onboard unit
ODOT	Ohio Department of Transportation
PennDOT	Pennsylvania Department of Transportation
PLOI	Predictive Layered Operation Initiative
POV	Port of Virginia
PROACT	Proactive Route Operations to Avert Congestion in Traffic
RFID	radiofrequency identification
RSM	roadside safety message
RSU	roadside unit
RTA	Regional Transit Authority
RWIS	road weather information systems
SCMS	Security Credential Management System
SDOT	Seattle Department of Transportation
SJTA	South Jersey Transportation Authority
SMC	Smart Mobility Corridor
SPaT	signal phase and timing
SWIW	Spot Weather Impact Warning
TDM	travel demand management
TDOT	Tennessee Department of Transportation
TIM	traveler information message
TIS	traveler information system
TMC	traffic management center
TPAS	Truck Parking Availability System
TRS	Truck Reservation System
TSMO	transportation systems management and operations
TSP	transit signal priority

TxDOT	Texas Department of Transportation
UI	user interface
UDOT	Utah Department of Transportation
U.S.C.	U.S. Code
USDOT	U.S. Department of Transportation
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
V2X	vehicle-to-everything
VCC	virtual coordination center
VDOT	Virginia Department of Transportation
WSDOT	Washington State Department of Transportation
WSP	Washington State Patrol

EXECUTIVE SUMMARY

BACKGROUND

This report is the fifth program report on the Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Program. The multiyear, comprehensive Fixing America's Surface Transportation Act (FAST Act) (Pub. L. No. 114-94) (2018) established, among other programs, the ATCMTD Program, which funds grantees to deploy advanced technologies to improve safety, efficiency, system performance, and infrastructure return on investment.[1] The law sets aside $60 million each fiscal year (FY), from FY 2016 through FY 2020, for grant awards[2] and requires the U.S. Department of Transportation (USDOT) to award grants each year to at least 5, and no more than 10, eligible entities.[3] This authority was extended through FY 2021 by the Continuing Appropriations Act (2021), and Other Extensions Act (2020).[4]

The FAST Act outlines key reporting requirements for the grantees, including submitting annual reports to the Secretary of Transportation.[5] These reporting requirements enable an understanding of grantees' progress and the outcomes of their project deployments, providing insight into which technologies and types of projects have the most potential to advance FAST Act goals of improving transportation safety, efficiency, and system performance. In addition, the FAST Act prescribes that USDOT must make publicly available a program report beginning 3 years after the first grant award and annually thereafter.[6] The purpose of the program report is to provide information on the effectiveness of grantees in meeting their projected deployment plans. As specified in the FAST Act, the program report should include data on effects related to the following parameters:

- Traffic-related fatalities and injuries;
- Traffic congestion and improved travel time reliability;
- Transportation-related emissions;
- Multimodal system performance;
- Access to transportation alternatives;
- Public access to real-time integrated traffic, transit, and multimodal transportation information to make informed travel decisions;

[1]FAST Act, § 6004 (codified at 23 United States Code (U.S.C.) 503(c)(4) (2018)).
[2]23 U.S.C. § 503(c)(4)(I)(i) (2018).
[3]23 U.S.C. § 503(c)(4)(D)(i) (2018).
[4]Pub. L. No. 116-159, div. B, title I, § 1101, 134 Stat. 709, 725 (2020).
[5]23 U.S.C. § 503(c)(4)(F) (2018).
[6]23 U.S.C. § 503(c)(4)(G) (2018).

- Cost savings to transportation agencies, businesses, and the traveling public; and
- Other benefits to transportation users and the public.[7]

STATUS OF GRANT AWARDS

The ATCMTD Program has awarded 58 grants through FY 2021, including 8 in FY 2016, 10 in FY 2017, 10 in FY 2018, 10 in FY 2019, 10 in FY 2020, and 10 in FY 2021.[8] The grantees represent a diverse set of metropolitan and rural areas from across the United States. They are deploying a range of advanced technologies, including connected vehicle (CV) applications, automated vehicles, adaptive signal systems, integrated corridor management (ICM) systems, real-time traveler information systems, green technologies (e.g., light-emitting diode, electric vehicle shuttles), artificial intelligence (AI) and machine learning (ML), and infrastructure maintenance and monitoring systems, among other technologies.

All grantees in FYs 2016–2020 have executed their agreements. In addition, all grantees in FYs 2016–2020 received funding obligations. As of March 31, 2024, 8 of the 10 FY 2021 grantees have executed their agreements, and 7 have received funding obligations. Chapter 2 lists the grant awards in each fiscal year.

SUPPORT TO GRANTEES

The Federal Highway Administration (FHWA) provides crosscutting project support to all grantees through a variety of mechanisms. The FHWA provides performance measurement support and has prepared a report, *Evaluation Methods and Techniques: Advanced Transportation and Congestion Management Technologies Deployment Program*, which is designed to assist grantees in evaluating their projects.[9] The FHWA also responds to any grantee requests for information and shares these responses with other grantees, if applicable.

Two cohorts to support grantees met during this reporting period. The FHWA-organized Early Deployer Cohort Program was a voluntary roundtable of 7 grantees (with an additional 18 grantees who chose to be informal members) that met monthly via a webinar conference to provide status updates, share technical knowledge, and exchange information about grantees' challenges and lessons learned.[10] In late 2023, the Early Deployer Cohort Program transitioned to a new Interoperable Connectivity (vehicle-to-everything (V2X)) Cohort sponsored by the

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[7] 23 U.S.C. § 503(c)(4)(G)(i)-(viii) (2018).

[8] For four grantees—Ada County Highway District, ID (FY 2017); Greenville, SC (FY 2017); Dallas, TX (FY 2020); and South Jersey Transportation Authority (FY 2021)—FHWA and the grantees mutually agreed to terminate the grant. For these projects, the obligated funds were deobligated (no ATCMTD funds were expended for any of these projects).

[9] *Evaluation Methods and Techniques: Advanced Transportation and Congestion Management Technologies Deployment Program*: https://ops.fhwa.dot.gov/publications/fhwahop19053/fhwahop19053.pdf.

[10] Informal members of the Early Deployer Cohort Program attend monthly meetings but do not present at the meetings or share status updates.

Intelligent Transportation Systems Joint Program Office. This new cohort of active, USDOT-funded deployers provides targeted support across multiple grant programs. The Interoperable Connectivity (V2X) Cohort meets monthly.

STATUS OF PERFORMANCE MEASUREMENT

As of March 31, 2024, six grantees—the Greater Cleveland Regional Transit Authority (RTA), Port of Virginia (POV), Delaware Department of Transportation (DelDOT), Central Ohio's NW 33 Innovation Council of Governments (COG), Washington State DOT (WSDOT), and Utah DOT (UDOT)—have completed their projects and submitted a final report.[11]

While many grantees are in the planning phase of their deployment processes, working on activities such as stakeholder engagement, system documentation (e.g., the concept of operations), and technology procurement, a growing number of projects have begun testing and deploying technology applications.

Grantees are using a range of performance measures (as described in their annual reports and evaluation plans) to assess the benefits of their deployments. The performance measures tend to focus on improving safety and mobility as well as improving system performance and operational efficiencies. Grantees also provide performance measures for reducing emissions, integrating real-time information, reducing costs, improving institutional efficiency, enhancing access to transportation alternatives, and advancing equity.

GRANTEE FINDINGS

The six projects completed to date represent a range of technology deployments, including two integrated transportation management systems, two CV projects, a freight management technology project, and a transit technology project. Grantees with completed projects reported the following findings to FHWA.

DelDOT deployed an integrated transportation management system enhanced by AI that incorporated a variety of data sources and reported that this improved its ability to detect incidents and monitor traffic signal operations. Likewise, WSDOT reported that its Virtual Coordination Center enabled multimodal ICM and improved coordination across partner agencies, particularly regarding incident detection. In both cases, the grantees reported that they were able to leverage their technology deployments to increase situational awareness about traffic operations.

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[11] Two of the six grantees are formally completed (i.e., closed), with final reports published as of March 31, 2024. Once published, final reports are posted on FHWA's Fixing America's Surface Transportation Act or "FAST Act" web page. As of March 31, 2024, final reports for Cleveland RTA and POV are published. See https://ops.fhwa.dot.gov/fastact/.

For the two CV projects, UDOT and Central Ohio's NW 33 COG deployed integrated CV systems along a corridor and were able to test the functionality of roadside units (RSUs) and CV applications. NW 33 COG reported on the strong reliability of the RSUs but also noted that some drivers expressed dissatisfaction with the CV warnings, which may have been due, at least in part, to a lack of training. UDOT piloted several safety CV applications as well as snowplow preemption, which showed promising results. Based on a limited test of V2X-enabled transit signal priority, UDOT also demonstrated improved ontime bus performance.

The grantees working on both the freight and transit projects reported achieving greater operational efficiencies with their technology deployments. The POV deployed a freight reservation system that improved overall port efficiency. Truck turn times in the port decreased significantly, and the POV was able to reduce operational hours while increasing overall container volumes at the port. The POV also found that safety compliance increased significantly. The Cleveland RTA deployed computer-aided dispatch and automatic vehicle location on its buses, as well as priority cellular service, and upgraded its radio communications. Due to enhanced system data, the project resulted in improved asset management and other operational efficiencies.

GRANTEE REPORTED INSIGHTS

Grantees reported a broad range of challenges, lessons learned, and recommendations in their final reports. A review of this reported information identified seven key themes: Data, National Events, Policy and Regulations, Project Scoping, Stakeholder and Project Management, Technology, and User Experience. Data-related topics were commonly cited and included data storage, data validation, and security standards, among other issues. National events were also mentioned by several of the grantees, whether it was in the context of reduced travel demand, supply shortages, or remote work requirements that affected projects. With respect to policy and regulations, the Federal Communications Commission's (FCC's) 5.9 GHz Rule[12] affected some projects. Several grantees cited project scoping issues, with several indicating that they overestimated the capabilities of immature technologies and had to rescope their projects. Stakeholder and project management issues tended to focus on the importance of engaging stakeholders and building community support. Grantees also mentioned a range of technology topics, including the importance of standardization, the need to adapt to rapidly changing technology, and the importance of technology testing and aligning the operational practices of new technologies within agencies' existing frameworks. Grantees also recommended being sensitive to user experience issues (e.g., related to user interface).

[12] The FCC's November 10, 2020, First Report and Order (86 FR 23281), approved on November 18, 2020, and published in the *Federal Register* on May 3, 2021, describes changes to the allocated 75 MHz of radio spectrum in the 5.9 GHz band used for vehicle and infrastructure communications, which is also known as the Safety Band.

About This Report

Section 6004 of the Fixing America's Surface Transportation Act (FAST Act) (Pub. L. No. 114-94) (2018), codified at 23 United States Code (U.S.C.) § 503(c)(4), requires the development of this program report, which fulfills the requirement of Section 503 (c)(4)(G) of Title 23, U.S.C., to make available to the public information that describes the effectiveness of grant recipients in meeting their ATCMTD projected deployment plans by posting an annual report on the U.S. Department of Transportation (USDOT) website. Per 23 U.S.C. § 503(c)(4)(G), the report shall include data on how the program has achieved the following activities:

- Reduced traffic-related fatalities and injuries;
- Reduced traffic congestion and improved travel time reliability
- Reduced transportation-related emissions;
- Optimized multimodal system performance;
- Improved access to transportation alternatives;
- Provided the public with access to real-time integrated traffic, transit, and multimodal transportation information to make informed travel decisions; and
- Provided cost savings to transportation agencies, businesses, and the traveling public.

CHAPTER 1. INTRODUCTION

This report is the fifth annual program-level report on the Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Program. The FAST Act, a Federal law providing long-term funding for surface transportation infrastructure planning and investment from fiscal year (FY) 2016 through FY 2021, established the ATCMTD Program, stating:

… the Secretary [of Transportation] shall establish an advanced transportation and congestion management technologies deployment initiative to provide grants to eligible entities to develop model deployment sites for large-scale installation and operation of advanced transportation technologies to improve safety, efficiency, system performance, and infrastructure return on investment.[1] This authority was extended through FY 2021 by the Continuing Appropriations Act, 2021, and Other Extensions Act.[2]

BACKGROUND

The ATCMTD Program funds grants to deploy advanced technologies in support of FAST Act safety, mobility, environmental impact, and operational efficiency goals.[3] The law sets aside $60 million each fiscal year from FY 2016 through FY 2021 for the grant awards,[4] with the Federal share of funding not to exceed 50 percent of the

[1] 23 U.S.C. § 503(c)(4) (2018).
[2] Pub. L. No. 116-159, div. B, title I, § 1101, 134 Stat. 709, 725 (2020).
[3] 23 U.S.C. § 503(c)(4)(A) (2018).
[4] 23 U.S.C. § 503(c)(4)(I)(i) (2018).

total cost of the project.[5] The law requires USDOT to award grants each year to at least 5, and no more than 10, eligible entities, with no more than 20 percent of the funds each year to a single entity. The awards should be diverse with respect to the technologies being deployed and geographic location.[6] In addition, the law requires that candidates' applications include a technology deployment plan;[7] quantifiable system performance objectives;[8] quantifiable safety, mobility, and environmental benefit projections; a plan for partnering with other institutions, and an explanation of how applicants will leverage existing technology and infrastructure for the project.[9]

GRANTEE REPORTING REQUIREMENTS

The ATCMTD Program includes several key reporting requirements for grantees, including annual reports to the Secretary of Transportation.[10] The reporting requirements allow the Federal Highway Administration (FHWA) to monitor grantees' deployment progress and to understand the effects of grantees' projects, providing insight into which technologies and types of projects are most effective at advancing FAST Act goals of improving transportation safety, efficiency, and system performance. The grantees can also use the information to improve the operations of their deployments. The grantees' reporting feeds directly into this program report, allowing other State and local entities to learn from grantee successes and challenges when executing their advanced technology deployments.

The following sections summarize grantees' key reporting requirements.

Quarterly Reports

All grantees submit quarterly reports to FHWA, which include descriptions of current work completed and work planned for the upcoming quarter, status of procurements and key milestone dates, any significant problems encountered, tabulated costs, the work performed in support of USDOT goals, and any budget revisions.

[5] 23 U.S.C. § 503(c)(4)(J) (2018).
[6] 23 U.S.C. § 503(c)(4)(D) (2018).
[7] 23 U.S.C. § 503(c)(4)(C)(ii)(I) (2018).
[8] 23 U.S.C. § 503(c)(4)(C)(ii)(II) (2018).
[9] 23 U.S.C. § 503(c)(4)(C)(ii)(III) (2018).
[10] 23 U.S.C. § 503(c)(4)(F) (2018).

Annual Reports

One year after each grantee completes its executed grant agreement, and each year thereafter, the law requires that grantees submit a report to the Secretary of Transportation (referred to as the "annual report" in this document) that describes deployment effects, including the following feedback:[11]

- Information on project deployment and operational costs compared to the benefits and savings the project provides;
- Data on whether the project has helped reduce traffic crashes, congestion, and costs, and data on other benefits of the deployed systems;
- Data on the effectiveness of measuring and improving transportation system performance through the deployment of advanced technologies;
- Data on the efficacy of providing real-time integrated traffic, transit, and multimodal transportation information to the public to make informed travel decisions; and
- Information on lessons learned and recommendations for future deployment strategies to optimize transportation efficiency and multimodal system performance.

Evaluation Plans

As part of their applications, many grantees proposed to develop evaluation plans, which were incorporated into their cooperative agreements after execution. Beginning in FY 2018, creating evaluation plans became mandatory for grantees. These plans outline project goals, evaluation methods and design, performance measures, data collection procedures, and evaluation risks.[12]

SUPPORT TO GRANTEES

FHWA provides performance measurement support to the grantees to assist them in meeting their reporting requirements. In addition, through cohort programs outlined later in this section, FHWA provides technical assistance to help grantees overcome any challenges or issues they may be facing in their deployments. FHWA also responds to any grantee requests for direction. If FHWA learns information from one grantee that applies to other grantees, the Agency shares the information.

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[11] 23 U.S.C. § 503(c)(4)(F) (2018).

[12] Beginning with FY 2018 awards, all grantees are required to prepare evaluation plans. See section A.5 of the 2018 FHWA Notice of Funding Opportunity No. 693JJ318NF00010: https://grants.gov/search-results-detail/303763.

Performance Measurement Support

The FHWA provided grantees with an annual report template that they are encouraged to use to fulfill this reporting requirement (see Appendix A). The annual report template contains four sections. The Introduction and Overview section asks grantees to provide a project description and indicate the technologies they are deploying and the project's goals. The Evaluation/Research Activities section asks grantees to list their performance measures and research activities by goal area. The Findings section requests information on grantees' findings (tied to performance measures). The Wrap-Up section presents grantees with the following series of questions:

- How is the project doing with respect to meeting original expectations (i.e., as stated in the project proposal)? Note here any *major* deviations or changes in scope from the original proposal due to either project-driven outcomes or other unforeseen challenges.
- Are there any aspects of your project that you consider cutting-edge, noteworthy, or innovative?
- How do the project's deployment and operational costs compare to the benefits and savings the project provides (i.e., can you provide an objective benefit-cost analysis or alternate subjective comparison)?
- What lessons have been learned to date from your deployment, specifically regarding future deployment strategies to optimize transportation efficiency and multimodal system performance? Please note lessons learned regarding challenges in technology deployment (e.g., technical, institutional), research (e.g., performance measurement), or other lessons learned.
- What recommendations can you provide regarding future deployment strategies in this/these area(s)?

To assist grantees in preparing their evaluation plans and conducting their evaluations, FHWA provided grantees with an "Evaluation Checklist"—a high-level list of issues and topics that grantees should consider when preparing their evaluation plans. In addition, FHWA has produced the report *Evaluation Methods and Techniques: Advanced Transportation and Congestion Management Technologies Deployment Program* to assist grantees in developing credible evaluations that measure the effects of their technology deployments.[13] The document provides an overview of evaluation design and performance measurement and includes chapters related to specific methods (benefit-cost analysis, survey design, and emissions analysis), as well as a limited set of technologies that are either being commonly deployed among grantees or where additional technical assistance would be particularly useful (CVs, automated vehicles (AVs), and adaptive signal control). FHWA has also developed a final evaluation report template that has been shared with grantees.

[13] *Evaluation Methods and Techniques: Advanced Transportation and Congestion Management Technologies Deployment Program*: https://ops.fhwa.dot.gov/publications/fhwahop19053/fhwahop19053.pdf.

Cohort Programs

FHWA provided support to grantees through the Early Deployer Cohort Program, a voluntary roundtable of 7 grantees (with 18 additional grantees who chose to be informal members) who met monthly via a webinar conference to provide status updates and share information about their progress, challenges, and lessons learned. The Early Deployer Cohort Program has been a resource for connecting grantees facing similar technical and institutional challenges. FHWA tailored the topics addressed at the meetings to the needs and interests of the grantees and developed a file-sharing site to exchange relevant resources.

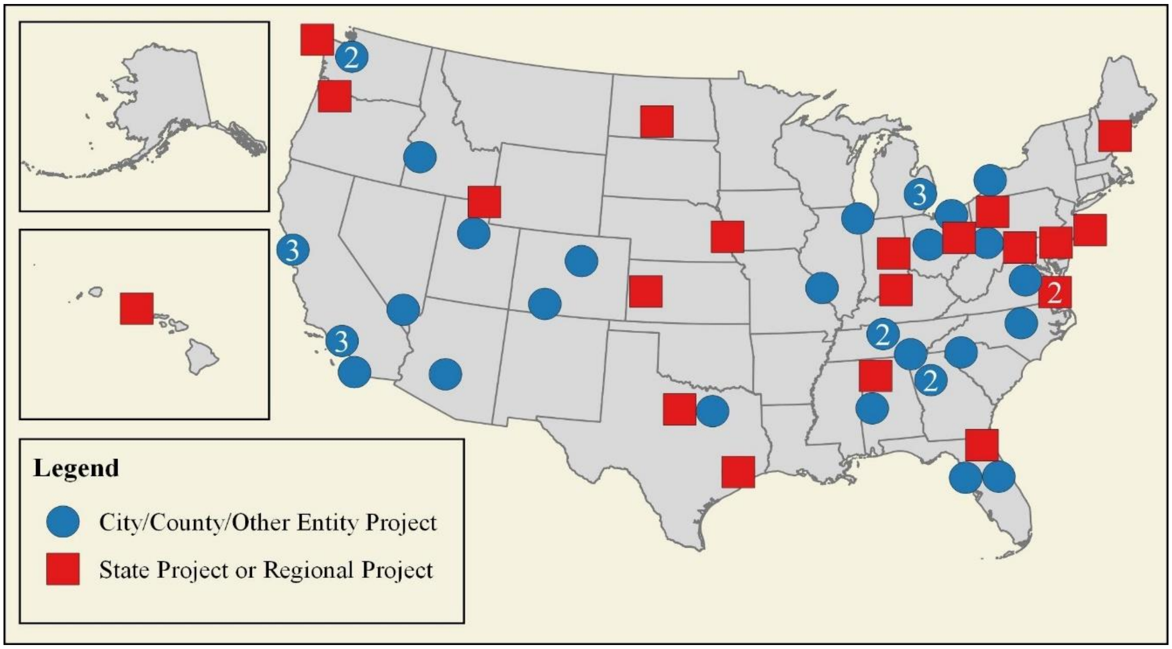
In late 2023, the Early Deployer Cohort Program transitioned to a new Interoperable Connectivity (vehicle-to-everything (V2X)) Cohort sponsored by the Intelligent Transportation Systems (ITS) Joint Program Office. The new Interoperable Connectivity (V2X) Cohort comprises active, USDOT-funded deployers and provides targeted support across multiple grant programs. The purpose of the cohort is to facilitate and support peer-led discussions that help advance V2X deployments. The cohort provides opportunities for engagement on a variety of topics, encouraging members to share their experiences, challenges, best practices, and documentation. Emphasis will be on advancing interoperable deployments of V2X. The Interoperable Connectivity (V2X) Cohort meets monthly.

CHAPTER 2. OVERVIEW OF GRANTEE PROJECTS

This chapter provides a general overview of the grantee projects. Across the 6 fiscal years of this program, FHWA received 298 applications and awarded 58 grants, including 8 in FY 2016, 10 in FY 2017, 10 in FY 2018, 10 in FY 2019, 10 in FY 2020, and 10 in FY 2021.[1]

The grantees represent a diverse array of agencies, including city, county, and other local agencies and State departments of transportation (DOTs), as shown in figure 1. In addition, the ATCMTD Program has awarded grants equally to rural and nonrural projects.

All grantees in FYs 2016–2020 have executed their agreements. In addition, all grantees in FYs 2016–2020 received funding obligations. As of March 31, 2024, 8 of the 10 FY 2021 grantees have executed their agreements, and 7 have received funding obligations.



Note: Locations with more than one project are marked with the number of projects.

Source: FHWA.

Figure 1. Map. Advanced Transportation and Congestion Management Technologies Deployment Program grantees.[2]

[1]For four grantees—Ada County Highway District, ID (FY 2017); Greenville, SC (FY 2017); Dallas, TX (FY 2020); and South Jersey Transportation Authority (SJTA) (FY 2021)—FHWA and the grantees mutually agreed to terminate the grant. For these projects, the obligated funds were deobligated (no ATCMTD funds were expended for any of these projects).
[2]See the Projects by Fiscal Year section for a complete list of projects.

PROJECTS BY FISCAL YEAR

Each of the project grantees is identified by fiscal year in the following lists. Each bullet point contains the project name at the time of award, followed by the lead entity grantee in italics. For brief descriptions of each project, please see appendix B.

Fiscal Year 2021 Awards

The ATCMTD Program awarded the following 10 grants in FY 2021:

- Proactive Route Operations to Avert Congestion in Traffic (PROACT) Alabama, *Alabama DOT (ALDOT)*;
- An End-to-End Decision Support System for Integrated Smart Electric Grid and Transportation System Management, *City of Chattanooga*;
- Chicago Centralized Transit Signal Priority Project (CCTSP), *City of Chicago*;
- Great Plains Rural Freight Technology Corridor Project, *Kansas DOT (KDOT)*;
- Kentucky's Wrong Way Driving and Integrated Safety Technology, *Kentucky Transportation Cabinet*;
- Port of Los Angeles Gateway, *Port of Los Angeles*;
- EZConnect: An Open and Cloud-Based Mobility Center Providing One-Stop Access for Travel Needs of Underserved Customers, *NEORide*;
- Electric Vehicle User Range Anxiety Solution for Rural North Dakota, *North Dakota DOT (NDDOT)*;
- Smart and Connected Atlantic City Expressway, *South Jersey Transportation Authority (SJTA)*; and
- Washington State Ferries Terminal Wait Times Traveler Information System, *Washington State DOT (WSDOT).*

Fiscal Year 2020 Awards

The ATCMTD Program awarded the following 10 grants in FY 2020:

- Advancing Connectivity and the Economy Through Technology in the San Diego Region, *San Diego Association of Governments*;
- Pinellas Connected Community, *Pinellas County Public Works Department*;

- Emergency Vehicle Preemption Using Connected Vehicle Technology, *Georgia DOT (GDOT)*;
- Maine Advanced Signal Control and Connected Vehicle System for Safe, Efficient, and Equitable Rural Transportation (MAST) Project, *Maine DOT*;
- Smart Intersections: Paving the Way for a National Connected and Automated Vehicles Deployment (CAV), *University of Michigan*;
- Integrated Safety Technology Corridor, *Regional Transportation Commission of Southern Nevada*;
- Charlotte Avenue/Dr. Martin L King, Jr Boulevard Transit Headways and Congestion Management, *Metro Government of Nashville and Davidson County (Public Works Department)*;
- SM Wright Smart Corridor, *City of Dallas*;
- Utah Broadly Connected, *Utah DOT (UDOT)*; and
- Autonomous Truck Ready, *Port of Virginia (POV)*.

Fiscal Year 2019 Awards

The ATCMTD Program awarded the following 10 grants in FY 2019:

- MWCOG: Deployment of Personalized and Dynamic Travel Demand Management (TDM) Technology in the Washington, DC, Baltimore, MD, Richmond, VA Megaregion, *Metropolitan Washington Council of Governments (MWCOG)*;
- I–4 Florida's Regional Advanced Mobility Elements (FRAME), *Florida DOT (FDOT)*;
- Implementing Cellular V2X Technology to Improve Safety and Intelligent Transportation Systems (ITS) Management in Hawaii, *Hawaii DOT (HDOT)*;
- Intelligent Woodward Corridor Project, *Michigan DOT (MDOT)*;
- I–270 Predictive Layered Operation Initiative (PLOI), *Missouri DOT (MoDOT)*;
- Multimodal Connected Vehicle Pilot, *North Carolina DOT (NCDOT)*;
- DriveOhio I–70 Truck Automation Corridor, *Ohio DOT (ODOT)*;
- Artificial Intelligence-Powered Decision Support Tools for Integrated Corridor Management, *Tennessee DOT (TDOT)*;

- Artificial Intelligence Meets Integrated Corridor Management: Realizing the Next Generation of Regional Mobility, *Virginia DOT (VDOT)*; and

- Deployment of the Washington State Virtual Coordination Center (VCC) for Multimodal Integrated Corridor Management, *WSDOT*.

Fiscal Year 2018 Awards

The ATCMTD Program awarded the following 10 grants in FY 2018:

- Bay Area Mobility-On-Demand Project, *Contra Costa Transportation Authority*;

- Advanced Connected Transportation Infrastructure and Operations Network (ACTION), *University of Alabama*;

- Wolf Creek Pass Advanced Technology Deployment, *Colorado DOT (CDOT)*;

- Artificial Intelligence-Enhanced Integrated Transportation Management System (AI-ITMS) Deployment Program, *Delaware DOT (DelDOT)*;

- Georgia DOT Connected Vehicles, *GDOT*;

- Multi-State Rural Integrated Corridor Management, *Nebraska DOT (NDOT)*;

- Oregon Smart Mobility Network, *Oregon DOT*;

- Work Zone Reservation and Traveler Information System, *Pennsylvania DOT (PennDOT)*;

- I–10 Corridor Coalition Truck Parking Availability System (I–10 Corridor Coalition TPAS), *Texas DOT (TxDOT)*; and

- Utah Connected, *UDOT*.

Fiscal Year 2017 Awards

The ATCMTD Program awarded the following 10 grants in FY 2017:

- Loop 101 Mobility Project, *Arizona DOT (ADOT)*;

- Global Opportunities at the Port of Oakland Freight Intelligent Transportation System, *Alameda County Transportation Commission*;

- Connecting the East Orlando Communities, *FDOT*;

- SMART Arterial Management, *Ada County Highway District*;

- Improving Safety and Connectivity in Four Detroit Neighborhoods, *City of Detroit*;
- Connecting Cleveland Project, *Greater Cleveland Regional Transit Authority (RTA)*;
- Greenville Automated (A-Taxi) Shuttle, *County of Greenville*;
- The Texas Connected Freight Corridors Project, *TxDOT*;
- Truck Reservation System and Automated Workflow Data Model, *POV*; and
- Multimodal Integrated Corridor Mobility for All, *Seattle DOT (SDOT).*

Fiscal Year 2016 Awards

The ATCMTD Program awarded the following eight grants in FY 2016:

- Freight Advanced Traveler Information System (FRATIS), *Los Angeles County Metropolitan Transportation Authority*;
- City of San Francisco Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Initiative, *San Francisco Municipal Transportation Agency*;
- Los Angeles DOT Implementation of Advanced Technologies to Improve Safety and Mobility within the Promise Zone, *Los Angeles DOT (LADOT)*;
- Denver Smart City Program, *City and County of Denver*;
- A Connected Region: Moving Technological Innovations Forward in the NITTEC[3] Region, *Niagara Frontier Transportation Authority (NFTA)*;
- NW 33 Smart Mobility Corridor, *Union County, City of Marysville, and City of Dublin*;
- SmartPGH, *City of Pittsburgh*; and
- ConnectSmart: Connecting TSMO[4] and Active Demand Management, *TxDOT*.

[3]Niagara International Transportation Technology Coalition.
[4]Transportation systems management plan.

SUMMARY OF TECHNOLOGY DEPLOYMENTS

The ATCMTD grants awarded from FY 2016 through FY 2021 support the deployment of a range of advanced transportation technologies.[5] Some of the key technologies include CVs and connected infrastructure; real-time traveler information; ICM and decision support systems (DSSs); infrastructure maintenance and monitoring technologies; adaptive traffic signal control; artificial intelligence (AI), machine learning (ML), and advanced analytics; AVs; and green technology (e.g., light-emitting diode (LED) lighting, electric vehicle (EV) shuttles). Table 1 highlights the number of deployment projects for each of these key technologies.[6] Many projects deploy more than one technology. For a more detailed list of the deployed technologies in the projects, please see appendix B.

Table 1. Advanced Transportation and Congestion Management Technologies Deployment grantee key technology deployments, as of March 31, 2024.

Technology	Number of Projects (54 Projects Total)
Real-time traveler information	47
CVs/connected infrastructure	45
ICM/DSSs	24
Infrastructure maintenance/monitoring	16
AI/ML/advanced analytics	13
Adaptive signals	12
AVs	6
Green technology (LED lighting, EV shuttles)	5

AI = artificial intelligence; AVs = automated vehicles; CVs = connected vehicles; DSS = decision support system; EV= electric vehicle; ICM = integrated corridor management; LED = light-emitting diode; ML = machine learning.

The grantee projects also span a range of modes and service models. In addition to passenger vehicles, many of the projects either focus on or have a component that includes freight, transit, pedestrian/bicyclist, or mobility-on-demand (MOD), as shown in table 2. Many projects address more than one mode or service model.

[5]For four grantees—Ada County Highway District, ID (FY 2017); Greenville, SC (FY 2017); Dallas, TX (FY 2020); and SJTA (FY 2021)—FHWA and the grantees mutually agreed to terminate the grant. These three projects are not included in this section or any following sections of this report.

[6]Table 1 is not an exhaustive list; it represents the most prevalent technologies being deployed.

Table 2. Advanced Transportation and Congestion Management Technologies Deployment grantee project modes/services as of March 31, 2024.

Mode/Service Model	Number of Projects (54 Projects Total)
Passenger vehicle	34
Transit	24
Pedestrian/bicyclist	22
Freight	14
MOD	7

MOD = mobility-on-demand.

GRANTEE DEPLOYMENT STATUS

Six projects completed their project as of March 31, 2024—the Cleveland RTA, POV, DelDOT, NNW 33 Innovation COG, WSDOT, and UDOT. Nineteen grantees are still in the planning phase of their deployment process, working on activities including stakeholder engagement, system documentation (e.g., the concept of operations (ConOps)), and technology procurement. A similar number of projects have begun testing and deploying technology applications. Table 3 illustrates the overall deployment status of FY 2016–FY 2021 grantees by showing the number of projects at different stages of deployment.[7]

Table 3. Advanced Transportation and Congestion Management Technologies Deployment Fiscal Years 2016–2021 grantee project status as of March 31, 2024.

Deployment Status	Number of Projects (52 Projects Total)
Planning stages	19
Piloting/testing/partial deployment	21
Completed deployment	12

OVERALL STATUS OF PERFORMANCE MEASUREMENT

As part of the ATCMTD Program application process, applicants are required to include:

> Quantifiable safety, mobility, and environmental benefit projections, such as data-driven estimates of how the project will improve the region's transportation system efficiency and reduce traffic congestion.[8]

As a result, all grantees from FY 2016 through FY 2021 included proposed performance measures or targets in their applications. In addition, as noted in chapter 1, executed agreements

[7]The table excludes four grantees who mutually agreed with FHWA to terminate their grants and the two FY 2021 grantees for whom funding has not yet been obligated by FHWA.
[8]23 U.S.C. § 503(c)(4)(C)(ii)(III) (2018).

require many grantees to develop evaluation plans that outline project goals, evaluation methods and design, performance measures, and data collection procedures. As of March 2024, 41 grantees had submitted evaluation plans: 5 FY 2016 grantees, 5 FY 2017 grantees,[9] 10 FY 2018 grantees, 9 FY 2019 grantees, 8 FY 2020 grantees, and 4 FY 2021 grantees.

As of March 31, 2024, two grantees—Cleveland RTA and POV—have received approval for their final report. DelDOT, NW 33 Innovation COG, WSDOT, and UDOT have submitted final reports, which FHWA is reviewing. All other grantees are in the piloting/testing or planning phase, so it is too early for them to have findings related to performance measurement.

SUMMARY OF GRANTEE PERFORMANCE MEASURES

In the annual reports and evaluation plans, grantees identify the performance measures they will use to evaluate the benefits of their projects. Grantees tailor performance measures to their specific projects; however, for many projects, the core metric is similar. For example, a grantee with a transit project may use “improved transit vehicle travel time,” whereas a grantee with a freight project may use “reduction in travel times along key port access corridors.” While these performance measures vary by mode and geographic location, depending on the scope of their respective projects, the core of both metrics is travel time. Table 4 lists the most common core performance measures grantees use across reported goal areas. If multiple grantees use a performance measure, the number of grantees is noted in parentheses, e.g., (n=3). The goals shown in table 4 align with requirements in the FAST Act and effects identified by the Secretary in the notices of funding opportunity (e.g., improved safety, reduced traffic congestion, equity).

Grantees are not reporting on all of the goal areas that align with the requirements in the FAST Act. Grantees focus on the goals and performance measures relevant to their deployments. As table 4 illustrates, safety and mobility are the two most common grantee goals.

While only a few grantees explicitly report on performance measures for equity, additional projects are pursuing equity goals that are categorized under other goal areas. For example, some projects are seeking to enhance access to transportation alternatives in underserved communities, and they report their performance measures under the goal area of enhanced access rather than equity.

[9]Three of the FY 2016 grantees and five of the FY 2017 grantees were not required to complete an evaluation plan per their grant agreements.

Table 4. Common advanced transportation and congestion management technologies deployment grantee performance measures by goal area, 2024.[10]

Goal Area	Common Performance Measures
Improved safety	• Number of crashes (including by severity and mode) (n=26) • Perceived safety (n=14) • Number of safety notifications/activations (n=10) • Incident response/detection time (n=9)
Reduced congestion/improved mobility	• Travel time (n=22) • Delay (n=19) • Travel time reliability (n=17) • Speed (n=9) • Transit ontime performance (n=6) • Number of riders/users/vehicles (n=6) • User satisfaction/perceived improvement (n=6)
Reduced environmental impacts	• Emissions (n=12) • Fuel consumption (n=9) • Delay (n=3) • Travel time (n=3)
Improved system performance (including optimized multimodal system performance)	• Ontime performance (n=7) • Accuracy (n=7) • Perceived system effectiveness (n=7) • Number of riders/users/vehicles (n=5)
Enhanced access to transportation alternatives	• User satisfaction (n=5) • Number of users/utilization rate (n=3) • Number of users that changed their behavior (n=3) • Number of passengers/ridership (n=2) • Number of users offered alternatives (n=2)

[10] If multiple grantees use a performance measure, the number of grantees is noted in parentheses, e.g., (n=3).

Table 4. Common advanced transportation and congestion management technologies deployment grantee performance measures by goal area, 2024 (continuation).[10]

Goal Area	Common Performance Measures
Effectiveness of providing integrated real-time transportation information to the public to make informed decisions	• User feedback/perception (n=11) • Number aware of/using information (n=6) • Data type/availability/open data (n=4) • Scope of area (n=2)
Reduced costs	• Benefit-cost analysis (n=10) • Mobility costs (n=4) • Reduced fuel costs/emissions savings (n=3) • Safety costs (n=3)
Institutional and/or administrative benefits	• Information sharing between agencies/stakeholders (n=7) • Improved understanding/awareness of technologies (n=3) • Improved efficiency/access to data (n=3) • Transferability of systems (n=2)
Equity	• Demographic information (n=1) • Rural-specific applications (n=1) • Number of trips (from Communities of Concern/provided to people with disabilities) (n=1) • Traffic-related injuries in Communities of Concern (n=1)

[10]If multiple grantees use a performance measure, the number of grantees is noted in parentheses, e.g., (n=3).

CHAPTER 3. GRANTEE-REPORTED FINDINGS AND INSIGHTS

This chapter provides the details of six completed projects as of March 31, 2024. These details include findings, challenges, lessons learned, and recommendations.

GRANTEE FINDINGS

This section summarizes each of the completed projects' final reports. The six projects completed to date represent a range of technology deployments, including two integrated transportation management systems, two CV projects, a freight management technology project, and a transit technology project. Any questions about the projects highlighted in this section can be sent to the ATCMTD program managers at ATCMTD@dot.gov.

Greater Cleveland Regional Transit Authority (Fiscal Year 2017)

Cleveland RTA, an FY 2017 grantee, became the first ATCMTD grantee to complete its deployment project in August 2020, and its final report has been accepted by FHWA. Cleveland RTA replaced and upgraded its transit communication, computer-aided dispatch (CAD), and automatic vehicle location (AVL) systems, implementing a number of new features, including state-of-the-art vehicle alarms, priority cellular service, new radio communications towers, and turn-by-turn navigations. After installing these technology components, Cleveland RTA observed numerous benefits, including improved system and operational efficiency, a more robust traveler information system (TIS), and an improved and more equitable user experience for Cleveland RTA's riders. The 2021 American Public Transportation Association Think Transit Conference honored Cleveland RTA with an award for "Most Innovative."[1] The 2021 program report described the key findings of Cleveland RTA's completed project.[2]

Port of Virginia (Fiscal Year 2017)

The POV's Truck Reservation System (TRS) and Automated Workflow Data Model project builds on POV's existing port management system to improve operational efficiency and share data with other ports. The ATCMTD award funded TRS-2, which is phase two of three deployment phases (the details of which are shown in table 5).

[1]"RTA Named 'Most Innovative' at the 2021 Trapeze-Vontas Conference," Greater Cleveland Regional Transit Authority, April 27, 2021, http://www.riderta.com/news/rta-named-most-innovative-2021-trapeze-vontas-conference.

[2]Margaret Petrella, Max Litvack-Winkler, and Katya Garcia-Israel. *2021 Program Report Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Program*. Washington, DC: FHWA, 2024, https://ops.fhwa.dot.gov/publications/fhwahop21059/fhwahop21059.pdf, accessed April 16, 2024.

Table 5. Port of Virginia Truck Reservation System deployment phases.

Phase 1	Phase 2	Phase 3
Deployed 2018	**Deployed 2021**	**Future Deployment**
Features: • Mandatory reservations • More efficient housekeeping at night • Decreased truck backup and congestion • Modern truck tracking hardware	Features: • Enhanced TRS system mobile application with off-terminal information • Subscription for stakeholders to track containers • AI-based yard housekeeping	Features: • Ability to schedule reservations in advance • Mobile application with onterminal information • Just-in-time truck appointment matching

AI = artificial intelligence; TRS = Truck Reservation System.

The TRS-2 redesign of the TRS enhances user experience by facilitating dynamic edits that reflect real usage by motor carriers for more efficient reservation making. The POV created a mobile application to access the truck reservation interface. The creation of a mobile application has numerous benefits that improve the trucker's experience by enabling truckers to perform the following actions:

- Confirm a reservation;
- Retrieve appointment status, container availability, or electronic interchange receipts;
- Update minor elements of a reservation, such as container number;
- Receive a lane confirmation; and
- Supplement automatic truck identification where applicable.

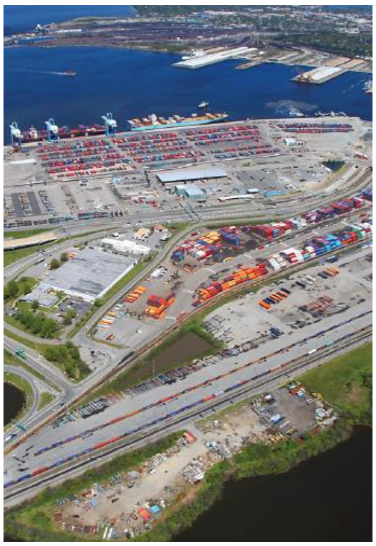
Additionally, POV published a data model that provides real-time updates to dispatchers and truckers. The system uses a data subscription model that pushes information for all POV terminals out to the truckers and other logistics chain stakeholders (shippers, brokers, shipping lines, etc.).

These system improvements make the port safer by reducing the need for drivers to exit their trucks to coordinate—an act that is considered the highest risk to drivers' safety at the port. At the port, while waiting to back into a lane, brief coordination with other motor carriers to determine who will back in next is acceptable for up to 2 minutes, then drivers must be in their cabs.[3] In 2018 and 2019, compliance with this rule, which is measured quarterly, was always in the "unsatisfactory" range, with one score as low as 62 percent. After the implementation of TRS-2, compliance scores for quarters evaluated in 2020 and 2021 rose above the 95-percent threshold to the "satisfactory" range.

[3] "Port of Virginia Health and Safety Rules – Motor Carriers," June 2022, https://wp.portofvirginia.com/wp-content/uploads/2022/06/Port-of-Virginia-Health-and-Safety-Rules-Motor-Carriers-20220505.pdf, 2024.

Despite supply chain issues in 2021 and 2022, thousands of containers were rerouted from other U.S. East Coast ports to the POV. While other ports saw turn times in the 3-to-5-hour range, POV's turn times were within a range of 50 to 60 minutes. The POV decreased operational hours by 40.9 percent (from 22 hours to 13 hours each day) while handling a 76.4-percent increase in ingate container volume (comparing 2019 to 2021). These results created cost efficiencies by reducing the number of employee labor hours outside operational hours, which were paid at a premium rate. The POV also anticipates that by reducing operational hours, subsequent benefits for maintenance and equipment repair will be realized through reduced machine operating time and improved access to preventative maintenance schedules.

Before the implementation of TRS-2, containers were often moved multiple times based on the order in which truckers arrived at the gate and at the stacks, contributing to longer queues and longer wait times. With AI housekeeping, the POV positions containers during off hours, resulting in fewer container moves, especially during port hours. Based on the results from the proof-of-concept, the POV could potentially eliminate 218 unnecessary moves per day. If moves are extrapolated over the course of a year, leveraging an AI-based housekeeping approach could eliminate 55,154 wasteful container repositioning moves per year. This approach enables the POV to operate at levels 25 percent above the design capacity for an extended period without an increase in truck turn times. Maintaining lower turn times also contributes to decreased time idling and, as a result, fewer emissions.



Source: Virginia Port Authority.

Figure 2. Photograph. The Port of Virginia.

This project ultimately allowed the POV (see aerial view in source: virginia port authority. figure 2) to improve traffic flow in and around the port and significantly reduce truck idling and carbon emissions associated with port operations. The POV both reduced internal costs and increased efficiencies. The benefits derived from this project enabled the POV to remain fluid through supply chain issues. Stakeholders at the POV are also benefitting from real-time information dissemination.

Delaware Department of Transportation (Fiscal Year 2018)

DelDOT enhanced its integrated transportation management system (see figure 3 for the system logo) with AI and ML algorithms to make operations and management more efficient. With consistent data monitoring and analysis, the system advises traffic management center (TMC) technicians by predicting traffic flows; identifying traffic anomalies; and generating, evaluating, and executing response solutions to traffic congestion. The system predicts traffic flow in the short term and leverages simulation tools to predict traffic flow more accurately in the long term. In conjunction with other applications, this system can predict when congestion might occur based on advanced traffic demand detection, and the system can integrate with DelDOT's traffic control system to optimize signal timing.

Source: DelDOT.

Figure 3. Graphic. Artificial Intelligence Integrated Transportation Management System logo.

Deployment of the AI-ITMS had three components:

- The first component was **infrastructure**, which included advanced sensors, video cameras, CAV, and software. DelDOT upgraded and deployed these key infrastructure improvements throughout the 3 years of the project.

- The second component was **operation**, which included the development, deployment, and testing of the Artificial Intelligence-Based Transportation Operations Management System (AI-TOMS) software toolkit. Most of DelDOT's sensors and systems were integrated into the AI-ITMS under this project, although the development and testing of AI-TOMS continues. The testbeds included machine vision (the portal for which is shown in figure 4), controller area network bus data, dilemma zone system, signal phase and timing (SPaT), and signal control.

- The third component was a **TIS**, which included updating the DelDOT Web portal and mobile application to inform the public of the advisories generated by AI-TOMS. Email and text alerts are currently sent to select DelDOT TMC staff members, and as confidence in AI-TOMS grows, DelDOT intends to integrate AI-TOMS-generated alerts into the public-facing components of the TIS.

The system performance of AI-ITMS was evaluated between July 2022 and June 2023, although evaluation was deferred for six of the performance measures. Over the course of the project, the AI-ITMS program's focus shifted considerably toward progressing the elements of the AI-ITMS that relate to signal operations. With this shift, several software components remain in the predeployment stage and have not yet been approved for full deployment. Despite deferred evaluation for six performance measures, the evaluation demonstrated positive results for the AI-ITMS program.

Source: DelDOT.

Figure 4. Graphic. Web portal for machine vision cameras.

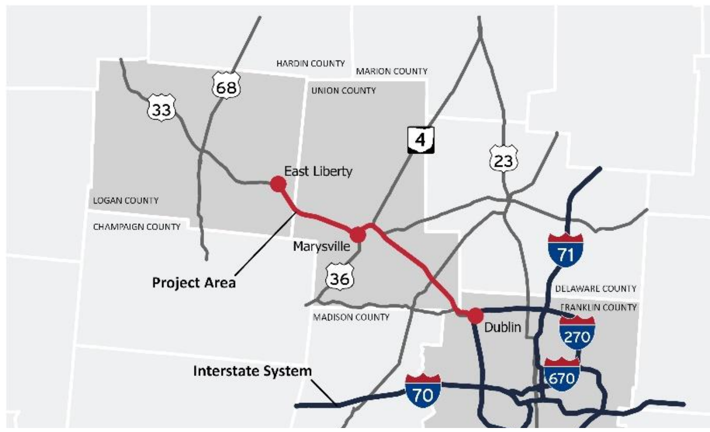
Both the incident detection time and incident detection accuracy performance measures demonstrated encouraging results. The average AI-TOMS freeway incident detection time was 14 minutes and 33 seconds, which is above the target time of 10 minutes. However, this result is nuanced, as most of the delay seen in the average incident detection times was due to latencies within DelDOT's existing system rather than within AI-TOMS itself. AI-TOMS was able to detect 87 percent of incidents on I–95, 56 percent of incidents on Delaware Route 1, and 69 percent of incidents overall. Detection accuracy was highest in areas with a high density of ITS devices, and accuracy was lowest during nighttime hours when an incident may not restrict capacity enough to be detected. Although these results do not meet the identified accuracy standards, they do demonstrate the potential for increased future accuracy as additional ITS devices are installed.

AI-TOMS easily cleared the threshold set for transportation system condition updates, because the system provides automatic updates on road anomalies and congestion every 5 minutes. The notification update speed and accuracy measures showed that AI-TOMS sends out notifications via email before incidents are registered in the AI-TOMS database, and that incident email alerts are 100-percent accurate but do not yet provide actionable information. As DelDOT continues to develop AI-TOMSs' incident notification capabilities, DelDOT intends to design notifications to each component of the TIS to provide the intended audience with an appropriate level of information to make educated decisions.

DelDOT made strides toward deploying an AI-ITMS throughout the ATCMTD grant period. DelDOT successfully integrated more than 10 sources of near-real-time traffic data into the system, concurrently monitoring nearly 90 percent of ITMS devices statewide. By enhancing DelDOT's existing system, the AI-ITMS provides the foundation for further advanced technology, including machine vision, in transportation. The system is designed to eventually act autonomously without relying on human technicians and to learn to improve over time. All efforts lead to the ultimate goal of operating a fully predictive and adaptive transportation management system.

NW 33 Council of Governments (Fiscal Year 2016)

Through the US 33 Smart Mobility Corridor (SMC) Program, the NW 33 COG initiated one of the first deployments of CV technologies in Ohio. From 2018 through 2023, this project developed and evaluated a transportation technology test corridor with a robust network of CV infrastructure to improve safety, foster innovation, and advance the use of transportation technology. The project was led by the NW 33 COG (Union County, City of Marysville, and City of Dublin) with support from ODOT and DriveOhio. The project location is shown in figure 5.



Source: NW 33 COG.

Figure 5. Map. US 33 project corridor.

The US 33 SMC Program deployed the following technological advancements:

- Two hundred onboard units (OBUs) on multiple vehicle types from the cities of Marysville and Dublin and in Union County;
- One hundred roadside units (RSUs) through the project corridor;
- Dynamic traffic SPaT through the cities of Dublin and Marysville;
- Pedestrian-in-crosswalk warning systems at high-traffic locations;
- Five applications, including lane closure warning, curve speed warning (CSW), reduced speed zone warning, pedestrian conflict warning, and red-light violation warning; and
- Fiber communication to connect the Dublin Metro and Honda Motor Co.® Data Centers.

Researchers evaluated the goal of improving safety by measuring the number of recorded safety-related OBU application events, as they represent near misses, and through stakeholder feedback. Between May 2022 and May 2023, 13,930 application notifications related to the project were recorded. An application notification is triggered to warn the driver of an unsafe condition, such as running a red light or excessive speed for the curve ahead. Most of the recorded events were red light violation warnings (58 percent), followed by CSWs (40 percent).

Lane closure warnings, reduced speed zone warnings, and pedestrian conflict warnings accounted for no more than 1 percent of events.

Stakeholder feedback was gathered to provide insight into the effectiveness of warnings in improving safety as well as satisfaction with, and attitudes toward, the technology. A survey was sent to 200 drivers of the CV-equipped public fleet vehicles in the cities of Marysville and Dublin and in Union County.[4] The survey revealed that 41 percent of respondents reported safety enhancements through fewer crashes (8 percent), increased driver awareness (28 percent), and fewer near misses (5 percent). Nevertheless, respondents had a negative view of the technology with most respondents indicating that the technology was unreliable. The survey results suggest that a lack of training was an underlying issue. Drivers' satisfaction with the technology was correlated with the ease of learning to use that technology. Users who reported that the technology was easy to learn also reported higher than average satisfaction.

The researchers evaluated the goal of accelerating the deployment of transportation technologies by measuring the RSU uptime percentages, the number of OBUs using the system, and the number of other deployments leveraging the technology infrastructure installed through this project. RSU uptime reflects the reliability of the roadside physical infrastructure. From the end of May 2023 to the end of August 2023, 65 RSUs were monitored, revealing an average uptime of 93 percent, with 72 percent of RSUs operating at 99 percent uptime or better. While these results indicate reliable and consistent operation among a majority of the RSUs, the instances of lower uptimes suggest potential issues or areas for improvement.[5]

In addition to the 200 OBUs that were operating in public fleet vehicles for this project, 366 OBUs were installed in vehicles as part of third-party deployments that benefitted from using the project infrastructure. Between May 2022 and May 2023, 21 CV applications were recorded, and only 5 of these were deployed and evaluated through this project. For the 5 project applications, 189 unique OBUs were recorded, 58 percent of which were third-party and did not correspond to OBUs deployed through this project.

One of the benefits of bringing together industry, government, and academic institutions for this project has been the growing activity in the region, which includes deploying new technology, testing against standards, and developing new standards. Overall, NW 33 COG identified at least 13 deployments or initiatives leveraging the technology infrastructure.[6]

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[4]Seventy-five responses were collected, which reflects a 37.5-percent response rate.
[5]Observations during the maintenance period provided potential explanations (e.g., power outages, loss of network connectivity, device failure, and the need for firmware upgrades).
[6]Some of these projects include the Connected Marysville project, wrong-way driving application tests, a vulnerable road user pilot deployment, a spot weather warning system deployment, an asset-protection system project, uncrewed aerial system projects, a connected intersection project, the Honda Smart Intersection deployment, the OmniAir Consortium Plugfest, and the Connect Vehicle Pooled Fund Study.

From the project and its evaluation, the NW 33 COG learned valuable lessons that have and will continue to shape the development of CV technology. For details, see the section on lessons learned and the US 33 SMC Program Final Report.

Source: WSDOT.

Figure 6. Photograph. Virtual coordination center interagency design session.

Washington State Department of Transportation (Fiscal Year 2019)

WSDOT led an effort to develop, deploy, and evaluate a VCC for the Seattle urban corridor. The VCC is a digital collaborative environment for integrated multimodal corridor management through which transit, fire department, police, Washington State Patrol (WSP), and WSDOT partners coordinate incident responses. An interagency design meeting is shown in figure 6. The project stemmed from a series of incidents that had significant negative effects on travel in the Seattle area during 2015–2017, which motivated the need for a new environment for interagency management of incidents that affected the regional transportation system.

The VCC includes the following key features and capabilities:

- An integrated dispatch feed that provides a running account of dispatch events, operational dispatches from the King County Metro Transit Control Center, and information from the WSDOT TMC log;
- A situational map linked to the dispatch feed and with numerous informational layers such as cameras, traffic, and construction sites;
- Incident models launched by users or the system indicating that a high-impact event is likely in progress and provide information for coordinated action;
- A population movement hub to help coordinate public messaging; and
- A records management capability that enables agencies to address issues of data retention and management.

From February 27 to September 30, 2023, the researchers evaluated the VCC model deployment. During this time, 354 incident models were launched either manually or by the system. Of these models, 52 were removed from the system because they were not sufficiently severe enough to be VCC-level incidents. Of the remaining 302 incidents, the VCC automatically launched 85, WSDOT launched 197, and SDOT launched 20. The average incident duration was 5 hours and 22 minutes, with a median duration of 1 hour and 36 minutes. The VCC was primarily evaluated through surveys and interviews of VCC users.

The VCC satisfaction survey found that users were satisfied overall with VCC's effect on obtaining information, collaborating across agencies, and coordinating during active incidents. Users trusted the information provided in the VCC overall, although some indication of certain users losing trust in the VCC over time was found. One survey respondent credited the VCC with improving the speed at which the information is updated and stated that the information in the VCC is always the best available data source at the time. The survey found that most respondents found the VCC useful to their work, saved time when working an incident, improved their ability to coordinate with other agencies, and received relevant information from the VCC that they could not have easily obtained elsewhere.

The evaluation asked interviewees whether interactions with legacy systems had changed since deploying VCC and found that overall, the use of legacy systems has not significantly changed. For example, the WSDOT TMC personnel continue to use a legacy WSP CAD client as their primary source of information due to the additional information available from that client. However, the WSDOT Incident Response Team staff members have come to rely on the VCC and use it daily.

Interviewees and survey respondents also noted a variety of additional data sources that could improve the VCC, including tow truck locations, WSDOT maintenance vehicles, construction equipment, electronic message sign locations, and weather data.

The work accomplished under this project can be sustained and enhanced with funding by the State legislature and under WSDOT guidance. A logical next step could be to integrate the management of an interstate corridor with the VCC, such as the Vancouver, WA, to the Portland, OR, corridor. Other city corridors across the Nation have started projects similar to the VCC, and these projects may learn from what was accomplished in the Seattle area.

Utah Department of Transportation

Through its Utah Connected project, the UDOT improves real-time situational awareness, safety, and mobility while developing lessons learned and recommendations for future deployments of advanced technologies. The Utah Connected project has three focus areas: Connected Systems, CVs, and Connected People. The service area includes corridors in and around Salt Lake City, UT, as well as extensions of technologies across the State.

The focus on **Connected Systems** creates a data ecosystem that integrates data from each of the project focus areas and promotes real-time situational awareness by developing a cloud-based data analytics platform and deploying cellular vehicle-to-everything (C-V2X) technology in the 5.9 GHz spectrum. The platform collects weather-related data to inform Spot Weather Impact Warnings (SWIWs) and integrates a Security Credential Management System (SCMS) into UDOT's vehicle-to-infrastructure (V2I) applications. In total, 199 road weather information systems (RWIS) sensors, 186 OBUs, 296 RSUs, 296 network switches, 236 signal command modules, and 236 traffic signal controllers are integrated and provide data used to generate insights about current roadway conditions and device health within the data ecosystem. Of the data elements collected from these sources, 100 percent are being ingested, and efforts to fully utilize all the available data remain underway.

Connected Vehicles are a major focus of the Utah Connected project, which has multiple deployments. Snowplow preemption coverage has been extended to an additional 4 corridors in Utah County by equipping 20 additional snowplows (shown in figure 7).

Source: UDOT.

Figure 7. Photograph. Snowplows.

UDOT uses existing fiber optic cable located along three canyon roads near Salt Lake City to monitor highway traffic through fiber sensing and an innovative distributed acoustic system, which detects acoustic events, such as crashes, avalanches, and rockfalls. Two roads were part of the original scope; however, the fiber placement techniques in some places limited responsiveness, resulting in the two corridors having monitoring coverage of 3.3 percent and 75 percent, respectively. A third corridor with ideal fiber placement was added for comparison. There, camera footage was used to verify that 96 percent of the traffic was sensed by the system. All nontraffic monitoring events—including construction efforts that cut the fiber, one mudslide, one flooding incident, and four avalanches—were detected. Because vehicle crashes generate strong signals, all four crashes that occurred were successfully detected by the fiber sensing system.

The snowplow preemption yielded the following findings:

- Plows can only request preemption when the salt spreader is activated, usually meaning the vehicle is plowing. Plows passing through intersections requested preemption 42.3 percent of the time, and over 83 percent of requests were granted.
- Where vehicles received snowplow preemption, general traffic speeds were 0.23 percent higher when it snowed, indicating a positive effect on corridor traffic. Overall, average plow speed was lower on equipped routes compared with nonequipped, although plow speeds at the corridor level showed mixed results. This variation may be due to differing storm characteristics, driver behavior, and other traffic conditions.
- The maintenance shed foreman reported positive feedback from plow operators, who indicated that plows stopped less and fewer passenger vehicles attempted to pass the plows on equipped routes.
- Plow drivers on one challenging route noted that the preemption capability reduced their plowing time from 90 minutes to 45 minutes.

UDOT also expanded V2X-enabled transit signal priority (TSP) coverage along a major State route by installing 48 new RSUs and equipping 30 additional buses with OBUs. Equipped buses in 2023 completed their route 2.3 minutes faster, on average, than nonequipped buses. Some deployment challenges prevented TSP from functioning at 24 of the 49 intersections during the data collection period, indicating that the ontime performance of equipped buses may further improve once all intersections are operational.

Additionally, UDOT deployed a V2I application—CSW—at eight high-risk curves in the Salt Lake Metro area, as well as an SWIW system and a V2X application. As part of the CV deployment, UDOT also installed human-machine interfaces (HMIs) into three vehicles; an HMI allows these vehicles to receive V2X messages from the SWIW and CSW applications to warn the drivers of hazards. Icy road events were detected by RWIS stations (1,233 events) and CVs (2,356 events). When the icy road event was within half a mile of an RSU, an alert in the form of an icy road SWIW traveler information message (TIM) was automatically generated and transmitted, which occurred 217 times during the study period. RWIS and CVs identified icy road events and generated TIMs independently, though never simultaneously, reinforcing the need for both, given their different methods of detection. The CSW and SWIW applications, while only proof-of-concept applications, provided insight into the value of these warnings and shed light on how they can be more effectively deployed in the future. The unanticipated benefit of these two projects is that they revealed serious hardware and firmware issues that might not have been recognized otherwise, resulting in improvements to this hardware.

Connected People efforts involved collecting lessons learned from an automated shuttle pilot deployment. UDOT performed a viability assessment for using AVs as a first-mile and last-mile public transit solution, collecting data on public attitudes and trust toward AVs at eight separate shuttle sites. Of AV shuttle riders who completed a survey, 98 percent reported feeling safe, and 95 percent felt that the shuttle could complement public transit. Figure 8 shows one of the tested shuttles.

Source: UDOT.

Figure 8. Photograph. Automated shuttle.

At the conclusion of this Utah Connected project, UDOT hosted a series of six webinars to foster collaboration and promote information sharing among its partners and industry stakeholders. More than 13 hours of recorded material are available on UDOT's YouTube® channel or on https://www.transportationtechnology.utah.gov. The presenters included 17 transportation professionals who shared unique insights, detailed aspects of each project, lessons learned, evaluation results, and recommendations for future deployers.

GRANTEE REPORTED INSIGHTS

In their final reports, grantees are required to share challenges, lessons learned, and recommendations from their project deployments. For the six grantees who have submitted final reports, a review of their challenges, lessons learned, and recommendations were performed, and key categories were identified based on the grantees' reported information. Grantees' challenges, lessons learned, and recommendations fell into the following seven categories:

- Data;
- National Events;
- Policy/Regulatory;
- Project Scoping;
- Stakeholder/Project Management;
- Technology and Equipment; and
- User Experience.

Each subsection provides a brief description of the category. Within each category, grantees' challenges, lessons learned, and recommendations were further classified into more specific subtopics. The sections below highlight both the shared and unique experiences of the seven grantees and are listed in order of the number of grantees who shared each takeaway. Notably, the grouping of these challenges, lessons learned, and recommendations into categories and subcategories was a subjective exercise designed to identify commonalities among grantees. In addition, the findings presented below are general summaries of the challenges, lessons learned, and recommendations. For more detailed information, please reference the grantees' published final reports.[7]

Data

The following challenges, lessons learned, and recommendations focus on issues with data collection, storage, and use:

- **Data Storage:** UDOT, DelDOT, and the NW 33 Innovation Corridor COG shared lessons learned about the high cost of data storage. Given the massive amounts of data these advanced technologies generated, deployers may need to balance what data need to be stored versus the cost of storage.

- **Data Validation:** A common theme among applicants collecting a large amount of data was the need to either manually or systematically validate the data collected. WSDOT and DelDOT both had issues with incident timelines being inaccurate and requiring validation, whereas UDOT recommended validating MAP messages[8] against real field conditions.

- **Security Standards:** DelDOT had issues with firewall updates significantly slowing the deployment of new capabilities, and the NW 33 Innovation Corridor COG shared that they could not detect which OBUs were installed on their project vehicles due to anonymity security measures. In contrast, WSDOT reported that users were concerned about their data being leaked if shared with the grantee, so WSDOT had to build trust with their stakeholders.

- **UDOT's Other Data Takeaways:** UDOT reported several other data issues. These matters include problems disseminating data from their data lake, issues gathering a sufficient amount of data to train their fiber optic sensors, the lack of comparability between their baseline data and their test case data, and Global Positioning System (GPS) data collection issues.

- **NW 33 Innovation Corridor COG's Other Data Takeaways:** The NW 33 Innovation Corridor COG lost a lot of data because of issues with their over-the-air download function not working properly between their RSUs and their OBUs.

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[7]Two of the six grantees are formally completed (i.e., closed), with final reports published as of March 31, 2024. Once published, final reports are posted on FHWA's Fixing America's Surface Transportation Act or "FAST Act" web page. As of March 31, 2024, final reports for Cleveland RTA and POV are published. See https://ops.fhwa.dot.gov/fastact/.
[8]USDOT. n.d. *MAP Tool* (software). https://webapp.connectedvcs.com/isd/, last accessed July 16, 2024.

National Events

The following challenges, lessons learned, and recommendations stem from national events that disrupted the projects in some capacity:

- **Reduced Travel Demand:** DelDOT had difficulties establishing a baseline between 2020 and 2021 to evaluate system performance due to lower travel demand. The NW 33 Innovation Corridor COG simply had a hard time using data during those years, and UDOT could not test their autonomous bus operations because with businesses closed, the demand for the system lessened.

- **Remote Work Requirement:** Both DelDOT and Cleveland RTA mentioned the inability to come into the office led to logistical challenges for the project, whereas the POV listed the need for remote work as a recommendation.

- **Supply Shortages:** DelDOT and the NW 33 Innovation Corridor COG both had difficulty acquiring all the required equipment for their project due to limitations in supply.

Policy/Regulatory

The following challenges, lessons learned, and recommendations relate to new regulations and policies that interrupted projects or caused delays:

- **Federal Communications Commission's (FCC's) 5.9 GHz Rule:**[9] This rule affected both UDOT and the NW 33 Innovation Corridor COG's projects, causing delays and reshaping their scope.

- **UDOT's Other Policy/Regulatory Takeaways:** UDOT experienced challenges resulting from the National Highway Traffic Safety Administration's suspension of EasyMile, a France-based autonomous shuttle company, in 2020 due to a passenger being injured. Ultimately UDOT experienced schedule delays and budget issues.

Project Scoping

The following challenges, lessons learned, and recommendations have to do with problems with project scoping:

- **Immature Technology:** NW 33 Innovation Corridor COG, WSDOT, and UDOT overestimated the ability of current technology and had to reduce their scope.

- **NW 33 Innovation Corridor COG's Other Scoping Takeaways:** NW 33 Innovation Corridor COG underestimated the amount of funds required to power their RSUs and recommended further coordination with power companies.

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[9]The FCC's November 10, 2020, First Report and Order (86 FR 23281), approved on November 18, 2020, and published in the *Federal Register* on May 3, 2021, describes changes to the allocated 75 MHz of radio spectrum in the 5.9 GHz band used for vehicle and infrastructure communications, which is also known as the Safety Band.

- **Cleveland RTA's Other Scoping Takeaways:** Cleveland RTA underestimated the number of staff members needed for the project, requiring staff to work overtime to complete the project on time.

Stakeholder/Project Management

The following challenges, lessons learned, and recommendations relate to stakeholder involvement and project management strategies:

- **Multiorganizational Structure:** Both WSDOT and the NW 33 Innovation Corridor COG recommend forming a committee of stakeholders and technology users who have a role in decisionmaking to provide feedback throughout the deployment process. Although DelDOT did not specify a committee, the grantee did mention the importance of creating a communication plan with all related stakeholders.

- **Community Support:** Both the NW 33 Innovation Corridor COG and WSDOT recommended building community buy-in to ensure the new technology has a user base and that the community will support continued investment in the technology.

- **WSDOT's Other Stakeholder/Project Management Takeaways:** WSDOT recommended building stakeholder feedback framework around existing stakeholder coordination mechanisms.

- **NW 33 Innovation Corridor COG's Other Stakeholder/Project Management Takeaways:** The NW 33 Innovation Corridor COG recommended developing a set of use cases first, then evaluating each by its technology viability, benefit-cost ratio, and stakeholder feedback.

- **UDOT's Other Stakeholder/Project Management Takeaways:** UDOT recommended creating a guidebook when installing something new to make it easier to install next time. Additionally, UDOT emphasized the importance of defining internal roles and responsibilities within a project.

- **Cleveland RTA's Other Stakeholder/Project Management Takeaways:** Cleveland RTA recommended having internal staff do installations so they have a better understanding of the system as a whole.

- **POV's Other Stakeholder/Project Management Specific Takeaway:** The POV recommended building extra time into project scheduling when working with cutting-edge technology.

Technology and Equipment

The following challenges, lessons learned, and recommendations relate to technology-specific issues:

- **Importance of Standardization:** The NW 33 Innovation Corridor COG and WSDOT emphasized the importance of creating consistency across technology. The NW 33 Innovation Corridor COG coordinated with DriveOhio to create SAE International J2945 standards,[10] whereas WSDOT collaborated with SDOT to standardize operating procedures for VCC usage.

- **Rapid Changes of Technology:** The NW 33 Innovation Corridor COG and DelDOT had rapid changes to technology that interrupted their original plan and schedule. In NW 33 Innovation Corridor COG's case, they needed to upgrade from Internet Protocol version (IPv)4 to IPv6 (the IPv4 standard was insufficient for conducting over-the-air-updates for OBU firmware and certificate top offs for the SCMS). In DelDOT's case, they needed to upgrade the firmware on many traffic signals.

- **Test Bed Effect:** Both the NW 33 Innovation Corridor COG and DelDOT mentioned the positive effects of their test beds. Since completing their project, they have had a "test bed" effect, attracting other advanced transportation technology deployers to their region for testing.

- **Agile Development:** DelDOT and WSDOT used an "agile development" process that relies on iterating with stakeholders in the development of software. This process enabled the grantees to continuously adjust and improve the design based on stakeholder input.

- **UDOT's Other Technology-Specific Takeaways:** UDOT had more difficulties managing SCMS than anticipated and learned that fiber optic data quality is very dependent on the installation method used. Additionally, UDOT recommended testing technology after installation to make sure that it is working properly.

- **DelDOT's Other Technology-Specific Takeaways:** DelDOT reported inclement weather interfering with their traffic cameras and an inability to successfully model vulnerable road users due to insufficient data. In addition, the grantee was uncertain about whether their AI-TOMS could be scaled to all statewide traffic lights.

- **WSDOT's Other Technology-Specific Takeaways:** WSDOT recommended that operational changes due to new technologies should align with current operational practices and agency roles. In addition, it recommended that deployers should not add too much complexity because busy users will likely skip over complicated features.

- **NW 33 Innovation Corridor COG's Other Technology-Specific Takeaways:** The NW 33 Innovation Corridor COG assumed J2945/4 would have been published in time for the project, but since it was not, the grantee had to shift to a less desirable alternative. The grantee also recommended that future CV projects should start small and develop the

[10] See https://www.sae.org/standards/content/j2945_201712/.

performance measures accordingly, rather than assuming a huge deployment of CVs when drafting performance measures. Finally, this grantee also mentioned that in the initial version of their project, pedestrian alerts relied on button presses, which did not always happen or did not always mean someone would be walking. They recommended making it more reliant on actually detecting pedestrians, as users need to trust the technology is accurate (if it says a pedestrian is walking, there should be one).

User Experience

The following challenges, lessons learned, and recommendations focus on the users' experience with the deployed technologies:

- **User Confusion:** WSDOT, UDOT, and the NW 33 Innovation Corridor COG had recommendations centered around addressing user confusion with their technology. WSDOT and UDOT's recommendations focused on user interface (UI); WSDOT suggested mobile compatibility, as their initial application was not well designed for mobile technology, and UDOT suggested collecting UI feedback from multiple users. NW 33 Innovation Corridor COG recommended user training for their use case.

- **WSDOT's Other User Experience Takeaways:** WSDOT shared that technology users often like the simpler option when given a choice, which is important to keep in mind when designing a system.

CHAPTER 4. GRANTEES' CONCLUSIONS

The FAST Act established the ATCMTD Program to develop model deployments to improve safety, efficiency, system performance, and infrastructure return on investment. USDOT has awarded 58 projects from FY 2016 through FY 2021, including city and county projects, as well as statewide or regional projects. The projects represent a diverse set of advanced technology deployments across the United States. Some of the key technology deployments include CVs, advanced TISs, ICM, AI-enhanced maintenance and monitoring technologies, adaptive traffic signal control, and AVs. The projects span a range of modes and service models: vehicle, freight, transit, pedestrian and bicyclist, and MOD.

This 2024 ATCMTD Program report summarizes key findings from six completed projects, including two integrated transportation management systems, two CV projects, a freight project, and a transit project. DelDOT deployed an AI-enhanced integrated transportation management system, and WSDOT's VCC enabled multimodal ICM. In both cases, the grantees were able to leverage their technology deployments to improve incident detection and increase overall situational awareness. For the two CV projects, UDOT and Northwest COG deployed integrated CV systems along a corridor and were able to test the RSUs and CV applications, and they demonstrated the potential of this technology. Both the freight and transit projects were able to achieve greater operational efficiencies with their technology deployments. The POV deployed a freight reservation system that improved overall port efficiency (e.g., reducing operational hours while increasing overall container volumes) and safety compliance. Cleveland RTA deployed CAD and AVL on its buses, as well as priority cellular service, and upgraded its radio communications, resulting in improved asset management and operational efficiencies.

This report also summarizes the grantees' challenges, lessons learned, and recommendations, as described in the final reports of the six completed projects. Key themes include data, national events, policy and regulations, project scoping, stakeholder and project management, technology, and user experience. Data-related topics were commonly cited and included data storage, data validation, and security standards, among other issues. A number of the grantees also mentioned national events, whether it was in the context of reduced travel demand, supply shortages, or remote work requirements that affected projects. With respect to policy and regulations, the FCC's 5.9 GHz Rule affected some projects. A number of grantees cited project scoping issues, with several indicating that they overestimated the capabilities of immature technologies and had to rescope their projects. Stakeholder and project management issues tended to focus on the importance of engaging stakeholders and building community support. Grantees also mentioned a range of technology topics, including the importance of standardization, the need to adapt to rapidly changing technology, as well as the importance of technology testing and aligning the operational practices of new technologies within agencies' existing frameworks. Grantees also recommended being sensitive to user experience issues (e.g., related to UI).

In addition to the 6 completed projects, 12 grantees have completed deployment and are collecting evaluation data; an additional 21 grantees are piloting, testing, or beginning to deploy technologies; and 19 grantees are still in the planning phases. As more grantees complete their projects in the next few years, subsequent program reports will highlight the effects of the ATCMTD technology deployments, challenges, and lessons learned.

APPENDIX A. ANNUAL REPORT TEMPLATE

The purpose of this template is to assist grantees in preparing uniform annual reports. This template, while not required, is highly recommended, as FHWA intends to use the information from the grantees' annual reports to prepare the required Program Level Reports on the effectiveness of the ATCMTD grantees in meeting their projected deployment plans. FHWA first issued this template to the grantees on February 11, 2019.

Reporting Requirement

Federal statute 23 U.S.C. 503(c)(4)(F) provides: *"For each eligible entity that receives a grant under this paragraph, not later than 1 year after the entity receives the grant, and each year thereafter, the entity shall submit a report to the Secretary that describes—*

(i) deployment and operational costs of the project compared to the benefits and savings the project provides; and
(ii) how the project has met the original expectations projected in the deployment plan submitted with the application, such as—
   I. data on how the project has helped reduce traffic crashes, congestion, costs, and other benefits of the deployed systems;
   II. data on the effect of measuring and improving transportation system performance through the deployment of advanced technologies;
   III. the effectiveness of providing real-time integrated traffic, transit, and multimodal transportation information to the public to make informed travel decisions; and
   IV. lessons learned and recommendations for future deployment strategies to optimize transportation efficiency and multimodal system performance."

This template has four parts:

- Part 1 of 4: Introduction and Overview
- Part 2 of 4: Evaluation/Research Activities
- Part 3 of 4: Findings
- Part 4 of 4: Wrap-Up

SAMPLE

PART 1 OF 4: INTRODUCTION AND OVERVIEW

Project Title:

Grant Award Recipient:

Annual Report Period: *[insert date range*]

Prepared By: *[name, agency, and title*]

NOTE: Responses to questions 1–3 should reflect the ***current*** *project scope and goals. If there have been no changes in project scope or goals (since the last annual report), responses to questions 1–3 should be the same as the previous annual report.*

1. **Please provide a *high-level* description of your project, including the intended beneficiaries. (Please limit to approximately 350 words or less.)** ***Note: in Part 4 of 4, question 1, you will be asked to note any major deviations or changes in scope due to either project-driven outcomes or other unforeseen challenges.***

2. **Please indicate which ATCMTD-targeted technologies your project covers** *(check all that apply).*

☐ Advanced traveler information systems

☐ Advanced transportation management technologies

☐ Infrastructure maintenance, monitoring, and condition assessment

☐ Advanced public transportation systems

☐ Transportation system performance (monitoring) data collection, analysis, and dissemination

☐ Advanced safety systems, including vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, autonomous vehicle development or deployment, and associated technologies that would enable V2V or V2I, including cellular or other technology

☐ Integration of ITS using a smart grid or similar energy distribution and charging systems

☐ Electronic pricing and payment systems

☐ Advanced mobility and access technologies, such as dynamic ridesharing and information systems to support human services for elderly, disabled, or disenfranchised individuals

☐ Other (Describe)

____

3. What are your project's goals? *(Check all that apply.)* Note: For each goal identified, you will be asked in Part 2 and Part 3 to map your project's performance measures and findings to date, respectively.

☐ Improved safety

☐ Reduced congestion and/or improved mobility (e.g., travel time reliability)

☐ Reduced environmental impacts (e.g., emissions and/or energy)

☐ Improved system performance/optimized multimodal system performance

☐ Enhanced access to transportation alternatives

☐ Effectiveness of providing integrated real-time transportation information to the public to make informed travel decisions

☐ Reduced costs

☐ Institutional or administrative benefits (e.g., increased interagency coordination)

☐ Other benefits (please specify): ______________________________

☐ Other goals (please specify): ______________________________

SAMPLE

PART 2 OF 4: EVALUATION/RESEARCH ACTIVITIES

Please complete the following table regarding your evaluation activities. For each goal area that is applicable to your project, provide the performance measures and a status update on your research activities. The update should include the status of baseline data collection (if applicable) and any challenges or data limitations. If research is completed, please indicate that here in Part 2, but please reserve findings for Part 3.

Goal Area	Performance Measures: Quantitative and Qualitative (if multiple technologies apply, please note the different technologies)	Research Update (e.g., baseline data collection, challenges, milestones achieved)
Improved safety (e.g., reduced crashes)	1. 2. Etc.	
Reduced congestion/improved mobility (e.g., travel time reliability)	1. 2. Etc.	
Reduced environmental impacts	1. 2. Etc.	
Improved system performance (including optimized multimodal system performance)	1. 2. Etc.	
Enhanced access to transportation alternatives	1. 2. Etc.	
Effectiveness of providing integrated real-time transportation information to the public to make informed travel decisions	1. 2. Etc.	
Reduced costs	1. 2. Etc.	
Institutional or administrative benefits	1. 2. Etc.	

SAMPLE

PART 3 OF 4: FINDINGS

For each applicable goal area, please describe the impacts of your project based on findings from the performance measures. If data collection is still underway (i.e., findings are not yet available), indicate "In Progress" in the Findings column. Please use the Notes/Considerations column to include any other relevant information regarding the evaluation. Note: the numbering for the findings should correspond to the numbering used for performance measures in Part 2.

Goal Area	Findings (tied to performance measures; also include any anecdotal evidence)	Notes/ Considerations
Improved safety (e.g., reduced crashes)	1. 2. 3. Etc.	
Reduced congestion/improved mobility (e.g., travel time reliability)	1. 2. 3. Etc.	
Reduced environmental impacts	1. 2. 3. Etc.	
Improved system performance (including optimized multimodal system performance)	1. 2. 3. Etc.	
Enhanced access to transportation alternatives	1. 2. 3. Etc.	
Effectiveness of providing integrated real-time transportation information to the public to make informed decisions	1. 2. 3. Etc.	
Reduced costs	1. 2. 3. Etc.	

SAMPLE

Goal Area	Findings (tied to performance measures; also include any anecdotal evidence)	Notes/ Considerations
Institutional and/or administrative benefits	1. 2. 3. Etc.	
Other benefits: Please specify:	1. 2. 3. Etc.	
Other benefits: Please specify:	1. 2. 3. Etc.	
Other goals [add if needed]: Please specify:	1. 2. 3. Etc.	

SAMPLE

PART 4 OF 4: WRAP-UP

1.	In your view, how is the project doing with respect to meeting original expectations (i.e., as stated in the project proposal)? Note here any *major* deviations or changes in scope from the original proposal due to either project-driven outcomes or other unforeseen challenges (e.g., unavailability of presumed data, unforeseen legal or administrative constraints, unexpected stumbling blocks, obvious delays, time-consuming tasks, or executive decisions to alter course).
2.	Are there any aspects of your project that you consider cutting-edge, noteworthy, or innovative? If yes, please describe.
3.	How do deployment and operational costs of the project compare to the benefits and savings the project provides (i.e., can you provide an objective benefit-cost analysis or alternate subjective comparison)?
4.	What are lessons learned to date from your deployment, specifically regarding future deployment strategies to optimize transportation efficiency and multimodal system performance? Please note lessons learned with respect to challenges in technology deployment (e.g., technical, institutional), research (e.g., performance measurement), or other lessons learned.
5.	What recommendations can you provide regarding future deployment strategies in this/these area(s)?
6.	Do you have any final comments or feedback?

APPENDIX B. ADVANCED TRANSPORTATION AND CONGESTION MANAGEMENT TECHNOLOGIES DEPLOYMENT PROJECT DESCRIPTIONS

This section summarizes each ATCMTD project selected for an award, including grant amount, project goals, and technologies being deployed.

FISCAL YEAR 2021 PROJECTS

Proactive Route Operations to Avert Congestion in Traffic (PROACT) Alabama *(ALDOT)*:

- Grant Amount: $5 million.
- Project Goals: This project improves highway management and operations to connect residents to jobs, healthcare, education, and service through reduced congestion, improved measurement of operational performance, a reduced number of and severity of crashes, and improved real-time information to improve mobility.
- Technologies Being Deployed: Advanced traffic technologies and decision support tools, including dedicated short-range communication (DSRC), C-V2X, cellular, 900-MHz radios, an advanced road weather monitoring and forecasting tool and technologies, CV probe data, a central traffic management system and machine vision for signalized intersection operations and safety, CV hardware for a freight priority application, and TIS applications.

An End-to-End Decision Support System for Integrated Smart Electric Grid and Transportation System Management *(City of Chattanooga)*:

- Grant Amount: $4,577,721.
- Project Goals: This project improves access to EV charging stations, accelerates deployment of clean transportation, reduces transportation-related emissions, reduces traffic incidents, improves travel time reliability, optimizes multimodal system performance and access, and provides cost savings to transportation agencies, businesses, and users.
- Technologies Being Deployed: A centralized citywide traffic management system, smart electric grid monitoring and management system, EV charging infrastructure online monitoring system, system-of-systems analytics and end-to-end DSS, a DSS for EV charging, personalized EV charging information system, cellular/DSRC, roadside cameras, intersection light detection and ranging, and wireless communication technologies.

Chicago Centralized Transit Signal Priority Project (CCTSP) *(City of Chicago)*:

- Grant Amount: $3,990,000.
- Project Goals: This project enhances the use of existing transportation capacity to reduce costs and improve return on investment, advance public transportation systems, implement advanced safety systems, reduce environmental impacts, and address racial equity barriers to opportunity.
- Technologies Being Deployed: Centralized TSP system utilizing existing infrastructure, high-frequency bus AVL location reporting, an interface between central bus system and advanced traffic management system (ATMS), video analytics and AI technology at intersections with DSRC or C-V2X communication, and remote TSP requests placed on the signal controller by ATMS.

Great Plains Rural Freight Technology Corridor Project *(KDOT)*:

- Grant Amount: $6,679,072.
- Project Goals: This project uses advanced technologies to deliver traffic, weather, and other operational information to commercial truckers to optimize freight routing, improve safety, reduce congestion, and improve economic opportunities for low-income communities of color.
- Technologies Being Deployed: Fiber optic communication cables to enable V2I, RWIS), microwave vehicle detection systems, SPaT, CV integrations for freight vehicles, dynamic message signs (DMSs), and an expansion of online real-time traveler information.

Kentucky's Wrong-Way Driving and Integrated Safety Technology *(Kentucky Transportation Cabinet)*:

- Grant Amount: $5,147,300.
- Project Goals: This project detects and deters wrong-way incidents by alerting other drivers and emergency responders and improves an existing ITS to monitor and detect other safety concerns related to pedestrians, debris, and halted vehicles on the roadway.
- Technologies Being Deployed: Computing and video processing with thermal cameras, automatically activated flashing LEDs on wrong-way signs, DMSs, machine readable QR codes on wrong-way signage, and DSRC/5.9 GHz spectrum.

Port of Los Angeles Gateway *(Port of Los Angeles)*:

- Grant Amount: $3 million.
- Project Goals: This project improves trucking, drayage, and terminal operator activities by streamlining cargo staging and empty returns, which will decrease congestion at the port.
- Technologies Being Deployed: Web-based user portal, digital twin, ML, AI, microservice architecture, Internet of Things, radiofrequency identification (RFID), Wi-Fi®, Bluetooth®, and an application program interface.

EZConnect: An Open and Cloud-Based Mobility Center Providing One-Stop Access for Travel Needs of Underserved Customers *(NEORide)*:

- Grant Amount: $1,493,313.
- Project Goals: This project improves the availability of real-time information to connect underserved riders to multiple transit agencies providing service through a central system, which reduces congestion and increases customer access and satisfaction.
- Technologies Being Deployed: A cloud-based real-time mobility coordination center with an open data exchange, V2X technologies, a trip planner with integration with the EZfare payment system, and a centralized reservation and coordination system.

Electric Vehicle User Range Anxiety Solution for Rural North Dakota *(NDDOT)*:

- Grant Amount: $1,449,000.
- Project Goals: This project accelerates the deployment of EV charging stations, creates jobs, and advances access to clean transportation in rural areas.
- Technologies Being Deployed: Wi-Fi, electronic pricing and payment systems at charging stations, and smart grid technologies.

Smart and Connected Atlantic City Expressway *(SJTA)*

- Note: This project was canceled, and obligated funds were returned.
- Grant Amount: $8,748,763.
- Project Goals: This project transforms the Atlantic City Expressway into a smart and connected corridor to serve transportation users safely and efficiently while supporting the deployment of CAVs in the future.
- Technologies Being Deployed: DSRC/C-V2X for cashless tolling, RSUs, OBUs, and congestion pricing algorithms.

Washington State Ferries Terminal Wait Times TIS *(WSDOT)*:

- Grant Amount: $5,122,345.
- Project Goals: This project improves service reliability and efficiency, increases ridership, improves customer experience, and supplements existing city and highway congestion information to provide more comprehensive travel information.
- Technologies Being Deployed: Cellular/4G/5G communications, Bluetooth® and Wi-Fi readers, microwave detection sensors, license plate recognition systems, LiDAR, location-based services data, RFID, and a systemwide terminal wait-time TIS.

FISCAL YEAR 2020 PROJECTS

Advancing Connectivity and the Economy Through Technology in the San Diego Region *(San Diego Association of Governments)*:

- Grant Amount: $9,298,300.
- Project Goals: This project improves safety, expands transportation services and choices, provides the tools for actively managing all transportation systems, enhances access and services to transportation information, and adapts to transportation trends and services for all modes.
- Technologies Being Deployed: Mobility hub technologies, smart intersection system, CV roadside and onboard equipment, border wait time monitoring system, next-generation traveler information, CV border tolling, and commercial vehicle inspection technology.

Pinellas Connected Community *(Pinellas County Public Works Department)*:

- Grant Amount: $9,298,300.
- Project Goals: This project improves the safety of pedestrians and intersections within the region; improves mobility within the region; accelerates deployment of V2X technologies; reduces the number and severity of traffic crashes; and increases driver, passenger, and pedestrian safety.
- Technologies Being Deployed: CV technologies, including emergency vehicle preemption, TSP, speed warning, intersection warning, vehicle hazard warning, and emergency vehicle warning; demand management; decision support; work zone monitoring; mobile phone-based OBU application; and video analytics technologies.

Emergency Vehicle Preemption Using Connected Vehicle Technology (*GDOT)*:

- Grant Amount: $3,206,809.
- Project Goals: This project reduces incident response time, reduces ambulance transport time, decreases pedestrian crashes, facilitates arterial traffic flow, reduces delay, measures and reports quantifiable system performance measures, and enables system reproducibility and transferability to other regions within metropolitan Atlanta and national locations.
- Technologies Being Deployed: 15 dual-mode (DSRC and C-V2X) RSUs, 170 dual-mode OBUs installed in incident management vehicles and ambulances, a real-time information smartphone application, and an SCMS.

Maine Advanced Signal Control and Connected Vehicle System for Safe, Efficient, and Equitable Rural Transportation (MAST) Project *(MaineDOT)*:

- Grant Amount: $3,471,615.
- Project Goals: This project maximizes investments, lessens environmental impacts by monitoring and rapidly correcting operating deficiencies, measures operational performance, reduces crash severity, increases traveling public awareness, responds rapidly to changing operational status, improves economic benefits, increases operational CV footprints and the integration of advanced technologies, and enhances the understanding of traffic flow.
- Technologies Being Deployed: Advanced traffic controllers, traffic detection system, DSRC and cellular V2I infrastructure and units, cellular modem and hardwire communication infrastructure, automated traffic signal performance measures, and traffic signal control data analytics based on AI.

Smart Intersections: Paving the Way for a National Connected and Automated Vehicles (CAV) Deployment *(University of Michigan)*:

- Grant Amount: $9,950,098.
- Project Goals: This project reduces crashes and fatalities; improves safety for drivers, passengers, vulnerable road users, and first responders; reduces carbon emissions; improves operational performance; reduces infrastructure costs; improves return on investment; and paves the way for a national CAV deployment.
- Technologies Being Deployed: C-V2X and DSRC dual-mode RSUs; DSRC and V2V fleets; smart sensors with edge computing, authentication, authorization, and accounting servers; data analytics; and an advanced V2X technology living lab.

Integrated Safety Technology Corridor *(Regional Transportation Commission of Southern Nevada)*:

- Grant Amount: $6 million.
- Project Goals: This project streamlines traffic flow, enhances the use of real-time data and analytics, reduces the number and severity of crashes, and enhances the monitoring of infrastructure to identify and prioritize repairs.
- Technologies Being Deployed: Active traffic management, wrong-way driver notifications, strategic traffic management sites, high-occupancy vehicle (HOV) detection, and an integrated data platform and interface.

Charlotte Avenue/Dr. Martin L King, Jr Boulevard Transit Headways and Congestion Management *(Metro Government of Nashville and Davidson County, Public Works Department)*:

- Grant Amount: $1,500,000.
- Project Goals: This project uses technology to enhance connectivity to employment, institutional, and cultural destinations, transforming the operation of a key transit corridor and setting the stage for future technology investments throughout the region. It also improves safety, mobility, equity, choice, and the overall quality of life for city residents.
- Technologies Being Deployed: Connected transit vehicle technology, connected V2I intersection upgrades, TSP, congestion management technology, fleet headway management software, and real-time bus occupancy data.

S.M. Wright Smart Corridor *(City of Dallas)*:

- Note: This project was canceled, and obligated funds were returned.
- Grant Amount: $4 million.
- Project Goals: This project was designed to improve the system performance of the S.M. Wright corridor, provide advanced performance measures for evaluating operations, reconnect and revitalize economically disadvantaged areas, connect high-density residential areas with small-scale neighborhood commercial uses, and provide information to other entities for deploying the project’s technologies.
- Technologies Being Deployed: Smart traffic signal packages, smart bus shelters, autonomous vehicles, advanced emissions monitoring, RSUs, OBUs, roadside control units, connected mobility control center, connected mobility platform, deep learning versatile platform, data analytics platform, integrated mobility interface, CV transit pedestrian alert system, and traffic management system improvements.

Utah Broadly Connected *(UDOT)*:

- Grant Amount: $5,450,000.
- Project Goals: This project leverages real-time information to improve safety, mobility, and system efficiency; enhance the quality of life; and prepare Utah's transportation network for future deployments.
- Technologies Being Deployed: CV applications using V2X technology, including DSRC and C-V2X for CSW, SWIW, intersection safety, roadway departure warning, variable speed limit, infrastructure monitoring, and TSP applications; data analytics, including ML, deep reinforcement learning, AI, and vehicle image reidentification and cellular telematics technology; automated traffic signal performance metrics; third-party probe data (e.g., Bluetooth®); and data-sharing tools.

Autonomous Truck Ready *(POV)*:

- Grant Amount: $2,102,500.
- Project Goals: This project improves safety, reduces freight turnaround times, prepares Virginia's ports for increased shipping activity in the future, and develops and shares findings with other ports.
- Technologies Being Deployed: Autonomous truck movement, DSRC and C-V2X communications infrastructure, mobile communications infrastructure, and traffic map integration.

FISCAL YEAR 2019 PROJECTS

MWCOG: Deployment of Personalized and Dynamic Travel Demand Management (TDM) Technology in the Washington, DC, Baltimore, MD, Richmond, VA Megaregion *(MWCOG)*:

- Grant Amount: $2,970,000.
- Project Goals: This project leverages the best available technology to maximize the cost effectiveness of a megaregion TDM program; integrates and expands existing TDM programs with a shared technology platform among all public- and private-sector partners; provides personalized, timely, and accurate travel information to all residents and visitors; and enhances multimodal transportation access and system performance for all user groups with rewards and gamification.
- Technologies Being Deployed: Advanced TISs; TDM; advanced transportation management technologies; advanced public and shared transportation systems; advanced mobility and access technologies; multimodal trip planner/TDM programs for rural, low-income, and elderly or disabled persons; personalized and dynamic traveler incentives; and multimodal payment and reward integration.

I–4 Florida's Regional Advanced Mobility Elements (FRAME) *(FDOT)*:

- Grant Amount: $10,071,600.
- Project Goals: This project will work toward FDOT's strategic plan vision of increasing the delivery rate of fatality-free and congestion-free transportation systems by implementing CV and other emerging technology solutions, bringing safety and mobility benefits to the I–4 corridor.
- Technologies Being Deployed: 689 CV RSUs and 670 OBUs included with roadside-to-vehicle messages for lane closures, work zones, delays, congestion, end of the queue, incidents SPaT, speeds, and pedestrian-bicyclist safety; advanced traffic signal controllers with automated traffic signal performance measures, blank-out signs for route diversion, transit and freight signal priority, advance railroad crossing warnings, and wrong-way driving alerts.

Implementing Cellular V2X Technology to Improve Safety and Intelligent Transportation Systems (ITS) Management in Hawaii *(HDOT)*:

- Grant Amount: $6,855,000.
- Project Goals: This project reduces costs and improves return on investment through the enhanced use of existing transportation capacity; delivers environmental benefits that alleviate congestion and streamline traffic flow; reduces the number and severity of traffic crashes and increases safety; collects, disseminates, and uses real-time transportation-related information; monitors transportation assets to improve infrastructure management; delivers economic benefits by reducing delays; and accelerates deployment of V2V, V2I, and AV applications.
- Technologies Being Deployed: A cellular-based V2X system for all traffic devices and infield devices in Hawaii, C-V2X and DSRC equipment for motor vehicles, a remote browser-based platform for traffic operations personnel, a smartphone application for travelers, and preemption for emergency vehicles.

Intelligent Woodward Corridor Project *(MDOT)*:

- Grant Amount: $5,500,000.
- Project Goals: This project provides increased safety for pedestrians, cyclists, and vehicle traffic; reduced congestion; more efficient public transportation; integrated multimodal transportation; transportation resiliency; operational effectiveness; and reduced maintenance and operating costs.
- Technologies Being Deployed: Pedestrian detection, prioritization, and alerts; traffic intersection preemption and signal priority for authorized vehicles; V2V and V2I communications; transportation system optimization through data analytics and edge computing; and wrong-way driver detection and alerts.

I–270 Predictive Layered Operation Initiative (PLOI) *(MoDOT: St. Louis Metropolitan Area, MO)*:

- Grant Amount: $1 million.
- Project Goals: This project predicts crashes and properly equips patrol officers to forestall crashes, thus lowering the number of incidents along I–270 North, improving incident detection time, and reducing arrival time for emergency response vehicles.
- Technologies Being Deployed: Predictive analytics and AI for incident management, advanced video analytics for improving pedestrian safety and wrong-way driving, and integrated modeling for road condition prediction.

Multimodal Connected Vehicle Pilot *(NCDOT)*:

- Grant Amount: $2,117,750.
- Project Goals: This project improves mobility, reduces safety incidents, reduces environmental impacts, improves agency efficiency, and allows NCDOT to deploy CV technology and applications more effectively within North Carolina for further safety, mobility, and environmental benefits.
- Technologies Being Deployed: V2V and V2I CV applications, including TSP, multimodal applications (e.g., pedestrian, driver, bicyclist); intelligent traffic signal timing; red light violation warning; speed warning; as well as traveler information, high-resolution data, automated traffic signal performance measures, and pedestrian presence detection accessible pedestrian signal system.

DriveOhio I–70 Truck Automation Corridor *(ODOT: I–70 Corridor)*:

- Grant Amount: $4,400,000.
- Project Goals: This project facilitates and provides host fleets and truck automation vendors with an opportunity to deploy technology in revenue service, accelerates truck automation technology adoption, prepares standards and regulations for use by other deploying entities, and shares data and field experiences with the logistics industry.
- Technologies Being Deployed: Truck automation, including truck platooning, partial automation (Level 2), and high automation (Level 4) in revenue service by host fleets, as well as roadway automation readiness audit and related roadway repairs.

Artificial Intelligence-Powered Decision Support Tools for Integrated Corridor Management *(TDOT)*:

- Grant Amount: $2,617,653.
- Project Goals: This project develops DSS and subsequent strategies through the use of AI; reduces the cost to deploy, operate, and maintain ICM systems; builds a more scalable system to support traffic operations on corridors statewide; and improves the efficiency of ICM. This system creates a balanced, responsive, and equitable arrangement that monitors and controls traffic; shares traveler information with the public; improves system and travel time reliability; encourages mode shift; and improves the safety, efficiency, maintenance, operations, and mobility of all users (motorists, transit riders, transit operators, and freight haulers) along the corridor.
- Technologies Being Deployed: AI-based ICM DSS, Web interface for ICM partners, and TMC ICM software integration.

AI Meets ICM: Realizing the Next Generation of Regional Mobility *(VDOT)*:

- Grant Amount: $4,355,000.
- Project Goals: This project will use advanced data management and communications technologies to provide transportation system operators, service providers, commuters, and travelers with multimodal information and tools that enhance safety; optimize system performance; mitigate congestion; improve travel time reliability; and support on-demand, multimodal trip options.
- Technologies Being Deployed: DSS, AI, a cloud-based data store, and a portal regional commuter parking management system.

Deployment of the Washington State Virtual Coordination Center (VCC) for Multimodal Integrated Corridor Management *(WSDOT)*:

- Grant Amount: $3,424,361.
- Project Goals: This project enhances both individual and interconnected agency operations in the day-to-day management of regional mobility to ensure the transportation system is safe, reliable, and sustainable, and it promotes economic vitality for the entire region. This project also enables real-time information flow to allow shared map-based situational awareness; facilitates joint action in a virtual workspace to speed incident response, mitigate traffic effects, and manage congestion on a daily basis; provides actionable information and alerts to agencies, mobility providers, and the traveling public; and enhances coordinated regional planning and operations through data analytics and predictive modeling.
- Technologies Being Deployed: A robust cloud-based system that enables multiagency, multimodal ICM through real-time information data collection, analysis, modeling, and dissemination.

FISCAL YEAR 2018 PROJECTS

Bay Area Mobility-On-Demand Project *(Contra Costa Transportation Authority)*:

- Grant Amount: $8 million.

- Project Goals: This project provides MOD to create a "one-stop shop" for viable mobility options by providing real-time, data-driven traffic updates and trip planning so travelers can make informed decisions about cost, travel time, mode, and route choices for their daily travel needs. The project will improve mobility trip reliability and congestion in the county.

- Technologies Being Deployed: MOD applications and services, mobility assets, and systems integration.

Advanced Connected Transportation Infrastructure and Operations Network (ACTION) *(University of Alabama)*:

- Grant Amount: $8,034,003.

- Project Goals: This project deploys CV and ITS technologies to allow the regional TMC to implement adjustments to traffic control strategies across the system. Data will enhance long-term planning in the region, and information will be shared with drivers.

- Technologies Being Deployed: Communications; DSRC radios; advanced data-logging traffic controllers; active signal control; wireless vehicle detection; TISs; cable median crash sensors; and an end-user mobile application that provides benefits including pedestrian detection, work zone warnings, curve warning, emergency vehicle preemption detection, and more.

Wolf Creek Pass Advanced Technology Deployment *(CDOT)*:

- Grant Amount: $2,366,298.

- Project Goals: This project transmits real-time information to travelers and dispatches emergency responders and incident management teams faster to improve safety on Wolf Creek Pass.

- Technologies Being Deployed: DSRC RSUs, weigh-in-motion technology and dynamic warning signs, road sensor systems, variable speed limits, cameras, variable message signs, and a fiber-optic and electric power network.

Artificial Intelligence Enhanced Integrated Transportation Management System (AI-ITMS) Deployment Program *(DelDOT)*:

- Grant Amount: $4,996,949.
- Project Goals: This project enables the deployment of an AI-ITMS and an AI-enhanced next-generation TMC to improve transportation systems performance for enhanced traffic safety, mobility, and air quality. In addition, the project will support people in making better transportation decisions by providing real-time information about incidents, travel times, anticipated delays, and routes.
- Technologies Being Deployed: Multimodal AI-enhanced transportation management and control system that collects and analyzes data to automatically detect anomalies and inefficiencies, disseminate real-time travel information, and generate congestion-mitigation solutions.

Georgia DOT Connected Vehicles *(GDOT)*:

- Grant Amount: $2,500,000.
- Project Goals: This project creates and operates a regionwide CV network, providing SPaT messages at all key intersections and freeway ramps, which will enable CV applications to use this network to improve road safety and operations.
- Technologies Being Deployed: DSRC RSUs at signalized intersections, metered ramps, supporting infrastructure, and an open data portal.

Multi-State Rural Integrated Corridor Management *(NDOT)*:

- Grant Amount: $2,755,000.
- Project Goals: This project provides information to travelers by expanding Wyoming's CV pilot, deploying a variable speed limit in Nebraska, providing critical messages directly to freight vehicles, and disseminating truck parking information.
- Technologies Being Deployed: Information and communication management, regional data sharing, variable speed limits, DSRC, V2I applications, and a mobile RWIS.

Oregon Smart Mobility Network *(Oregon DOT)*:

- Grant Amount: $12 million.

- Project Goals: This project creates an integrated multimodal network and helps the Oregon DOT with performance measurement, decision support, and active traffic, incident, and weather management.

- Technologies Being Deployed: Automatic traffic recorders, bicyclist and pedestrian counters, Bluetooth® travel-time systems, road weather decision support and information dissemination, closed-circuit television (CCTV) monitoring cameras, adaptive ramp metering, dynamic speed limits, freight signal priority, queue warning systems, SPaT, dynamic routing, next-generation TSP, V2X pedestrian/bicyclist, automated speed enforcement, red-light-running crash mitigation systems, unmanned aircraft system crash reconstruction, and battery backup systems.

Work Zone Reservation and Traveler Information System *(PennDOT)*:

- Grant Amount: $2,697,750.

- Project Goals: This project enhances work zone operations and safety by providing accurate, standardized, and real-time work zone information across 40,551 miles of roadway traversing through Ohio and Pennsylvania. The system will also streamline work zone coordination between maintenance crews, construction crews, and traffic operation centers by removing the redundant and manual data inputs used today to schedule work zones.

- Technologies Being Deployed: Advanced TISs, advanced transportation management technologies, and a digital road work reservation system.

I–10 Corridor Coalition Truck Parking Availability System (I–10 Corridor Coalition TPAS) *(TxDOT)*:

- Grant Amount: $6,850,000.

- Project Goals: This project provides real-time parking information to truck drivers and dispatchers so they can make informed parking decisions. This project will increase public safety by reducing fatigue-related crashes with associated reductions in congestion and delay.

- Technologies Being Deployed: Advanced TISs; advanced transportation management technologies; infrastructure assessment technologies; and transportation system performance data collection, analysis, and dissemination systems.

Utah Connected *(UDOT)*:

- Grant Amount: $3 million.
- Project Goals: This project measures and improves the operational performance of the system to gain additional capacity, improves safety and preserves infrastructure, implements CV technology to improve safety and mobility, and uses AV technology to help solve the first-mile/last-mile problems.
- Technologies Being Deployed: Autonomous shuttle(s); fiber sensing; CV applications (plows, signals, transit, CSW, weather impact warning); and a data-sharing portal.

FISCAL YEAR 2017 PROJECTS

Loop 101 Mobility Project *(ADOT)*:

- Grant Amount: $6 million.
- Project Goals: This project improves safety and existing arterial capacity in the Loop 101 corridor by deploying technology and systems to support ICM, public transportation, the Maricopa County DOT's SMARTDrive Program℠, and other connected traffic management and real-time information technologies.
- Technologies Being Deployed: A DSS; adaptive signal control technology; CV applications, including transit and emergency vehicle signal priority; ramp metering technology; and an ICM mobile applications suite.

GoPort Freight Intelligent Transportation Systems *(Alameda County Transportation Commission)*:

- Grant Amount: $9,720,000.
- Project Goals: This project improves traffic flow and goods movement to and within the Port of Oakland, reduces congestion, improves safety, provides improved traveler information, and reduces emissions. Collectively, these benefits will significantly improve port operational efficiencies, increasing the competitiveness of the port in the global market.
- Technologies Being Deployed: A new port-specific TMC, traffic sensors, advanced traveler information, traffic messaging, trucking information for mobile applications, a rail grade warning system, and terminal queue information.

Connecting the East Orlando Communities *(FDOT)*:

- Grant Amount: $11,946,279.
- Project Goals: This project improves pedestrian and bicyclist safety, enhances multimodal transportation, provides integrated real-time information for travelers, and connects/integrates data sources created and utilized by FDOT.
- Technologies Being Deployed: An innovative pedestrian and bicyclist collision avoidance system, RSUs, parking sensors, active detection technology, digital kiosks, advanced traffic signal controls, dynamic ridesharing, and information systems for elderly and disabled individuals.

SMART Arterial Management *(Ada County Highway District)*:

- Note: This project was canceled, and obligated funds were returned.
- Grant Amount: $2,250,000.
- Project Goals: This project was designed to optimize signal timing on five corridors to reduce congestion, increase safety, and enhance traffic flow.
- Technologies Being Deployed: DSRC radios, OBUs, radar technology for bicycle and vehicle detection, traffic software, and accessible pedestrian signals.

Improving Safety and Connectivity in Four Detroit Neighborhoods *(City of Detroit)*:

- Grant Amount: $2,182,000.
- Project Goals: This project improves safety at intersections, improves connectivity for residents, and increases the capacity for data communications.
- Technologies Being Deployed: Video detection and analytics, sensors, V2I communications, vehicle preemption, digital kiosks, DSRC, and Internet of Things gateway.

Connecting Cleveland Project *(Greater Cleveland RTA)*:

- Grant Amount: $5,850,000.
- Project Goals: This project improves communications infrastructure, enhances rider and passenger safety, and reduces rider travel time. The project also enhances the overall efficiency of the transportation system while contributing to community revitalization.
- Technologies Being Deployed: Advanced onboard equipment, real-time information and maintenance software, and an upgraded radio system.

Greenville Automated (A-Taxi) Shuttle *(County of Greenville)*:

- Note: This project was canceled, and obligated funds were returned.
- Grant Amount: $4 million.
- Project Goals: This project improves access to transportation for disadvantaged and mobility-impaired residents.
- Technologies Being Deployed: Automated taxi shuttles using V2V and V2I technology, AV data collection and analysis, and real-time traveler information.

The Texas Connected Freight Corridors Project *(TxDOT)*:

- Grant Amount: $6,090,221.
- Project Goals: This project integrates high-quality data from the I–35 Advanced TISs into an existing route optimization software platform to enhance/optimize pretrip and enroute planning for regional carriers, leading to safety and congestion improvements.
- Technologies Being Deployed: Advanced TISs and transportation management technologies, infrastructure condition-monitoring technologies, connected V2I and V2V technologies, freight parking system technologies, truck platooning technology, and border crossing technologies.

Truck Reservation System and Automated Workflow Data Model *(POV)*:

- Grant Amount: $1,550,000.
- Project Goals: This project creates a two-way data flow with the port and truckers, railroads, etc. The data model will model the size of scheduling windows and estimate the effects of congestion on mobility. RFID tag readers will automate the workflow of arriving trucks, reducing turnaround time.
- Technologies Being Deployed: RFID tag readers, software integration with container inventory management system, and a data model for standardizing status updates to truck dispatchers.

Multimodal Integrated Corridor Mobility for All *(SDOT)*:

- Grant Amount: $4,091,000.
- Project Goals: This project improves traveler safety and mobility and creates real-time traveler plans.
- Technologies Being Deployed: Traffic signal system upgrades, communications network, CCTV, DMSs, passive pedestrian detection and pedestrian demand-based signal timing, bicycle detection and mobile application, ICM solutions, mobility-as-a-service software, and kiosks.

FISCAL YEAR 2016 PROJECTS

Freight Advanced Traveler Information System (FRATIS) *(Los Angeles County Metropolitan Transportation Authority)*:

- Grant Amount: $3 million.
- Project Goals: FRATIS will reduce truck congestion and fuel usage by optimizing freight routes.
- Technologies Being Deployed: Truck trip dispatching optimization software, real-time information exchange system, and ecodrive applications to communicate between vehicles and traffic signals to encourage fuel-efficient driving when trucks approach signalized intersections.

City of San Francisco Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Initiative *(San Francisco Municipal Transportation Agency)*:

- Grant Amount: $10,990,760.
- Project Goals: This project uses a series of advanced technologies to lower congestion in heavily trafficked areas, increase public transit speeds, reduce pedestrian collisions, decrease emergency vehicle response times, reduce truck signal delay, and lower truck speeds through sensitive neighborhoods.
- Technologies Being Deployed: New highway HOV lanes for transit/carpools; TSP and emergency vehicle preemption; electronic, autonomous shuttles; curb space for pickup/dropoff by carpools and ride-sourcing services; multimodal intelligent traffic signal systems (MMITSSs) located roadside and in-vehicle; and a connected, electronic toll system for the congestion pricing program.

Los Angeles DOT Implementation of Advanced Technologies to Improve Safety and Mobility within the Promise Zone *(LADOT)*:

- Grant Amount: $3 million.
- Project Goals: This project uses advanced technology on Los Angeles' transit vehicles to improve safety and traffic flow and provides real-time information to transit riders in low-income neighborhoods.
- Technologies Being Deployed: Upgrades to the automatic traffic control and surveillance connected signal system, Bluetooth® Low Energy beacons, real-time bus arrival signs, and interactive digital kiosks with real-time information about transportation services.

Denver Smart City Program *(City and County of Denver)*:

- Grant Amount: $6,000,007.
- Project Goals: This project uses connected fleets and DSRC technology to improve travel time reliability, freight efficiency, and traffic management to make safer pedestrian crossings.
- Technologies Being Deployed: DSRC in 1,500 city fleet vehicles, automated pedestrian detection devices, a CV operational environment at the Denver TMC, and flashing beacons for slower pedestrians.

A Connected Region: Moving Technological Innovations Forward in the NITTEC Region *(NFTA)*:

- Grant Amount: $7,813,256.
- Project Goals: This project deploys technologies and strategies to improve border crossing performance, travel time, commercial vehicle operations, and safety. Additionally, the project will improve incident management and promote operational integration within NFTA.
- Technologies Being Deployed: CV applications supporting in-vehicle dissemination of alerts, advisories, parking, traffic, and weather information; an improved traffic signal system, a parking management analytics engine, and DSS.

NW 33 Smart Mobility Corridor *(Union County, City of Marysville, and City of Dublin)*:

- Grant Amount: $5,997,500.
- Project Goals: This project creates an SMC with CV applications across multiple communities to improve safety and congestion while enhancing access to large employment sites and economic development.
- Technologies Being Deployed: CV technology for queue warning and speed harmonization, dynamic SPaT, pedestrian warning systems on the local street network, and real-time road weather performance data.

SmartPGH *(City of Pittsburgh)*:

- Grant Amount: $10,899,318.
- Project Goals: SmartPGH deploys "Smart Spine" corridors in Pittsburgh that layer environmental, communications, energy, and transportation infrastructure technologies to improve connections between isolated neighborhoods and major centers of employment. This project may improve real-time information access and optimize transit operations.
- Technologies Being Deployed: Conversion of nearly 40,000 City of Pittsburgh streetlights to LED technology with integrated control systems and installation of supplemental sensor technology, including pedestrian detection and air quality monitoring along Smart Spine corridors. In addition, Pittsburgh will deploy real-time adaptive traffic signals and DSRC units on buses for TSP, advanced traveler information systems, and optimized mobility.

ConnectSmart: Connecting TSMO and Active Demand Management *(TxDOT)*:

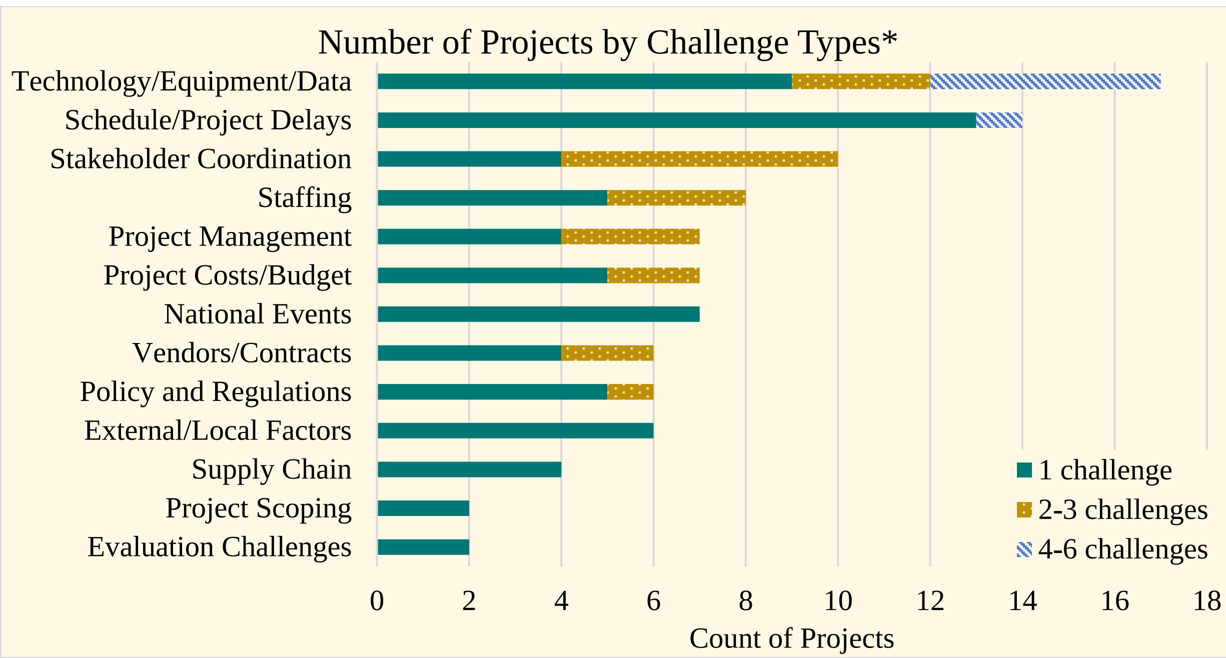
- Grant Amount: $8,939,062.
- Project Goals: ConnectSmart integrates various mobility technologies for carpooling, ridesharing, and shared electric bicycles to provide reliable multimodal travel time information.
- Technologies Being Deployed: Various regional advanced traveler information systems and data sources for predictive multimodal/intermodal travel time, cost, and reliability information in an application.

APPENDIX C. SUMMARY OF GRANTEE REPORTED CHALLENGES AND LESSONS LEARNED

CHALLENGES

Various challenges cited by the grantees in their quarterly and annual reports include technology, equipment, or data problems; schedule delays; project costs or budgets; vendor or contract issues; supply chain matters; legal and regulatory requirements' impacts on projects (such as the FCC ruling regarding the Safety Band);[1] stakeholder coordination; internal project coordination; national events; staffing; external or local factors; and evaluation challenges, among others.

Figure 9 shows the frequency of challenges reported by grantees, both across and within categories. For instance, 17 projects reported experiencing challenges related to technology, equipment, and data. Of those 17, 5 grantees had between 4 and 6 distinct challenges within this category, and 3 grantees had either 2 or 3 distinct challenges within this category.



Note: Projects may report challenges across and within challenge types.

Source: FHWA.

Figure 9. Graph. Number of projects by challenge types.

Within figure 9, individual challenges are sorted into only one category per challenge, but these challenges often have a cross-cutting nature in that a single challenge may contain elements of

[1]The FCC's November 10, 2020, First Report and Order (86 FR 23281), approved on November 18, 2020, and published in the *Federal Register* on May 3, 2021, describes changes to the allocated 75 MHz of radio spectrum in the 5.9 GHz band used for vehicle and infrastructure communications, which is also known as the Safety Band.

multiple categories. For example, national events or external/local factors could contribute to supply chain delays, or changes in staffing could contribute to challenges within internal project coordination and lead to schedule/project delays.

LESSONS LEARNED

Table 6 lists reported lessons learned from all grantees, regardless of their project status. The reported lessons learned are edited for length, and references to individual agencies were removed. The lessons are grouped into broader categories of costs, evaluation, policy and regulation, industry partners/third-party vendors, project management, scope, staffing, stakeholder engagement, and technology/equipment/data. The views and opinions expressed in this table are the grantees' and do not necessarily reflect those of FHWA or the U.S. Department of Transportation (USDOT).

Table 6. Grantees' lessons learned (April 2023–March 2024).

Category	Grantees' Reported Lessons Learned
Costs	• We learned to consider ongoing maintenance costs before entering deployment, especially software and procurement of external data sources. While grants like ATCMTD are a one-time sum, the systems being funded often follow a subscription or annual support model, so continuing to pay for them in the future requires significant foresight. • Technology maturity has resulted in reduced costs for some elements of the innovations on this contract, but staffing costs have increased. The grant requirement to not exceed budgeted costs in a major category without an amendment to do so complicates the ability to react quickly to such changes.
Evaluation	• In light of the recent changes in the operating hours of the HOV system, it remains a challenge to determine the best use for the HOV video occupancy detection system in real-time traffic management applications. • Research and evaluation: Identifying an evaluation plan and appropriate performance metrics before identifying the needs of the corridors is hard. The ConOps report is critical in its development in the system engineering process to provide a road map and understanding the needs of a corridor in relation to the goals proposed as part of the ATCMTD grant project. • TSP systems have been shown to improve schedule reliability. Studies within this project are confirming those improvements. • Snowplow preemption systems have produced positive feedback among plow operators, including decreased route traversal times. • Efforts to measure the effectiveness of V2X-enabled systems have been impacted by the "noise" in various datasets. This "noise" is not inherent in V2X systems or new to performance measurement, but it presents challenges in our evaluations and will impact our future assessment designs.

Table 7. Grantees' lessons learned (April 2023–March 2024) (continuation).

Category	Grantees' Reported Lessons Learned
Evaluation (continued)	• The anonymization of basic safety message (BSM) data makes the assessment of CSW and SWIW applications more difficult. In our previous installations, we chose to circumvent the anonymization of the data on our fleet vehicles. In current installations, we are strictly adhering to standards, which will render the BSM fully anonymous and challenge our ability to monitor these fleet vehicles in our performance studies. We are exploring alternate ways to monitor the vehicles and have recently implemented a minor change, which should aid our analysis. • Research, relative to the road audit, continues to evolve through the evolution of automated driving system (ADS) equipment: With the continuous evolution of ADS (and the infrastructure) and the variety of sensor suites available, adhering to the original road audit plan was challenging. This plan was adapted to accommodate multiple vendors/sensor suites so that validation and verification could occur. Likewise, repeatability in terms of conditions and daylight had to be accounted for in the road audit schedule and approach. • Upon the reviewer's recommendation for the first annual report, a survey of TMC technicians in the State was conducted. Overall, the technicians' responses to the survey indicated their ability to implement traffic management strategies has improved with the deployment of various technologies. The Statewide Travel Management System locations, which includes advanced DMS messaging and Highway Patrol presence, resulted in noticeable reductions in both speeding and reckless behaviors. The ATMS gantries improve the ease of implementing lane closures, notification of downstream road hazards, and the ability to provide more specific traveler information and warnings. The ATMS went live in March 2020 and has been a learning curve for the technicians and the system developers. An iterative process of experimentation with messaging and gauging the motoring public's reaction to this heightened level of traveler information has ensued. The results of this survey provided cautionary insights and lessons learned from the deployment of the traffic management technologies, which can be carried forward into this project.
Policy and regulation	• Government and related public authorities have an important role to play in setting open data policies and frameworks and creating the right ecosystem and conditions to encourage businesses and users to use and share data within the platform. As such, and to continue the region's history of collaboration among regional agencies, the project is coordinating with regional agency partners to expand adoption and data integration. • Develop data privacy and security plans: Be ready to adjust to new security standards or requirements from your agencies, State/national laws, technology companies, or third-party providers.

Table 8. Grantees' lessons learned (April 2023–March 2024) (continuation).

Category	Grantees' Reported Lessons Learned
Policy and regulation (continued)	• Define the role of the infrastructure owners and operators in AV technology: In a largely private-sector market, the team members had to define their roles. For this project, the agencies can identify their roles in preparing both the physical environment through the road audit as well as the institutional environment by identifying and addressing permitting and inspection processes for equipped vehicles. • The regulatory environment can often present challenges that are unforeseen or more complicated than expected. The first example of such challenges is the FCC's decision to reduce the 5.9 GHz spectrum and pivot away from DSRC to C-V2X radio technology. This decision affected the scope, cost, and approach to some of our projects. As we anticipate future deployments, the increased cost of the new hardware platform will affect the scope of those deployments. The second example is the process of obtaining site approval for the operation of the AV Shuttle. This regulatory effort was outside of this grant, but it reduced the amount of time the Shuttle could be deployed. If this technology is to be deployed at scale, the regulatory process will need to be streamlined.
Industry partners and third-party vendors	• Some lessons learned during construction sequencing and scheduling were attributed to ITS/CAV equipment delays due to supply chains. In the future, we would recommend contacting equipment vendors to project delivery timeframes prior to contractors/subcontractors scheduling work. This scheduling also impacts our system managers because they are responsible for configuring many devices before delivery to the contractor for deployment. • Navigate different technology track definitions/expectations. Although the project team specified platooning—L2 and L4 technologies per SAE definitions—contracting discussions with selected deployment teams revealed some differences in interpretation of the SAE definitions. For example, the proposal received from one team included a definition of L2 technology that included low-speed and remote driving. Technology definitions are being carefully reviewed to ensure alignment with grant and project team expectations. For example, this optional element of the platooning deployment team's solution will not be included in the project. • Engage with technology developers who are moving from research into production. Some developers noted that the project does not align with their roadmap in terms of location and timing, and deviation is impossible.
Project management	• Early recognition of needs, and again as a situation develops, allows for proper contributions, participation, data collection, or design of systems based on learnings and developments. • Early and continued identification of tasks that can be "started earlier" or have "more resources dedicated to them" allows for continued progress in other supporting tasks.

Table 9. Grantees' lessons learned (April 2023–March 2024) (continuation).

Category	Grantees' Reported Lessons Learned
Project management (continued)	• The research and planning development, stakeholder engagement and coordination, and time to scope those specific ATCMTD new and innovative solutions and technologies (even prior to actual design) are highly time-critical and sensitive so that more accurate costs and time to deploy technologies can be better defined to stay within project budgets and schedules, while maximizing the benefits to costs derived along both study corridors. Not all solution systems could be provided to every location along both signalized corridors. Engineering judgment needed to be made to provide those systems where positive impact and rate of return are maximized. • The primary lesson learned to date has been that the scenario-based approach for the ConOps was well received by the stakeholder group. The team provided examples in the ConOps to demonstrate how truck drivers and TMC operators would interact and interface with the system. • National events and the resulting supply chain disruption have wreaked havoc on the vendor's ability to deliver equipment and have, therefore, impacted our ability to deploy. The team will likely be more skeptical of vendor-proposed delivery schedules in the future and will be more proactive in maintaining and executing backup plans with backup vendors. • Current lessons learned from this construction season would be to make sure the contractor follows through on their schedules. When there is a deviation from their plan, a meeting should be held to discuss the impact of the delay on project delivery and have the contractor provide written reasons for the delay. • The lane reservation system (LRS) is a significant effort that will transform most units within the agency (maintenance, traffic, construction, etc.). The project team established working groups across all State DOT districts and work units to gather feedback on the initial concept of LRS and the requirements of the system. Multidisciplinary units should be involved in ATCMTD projects. • Defining data management and project evaluation metrics before finalizing deployment participants is a challenge, given that the participants are not yet selected. The team is compiling a complete inventory of data from technology, fleets, telematics, and the road audit and will negotiate final data requirements with the deployment team(s) as part of the contracting process. • Understanding and accommodating the priority of this project relative to other pressing concerns and initiatives is a lesson learned. • In addition, understanding the ramifications of obtaining a "free" piece of equipment should be considered. Although funds have been budgeted for the repairs and maintenance of the vehicle, technical support and service are critical elements that should not be overlooked. Fully understanding these ramifications will be key to the overall success.

Table 10. Grantees' lessons learned (April 2023–March 2024) (continuation).

Category	Grantees' Reported Lessons Learned
Project management (continued)	• The cutting-edge nature of this ATCMTD project limits the amount of relevant data available during research efforts. Various vendors have all provided their expertise in how the detection and data-processing equipment is selected and connected together within the existing roadside traffic signal/ITS environment. As mentioned previously, the recent addition of university partners to the grant partner team has provided a wealth of initial data regarding C-V2X performance.
Scope	• Differentiate the project: With truck automation rapidly advancing from research to real-world deployment, the team had to define what made this project different from a commercial deployment. One key point that the team has carried forward through recruiting is to tackle the stated concerns of potential fleet adopters who are interested in truck automation but doubtful of its capabilities in diverse and unpredictable weather conditions. Engagement through industry events and logistics councils continued to provide updates on the project and its status. • Technology scoping and deployment: First, the project was originally let for advertisement of its plans/proposal/specification package with the State DOT's local agency program for competitive bid and let to contractors/vendors in October 2022. Original bids came in higher than the construction budget allowed, and the project had to be pulled, reduced in scope/size to accommodate the budget, and relet in December 2022. Since then, we have received a successful low-bid award to a contractor (and their planned vendors) within budget, but we are still reviewing contractor/vendors' submittals to ensure that the vendor's proposed technologies are within ITS technologies' intended specifications. In retrospect, if the project was planned to be sole sourced in the beginning, with more extensive specific technology scoping planning, it potentially could have saved time and costs to the project with the city procuring specifically intended technologies aimed toward meeting the goals of the ATCMTD grant and within budget. Part of the challenge is that the technologies derived and introduced from the ATCMTD project goals and ConOps involve technologies considered new to the city and/or the industry. Project planning in advance may not catch all technical challenges that may arise during the course of the planned deployment, acceptance testing, and integration into the city's current infrastructure.
Staffing	• Agility related to team resources and skills allows for diversification and quick response when situations, such as changes in travel patterns, arise. • Staffing challenges, especially for technical staff, were encountered. The impacts of national events, the tight job market, rising wages, and other factors have made this period especially difficult. We have been relying more heavily on consultant support, but some functions cannot readily be provided by consultants (e.g., installing field equipment and performing internal information technology implementations).

Table 11. Grantees' lessons learned (April 2023–March 2024) (continuation).

Category	Grantees' Reported Lessons Learned
Stakeholder engagement	• When multiple jurisdictions and agencies are involved, coordination and organization should be addressed very early in the project. Having consensus on project objectives, a decisionmaking framework, and a plan for communication at the onset would have better simplified some of the initial challenges that were faced. We identified a small group of key individuals (executive committee) representing each entity, who are empowered to make decisions for their entity or are responsible for obtaining decisions from their entity after consultation. We have regular meetings via phone calls to review current issues and hold at least one face-to-face meeting each month. • The biggest lesson learned to date is the need for outstanding coordination from all involved agencies. The ability of the agencies to work together through the processes is critical to both the long-term and short-term success of this project. The regional transit agency owns and operates the transit vehicles, the county owns and operates a tunnel within the system, the State DOT owns streets and the Realtime Monitoring and Control Software, and the city maintains streets and owns the signal system. This coordination also involves technology companies/original equipment manufacturers and troubleshooting advanced technology testing. Since the technology is new and always advancing, testing and complete deployment may take longer than expected and require multiple attempts to get the technology fully deployed. • The toll system has conducted extensive outreach related to toll policy, affordability, and racial equity. Based on this outreach, the board adopted several components of an affordability program in 2021. The project team continues to refine the affordability program to address concerns from the community and elected leaders about the equity and affordability of the toll program. In addition, the project team is exploring the technical aspects of implementing the affordability program elements to ensure they can be administered accurately and efficiently. • Public-private partnerships are encouraged via this ATCMTD grant program. However, this innovative type of solicitation creates a conundrum for State and local government applicants who are bound by strict procurement requirements, which prevents us from procuring/contracting until a funded project is in place.

Table 12. Grantees' lessons learned (April 2023–March 2024) (continuation).

Category	Grantees' Reported Lessons Learned
Stakeholder engagement (continued)	• From a process standpoint, our team has found it necessary to emphasize and understand agency-specific communication and decisionmaking processes for all the agency stakeholders on this project. As some of the individual project tasks were implemented, the project team encountered instances during which a disconnect occurred between technical stakeholders directly involved in the project and the management and decisionmaking staff at that same agency. Ensuring clear processes are in place is essential so that both technical and management staff members are aware of project activities, project decisions, implementation timeframes, and individual agency roles. Part of the coordination with individual agencies implementing specific projects will be to review internal processes, support internal communications and meetings, and ensure key staff at local agencies are receiving pertinent information. • In addition, the successful implementation and integration of CV-related technologies requires constant engagement with over 30 stakeholders across a variety of domains, inclusive of many divisions and local offices of the State DOT, city governments, multicounty agencies (e.g., metropolitan planning organizations), and a variety of private-sector partners. Types of engagements have included holding biweekly core team calls; conducting quarterly stakeholder calls; performing a public-sector survey to prioritize CV applications; establishing a Texas Triangle tour to meet with public and private stakeholders in person, refining CV applications and identifying candidate corridors; conducting a private-sector survey to estimate truck traffic along each candidate corridor; and holding ongoing, individual engagements with freight partners, telematics partners, and third-party software companies. An in-person training session was held for private- and public-sector participants; however, a significant time gap occurred between the training and the present when we are finally getting to distribute and install equipment. During this time, stakeholders have experienced staffing turnover and have likely forgotten some, if not much, of the information that was presented during the workshop. This turnover is likely already or will likely lead to inefficiencies in the installation/deployment process and may require additional or repeated training.

Table 13. Grantees' lessons learned (April 2023–March 2024) (continuation).

Category	Grantees' Reported Lessons Learned
Stakeholder engagement (continued)	• Private-sector partners have been onboarded using a three-step, tiered process: Expression of Interest (for Industry Affiliates and Active Partners), Memorandum of Understanding (for Active Partners), and Data Sharing and Implementation Agreement (for Active Partners). Partners receiving OBUs from TxDOT will also sign an Equipment Loan Agreement. The development of the Data Sharing and Implementation Agreement has been particularly challenging as the team worked to clearly outline the data needed from partners to support the project. The team continues to work on refining details on what information is needed for the project evaluation and what is needed for the CV ecosystem to function—this distinction is important because the research agencies are able to sign nondisclosure agreements, whereas the State DOT cannot. This process continues to evolve, and the resulting solutions will be well-documented to provide guidance for future projects. Regarding telematics partners and third-party software companies, the team recommends engaging them early in the process to determine whether opportunities to integrate the project data feed into electronic logging devices that are already in the cab are available. This decision has allowed the project to scale beyond the constraints of OBU costs, covering more vehicles and generating more data. • Partner with public agencies: Coordinating and partnering with neighboring State agencies is important; however, multiple options for grant funding or sharing should be established. • Recommend beginning the stakeholder coordination as early as possible, especially regarding the establishment of the data-sharing license agreements that will be used during the deployment and ongoing operation of the systems. This project has a lot of stakeholders along the corridor, and making sure the legal teams representing all the stakeholders agree on the terms and conditions can take time. • Engage stakeholders: The team had to differentiate this opportunity between potential fleets and developers. Although it took more effort, the team found that focused, directed engagement via one-on-one conversations was the most effective way to start conversations and understand both opportunities and challenges. Year 2 update: At the end of Year 2, one of the two selected deployment teams had to withdraw due to a change in technical direction within the technology company. This issue remains a challenge, and the project team will begin Year 3 by defining additional engagement to seek renewed interest in this project opportunity, especially for L2 and L4 technology. • Stakeholders either see recruiting potential participants for edge case deployment (e.g., Midwest weather) as an opportunity or a challenge in which they do not want to engage.

Table 14. Grantees' lessons learned (April 2023–March 2024) (continuation).

Category	Grantees' Reported Lessons Learned
Stakeholder engagement (continued)	• For most of these challenges, the team found frequent and ongoing engagement was the best way to start and continue conversations, whereas events and conferences provided new connections with existing or newly interested parties. Some conversations came to a natural end for stakeholders who ultimately were not interested. Year 2 update: Late in Year 2, the L2 technology developer withdrew their proposal. These fleet and developer challenges remain active as the project team prepares for a second procurement. The project team is assembling a strategy and materials to support expanded engagement and strengthen the message around the opportunity. Using lessons learned from Years 1–2, the team will focus energy on setting up one-on-one conversations with the technology companies that are the most production ready to identify potential pain points and concerns. The team will also focus on engaging with fleets that may have or are ready to deploy technology in other locations to present opportunities to scale these projects to other States. • The major lesson learned is the importance of stakeholder engagement in the planning phase to get their feedback and buy-in for the pilot locations. Further lessons learned and recommendations will be cataloged through all the phases of the project and will be included in future reports. Surveys and interviews will be vital in collecting qualitative data to complement quantitative data. System users, local agencies, and regional agencies will be interviewed to understand system effectiveness across jurisdictions. Information from these interviews may also serve as lessons learned for the project.
Technology/ equipment/ data	• The project desired to have complete RSU coverage along 35 miles of a U.S. highway, much of which is rural. Due to the spacing of RSU installations required to provide complete coverage, sourcing and providing power at all RSU sites was extremely challenging. The State DOT also desired to have enough power available at each site so that additional equipment could be added in the future and, as such, the spacing of the poles made it difficult to meet the desired power requirements, given limited sources of power and the large amount of voltage drop between sites to run nominal 120/240 power for the RSUs. Multiple iterations of power designs were developed, and extensive coordination was required with the three local power companies before a power design was selected. • The project system requirements specified the use of the SAE formatted roadside safety message (RSM) as defined in SAE J2945/4 for the CSW and reduced speed zone/lane closure application. When moving into the engineering and project development phase, since the standard was not yet finalized, concerns arose that using the RSM set as defined in the draft version could potentially create interoperability issues. The project wanted to ensure that the message format was sustainable with OBUs in the future since it was not yet standardized by SAE International.

Table 15. Grantees' lessons learned (April 2023–March 2024) (continuation).

Category	Grantees' Reported Lessons Learned
Technology/ equipment /data (continued)	• Consistency between infrastructure owners and operators on how applications are interpreted to function across industry can be problematic. The functionality can be, and has been, interpreted differently by the OBU vendors. Without national guidance specific to application standardization, consensus on how applications should function and how to interpret the SAE J2945 standard is unlikely. In addition, the interpretation of applications such as CSW and how it correlates to the *Manual of Uniform Traffic Control Devices for Streets and Highways*[2] is inconsistent. • A network architecture that is based on an IPv4 standard does not sufficiently provide the medium to conduct over-the-air updates for OBU firmware or certificate updates for the SCMS. Due to multiple networks, some IPv4 and some IPv6, the project has been able to navigate this issue; however, the conversion of existing networks to support IPv6 is not simple and not without significant cost. • For the CV applications included in this project, our team decided during the concept development stage that dual-mode DSRC/C-V2X RSUs would be necessary to allow for near-term deployment with DSRC (which is the current proven technology) while enabling future migration to C-V2X on July 1, 2024, when DSRC is anticipated to be retired. Several waivers are also in process, so it is not certain how firm this date is, but we are monitoring any changes in regulatory timeframes to assess potential impacts. The team will procure dual-mode RSU technology and can share lessons learned on the processes of developing dual-mode specifications as well as procurement processes for these in 2024 when these activities are completed. • Procurement remains a challenge to project schedules. The State DOT has recently encountered delays in procuring pedestrian survey technology and incident management software. • During the candidate equipment evaluation, the team observed a wide range of performance levels across devices. As expected, the team found newer C-V2X equipment to be much less mature than commercially available DSRC equipment. Execution of the equipment evaluation plan required fairly frequent engagement with a subset of the equipment vendors to work through performance issues, which in some cases required firmware or software updates to address. Such issues should be considered in other near-term deployments until the C-V2X equipment becomes more mature. • Different agencies and entities involved in a project may have very different objectives and perspectives on the project. Although these differences are not often mutually exclusive, they may lead each entity to draw different conclusions. Striving to understand these different perspectives to evaluate outcomes appropriately is important.

[2]FHWA. 2012. *Manual on Uniform Traffic Control Devices for Street and Highways*. Washington, DC: Federal Highway Administration. https://mutcd.fhwa.dot.gov/pdfs/2009r1r2/pdf_index.htm, last accessed June 14, 2024.

Table 16. Grantees' lessons learned (April 2023–March 2024) (continuation).

Category	Grantees' Reported Lessons Learned
Technology/ equipment/ data (continued)	• Because innovative technologies are not fully mature, procurement processes can be challenging. Describing the technical and operational characteristics of a new technology completely and clearly enough to allow for competition among vendors is difficult and can yield results that are different than anticipated. • Another impact of the fact that innovative technologies are not fully mature is the additional work needed to bring those technologies into full operation. Incompatibilities between hardware and software, incompatibilities between various hardware components, and unreliability in field deployments are all factors that impact the schedule of deployment. One specific example of field unreliability is GPS drift with V2X OBU devices. The source of this problem took 3 years to identify and overcome, but the impact on the reliable operation of the applications is significant. We can, however, add that the maturity of these systems have improved during the span of our work in this program, partially due to improved specifications and efforts by deployers and vendors of these systems. • Using our deployed dual-mode RSUs, we have been able to assess the range of message receipt of both DSRC and C-V2X radios. Results indicated that both DSRC and C-V2X RSUs exceeded the nominal range of 300 m in their ability to receive BSMs, and the C-V2X range was 25 percent higher, on average. Furthermore, when both DSRC and C-V2X were being operated simultaneously, no degradation in the range of receipt occurred. This information will provide one measure of confidence for future deployment of C-V2X devices and could impact device spacing and placement. • Contractual language with the V2X deployment and installation contractor did not address device, application, and system performance expectations in sufficient detail, nor did it specify data recording and provision requirements. Consequently, unwritten assumptions did not always align between the project team and the deployment contractor. Part of the challenge was the lack of V2X device and application maturity; we were unaware that certain performance issues would be observed. In future deployment contracts, clarifying language will be added, and a phased approach will be considered to better define expected performance, require demonstration of that performance, and phase in the full deployment in accordance with performance milestones.

Table 17. Grantees' lessons learned (April 2023–March 2024) (continuation).

Category	Grantees' Reported Lessons Learned
Technology/ equipment/ data (continued)	• Based on the FCC restrictions and elimination of 45 MHz of the 75 MHz DSRC band, we decided to replace 30+ DSRC RSUs already deployed along the avenue. The new RSUs will be C-V2X based and operate using V2X hubs at the roadside and within the vehicle. This change will eliminate the need to upgrade roadside equipment through future contracts and allow for greater longevity of this deployment. The university team's involvement in developing the MMITSS application has been a significant leap forward. Eliminating the need for several versions of software alpha builds will reduce cost and accelerate the schedule toward deployment and testing. The results of the city pilot prove valuable in how the TSP MMITSS application must operate when deployed along the M–1 corridor. • Year 2 focused on identifying and reauditing hotspots (subsections of the route consistently likely to be associated with anomalies observed in ADS behavior). Hotspots center primarily around lane lines and signage detection. For lane lines, nondetection event types included rerouting lines (creating confusion between previous and new lines), mistaking tar lines for lane lines, faded lane lines, the impact of repair patches and tire marks, and the impact of bridges and bridge or truck shadows. For signage, lateral offset from the roadway, background, lighting, and LED-based variable speed limit signs in work zones impacted detection. False positives, such as detecting a U.S. route sign as a speed limit sign, were also found. • Discover and document needed infrastructure to support ADS. • Senior management at the port requested that the project team look into the viability of using an electric truck for this project without increasing costs or delaying the overall project schedule, an oversight that could have been avoided by more clarifying communications upfront. Because the project is innovative, the process of finding large truck manufacturers who were willing to discuss the vision and participate was far more difficult than planned. • The private 5G portion of this project revealed three big takeaways: First, each 5G network is vendor specific, meaning that if one chooses a specific vendor, only that vendor's radios will work with your 5G network. Second, when the 5G network is turned on for a particular vendor, then all devices for that vendor will attempt to use your private network. This issue becomes problematic if a way to get back into the vendor's network is not available. Third, a large network pipe (at least 10 GB), needs to be implemented from the private 5G network back to the vendor to allow the vendor's customers to connect through your private network back to them.

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