Connected Vehicle Pilot Deployment Program Independent Evaluation

Public Agency Efficiency Impact Assessment—Wyoming

www.its.dot.gov/index.htm

Final Report—July 28, 2022

FHWA-JPO-22-950

U.S. Department of Transportation

Produced by Texas A&M Transportation Institute, Texas A&M University System
U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology
Federal Highway Administration

Cover photo courtesy of ITS Joint Program Office Module 13 ePrimer Presentation
(Connected Vehicles)

Notice

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-22-950		

4. Title and Subtitle Connected Vehicle Pilot Deployment Independent Evaluation Program Public Agency Efficiency Impact Assessment—Wyoming	**5. Report Date** July 28, 2022 **6. Performing Organization Code**
7. Author(s) Balke, K. and C. Simek	**8. Performing Organization Report No.**
9. Performing Organization Name and Address Texas A&M Transportation Institute The Texas A&M University System 3135 TAMU College Station, TX. 77843-3135	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTFH6116D00045/0003
12. Sponsoring Agency Name and Address ITS-Joint Program Office 1200 New Jersey Avenue, S.E., Washington, DC 20590)	**13. Type of Report and Period Covered** Research Report **14. Sponsoring Agency Code**

15. Supplementary Notes

Work Performed for: Tom Kearney, Federal Highway Administration (FHWA) and Walter During, FHWA

16. Abstract

The Wyoming Department of Transportation's (WYDOT's) primary goal for implementing the Wyoming Connected Vehicle Pilot Deployment (CVPD) was to demonstrate the potential and feasibility of using connected vehicle (CV) technologies to improve safety and mobility along 402 miles of Interstate 80 (I-80) in southern Wyoming. As the lead agency, WYDOT wanted to explore using CV technologies to communicate road and travel information to commercial truck drivers and fleet managers that routinely travel the I-80 corridor. Using data provided by the Wyoming CVPD Team, the Texas A&M Transportation Institute (TTI) conducted a qualitative assessment of the impacts of the deployment on public agency efficiency. The TTI Team looked at two elements associated with improved public agency efficiency: improved situational awareness by traffic management center operators and enhanced traveler information dissemination. The assessment found that although the number of equipped vehicles was relatively small, WYDOT was able to improve its situational awareness in the corridor. The CVPD Team also found that providing messages via commercial satellite information was an effective way of reaching commercial fleet vehicles in the corridor.

17. Keywords	18. Distribution Statement
Connected Vehicles, Connect Vehicle Pilot Deployment, Independent Evaluation, Wyoming, Public Agency Efficiency Impact Assessment	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
		43	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Acknowledgements

The authors would like to thank the following individuals for their assistance in developing this plan in support of the independent evaluation of the Connected Vehicle Pilot Deployment Program:

- Walter During, Federal Highway Administration (FHWA)
- Tom Kearney, FHWA
- Kate Hartman, Intelligent Transportation Systems Joint Program Office (ITS JPO)
- Jonathan Walker, ITS JPO
- Govindarajan Vadakpat, FHWA
- Douglas Laird, FHWA
- Neil Spiller, FHWA
- James Colyar, FHWA
- James Sturrock, FHWA
- Volker Fessmann, FHWA
- Margaret Petrella, Volpe National Transportation Systems Center
- Wassim Najm, Volpe Center
- Karl Wunderlich, Noblis
- Meenakshy Vasudevan, Noblis
- Sampson Asare, Noblis
- Kathy Thompson, Noblis
- Peiwei Wang, Noblis
- Claire Silverstein, Noblis

Table of Contents

List of Tables

List of Figures

Executive Summary

The Wyoming Department of Transportation's (WYDOT's) primary goal for implementing the Wyoming Connected Vehicle Pilot Deployment (CVPD) was to demonstrate the potential and feasibility of using connected vehicle (CV) technologies to improve safety and mobility along 402 miles of Interstate 80 (I-80) in southern Wyoming. As the lead agency, WYDOT wanted to explore using CV technologies to communicate road and travel information to commercial truck drivers and fleet managers that routinely travel the I-80 corridor. The deployment built upon WYDOT's extensive road weather and traveler information systems to provide warnings and alerts about road conditions, particularly during severe winter weather and high wind events. (1)

At a high level, the scope of deployment included implementing the following: (3)

- Deploying around 76 roadside units (RSUs) that could receive and broadcast messages using dedicated short-range communications (DSRC) along various sections of I-80.
- Equipping a combination of WYDOT fleet vehicles (e.g., snowplows, highway patrol vehicles, and others) and commercial trucks—all regular users of I-80—with onboard units (OBUs) capable of receiving alerts and broadcast basic safety messages. A portion of the vehicles could also collect and disseminate environmental and road condition information using mobile weather sensors.
- Developing multiple vehicle-to-vehicle and vehicle-to-infrastructure applications that communicate alerts and advisories to drivers about road conditions. The applications were designed to support the in-vehicle dissemination of advisories for avoiding collisions, managing speeds, implementing detours, and alerting to the presence of downstream work zones and maintenance and emergency vehicles based—all based on the vehicle's location in the network.
- Enabling improvements to WYDOT's traffic management center (TMC) and traveler information practices by using data collected from CVs. Targeted improvements included better activation of WYDOT's variable speed limit and traveler information dissemination systems (i.e., 511, dynamic message signs)

This assessment focuses on how the Wyoming CVPD may have improved public agency efficiency. Examples of improvements in public agency efficiency include, but are not limited to, a) improvements in situational awareness of travel conditions in the deployment corridor, and b) improved capabilities to disseminate roadway and weather conditions within and beyond the deployment corridor. This analysis was strictly qualitative based on the data and information provided by the Wyoming CVPD Team.

Using records for 499 weather events from January 2021 to April 2022, the Wyoming CVPD team examined the extent to which the CVPD improved the quality, coverage, and timeliness of road condition reports coming into the TMC during the deployment. The following is a summary of their findings:

- The quantity of road condition reports coming into the TMC increased from 4.3 reports per section of I-80 per day during weather events in the baseline conditions to 16.9 reports per section per day in the post-deployment period. An increase in the number of road condition reports will allow WYDOT operators to be more responsive to changing travel conditions.

- The CVPD improved WYDOT's coverage of road conditions reports. The average number of road sections that had at least one road condition report per hour during weather event increased from 5.0 in the baseline condition to 6.4 in the post-deployment period. Increasing the coverage of the network using CV technologies would reduce the dependency of using maintenance vehicles to traverse the segment to generate road condition reports. This means that with higher market penetrations, WYDOT would be able to detect more quickly when road conditions were beginning to deteriorate or improve.
- The latency, express as average refresh time in hours, between road condition reports per section during weather events dropped from 3.9 hours to 3.2 hours. Reducing the frequency between updates helps TMC operators better match traffic management strategies to changing operational and weather conditions.

The data generated by the Wyoming CVPD vehicles became an additional source information for WYDOT's existing traffic management system, which uses travel condition and road weather information from multiple sources to assist TMC operators manage WYDOT's traffic management assets (VSL signs, DMS, road closure gates, etc.). Having better quality, quantity, and timeliness of road condition information allowed TMCs operators to better manage those traffic management assets through the following:

- Increasing the accuracy and quality of road condition information that TMC operators could use to adjust VSL and other traffic management assets in response to changing weather conditions.
- Expanding the coverage in the network where information is available to make real-time adjustments to traffic management strategies.
- Reducing the time lag between status updates on travel conditions on the roadway network.
- Increasing the frequency of updates to DMS and other traveler information system messaging to reflect evolving travel conditions during significant weather events.
- Sending targeted weather alert messages to vehicle entering specific segments of the deployment corridor.
- Directing maintenance resources to locations requiring attention.
- Enhancing the credibility of WYDOT's weather-related messaging by ensuring that messaging reflects the conditions observed by drivers.

WYDOT also hypothesized that CV technologies would improve its ability to disseminate changing road condition information. In the deployment, all the equipped vehicles had the ability to receive traveler information message (TIMs) alerts and warning via both Dedicated Short-Range Communications (DSRC) and satellite communications. Both technologies were shown to have comparable performance in disseminating alert and warnings to equipped vehicles.

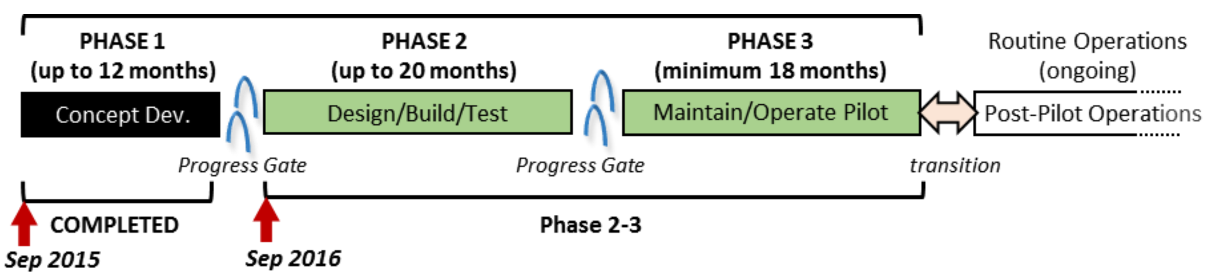
As a results of the deployment, WYDOT has expanded its ability to provide traveler information not only in the corridor, but throughout the state. Using the data structures, data exchanges, and processes developed in the CVPD, WYDOT extended their ability to disseminate traveler information messages via satellite to include all state and federal highways throughout the state. WYDOT extended their information dissemination capabilities by developing an Alexa Skill that can also produce alerts and warnings using the data provided by WYDOT's Situational Awareness applications.

Chapter 1. Introduction

Connected vehicle (CV) technologies offer immense potential to improve safety and enhance mobility. The technologies use advanced mobile communications to share information between users of the transportation system (passenger vehicles, buses, pedestrians, etc.) and the infrastructure. Applications embedded in vehicles, mobile devices, and infrastructure use new levels of information to issue alerts. Using data from CVs, agencies can deploy traffic management strategies designed to improve safety, enhance mobility, and reduce emissions and fuel consumption. To explore the benefits of CV technology, the U.S. Department of Transportation (USDOT) initiated the Connected Vehicle Pilot Deployment (CVPD) Program. USDOT's goals for this program included the following:(2)

- To spur early CV technology deployment not just through wireless CVs but also through other elements such as mobile devices, infrastructure, and traffic management centers (TMCs).
- To target improving safety, mobility, and environmental impacts and commit to measuring those benefits.
- To resolve various technical, institutional, and financial issues commonly faced by early adopters of advanced technologies.

On September 14, 2015, USDOT's Intelligent Transportation Systems Joint Program Office (ITS JPO) launched the CVPD Program. (2) ITS JPO selected three locations as pilot deployment sites: Wyoming, New York City, NY, and Tampa, FL. Each deployment represents different potential settings for CV technologies. Each site developed different applications to address vastly different problems specific to their needs. For example, the Wyoming deployment focused on better dissemination of travel information during winter weather events to reduce the potential of multi-vehicle collisions involving commercial trucks. The New York deployment focused on improving safety and traffic flow in a very dense urban environment, while the Tampa deployment focused on improving safety and mobility in a typical central business district of a smaller community. As illustrated in Figure 1, each deployment went through a similar life cycle. In Phase 1 of the life cycle, each site developed and refined the concepts behind its deployment. In Phase 2, each site, following the systems engineering approach, designed, built, and tested its deployments. In Phase 3, each site was responsible for managing and operating its deployments under actual traffic conditions. This report focuses on Phase 3 and includes an evaluation of the overall mobility benefits associated with the Wyoming deployment.



Source: Federal Highway Administration, 2015.

Figure 1. Flowchart. Three Phases of a Connected Vehicle Pilot Deployment.

Wyoming Connected Vehicle Pilot Deployment

The Wyoming Department of Transportation's (WYDOT's) primary goal for implementing the Wyoming CVPD was to demonstrate the potential and feasibility of using CV technologies to improve safety and mobility along 402 miles of Interstate 80 (I-80) in southern Wyoming. As the lead agency, WYDOT wanted to explore using CV technologies to communicate road and travel information to commercial truck drivers and fleet managers that routinely travel the I-80 corridor. The deployment built upon WYDOT's extensive road weather and traveler information systems to provide warnings and alerts about road conditions, particularly during severe winter weather and high wind events. (2)

At a high level, the scope of deployment included implementing the following:(3)

- Deploying around 76 roadside units (RSUs) that could receive and broadcast messages using dedicated short-range communications (DSRC) along various sections of I-80.
- Equipping a combination of WYDOT fleet vehicles (e.g., snowplows, highway patrol vehicles, and maintenance supervisor vehicles) and commercial trucks—all regular users of I-80—with onboard units (OBUs) capable of receiving alerts and broadcast basic safety messages (BSMs). A portion of the vehicles could also collect and disseminate environmental and road condition information using mobile weather sensors.
- Developing multiple vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications that communicate alerts and advisories to drivers about road conditions. The applications were designed to support the in-vehicle dissemination of advisories for avoiding collisions, managing speeds, implementing detours, and alerting drivers to the presence of downstream work zones and maintenance and emergency vehicles—all based on the vehicle's location in the network.
- Enabling improvements to WYDOT's TMC and traveler information practices by using data collected from CVs. Targeted improvements included better activation of WYDOT's variable speed limit (VSL) and traveler information dissemination systems (i.e., 511, dynamic message signs, and others).

Purpose of Report

ITS JPO selected the Texas A&M Transportation Institute (TTI) CVPD Evaluation Team to be the independent evaluator for the mobility, environmental, and public agency efficiency benefits for the CVPD Program. An independent evaluation by a third party who has no personal stake in the project would eliminate potential bias in the findings. USDOT has sponsored an independent evaluation of CVPD to help inform USDOT of the following:

- The extent to which the CVPD Program was effective in achieving its goals of transformational safety, mobility, public agency efficiency, and environmental improvements.
- The lessons learned that others could use to improve the design of future projects.
- The institutional and financial impacts of the CVPD.
- The best way to apply resources in the future.

This report provides an independent public agency impacts assessment (PAEIA) associated with the Wyoming CVPD. Because of delays in the deployment and unforeseen external factors (e.g., the COVID-19 pandemic), the Federal Highway Administration (FHWA) revised TTI's evaluation scope to include only data collected by the sites during their evaluation. TTI did not perform an extensive quantitative analysis of the data collected by the Wyoming CVPD Team. Instead, TTI's evaluation was primarily qualitative in nature with some supporting explanatory quantitative analyses appropriately scoped to reduce technical risk and consistent with the nature, quality, and quantity of underlying data. To complete the analysis, TTI used materials and information provided through published information and outcomes of other evaluation efforts, including the following:

- Performance measurement activity performed by the Wyoming CVPD Team.
- The Volpe National Transportation Systems Center's safety impact assessments.
- Site-generated dashboards and lessons-learned logbooks generate by the Wyoming CVPD Team

This report focuses solely on the PAEIA associated with the deployment. Other reports have been produced to summarize the independent evaluation of the safety, mobility, and environmental benefits of the deployment.

Organization of Report

The organization of this report is as follows:

- Chapter 2 is a summary of the Wyoming CVPD. The chapter summarizes the deployment goals and objectives, the infrastructure, and vehicle subsystems implemented to support the deployment. The chapter contains a brief explanation of the applications and the evaluation conditions.
- Chapter 3 provides TTI's assessment of the impacts of the deployment on public agency efficiency, based on the data provided by the Wyoming CVPD Team.
- Chapter 4 provides a summary of findings and conclusions through the deployment.

Chapter 2. Wyoming Deployment

This chapter provides a brief summary of WYDOT's goals and objectives for the deployment, the infrastructure and vehicle subsystems that made up the system, and the applications used in the deployment. This chapter also summarizes the general operating conditions during the deployment.

For detailed information on the design and implementation of the Wyoming CVPD, please consult the following references:

- *Connected Vehicle Pilot Deployment Phase 2: System Architecture Document, WYDOT CV Pilot.* [4]
- *Connected Vehicle Pilot Deployment Program: System Design Document (SDD)—Wyoming CV Pilot.* [5]

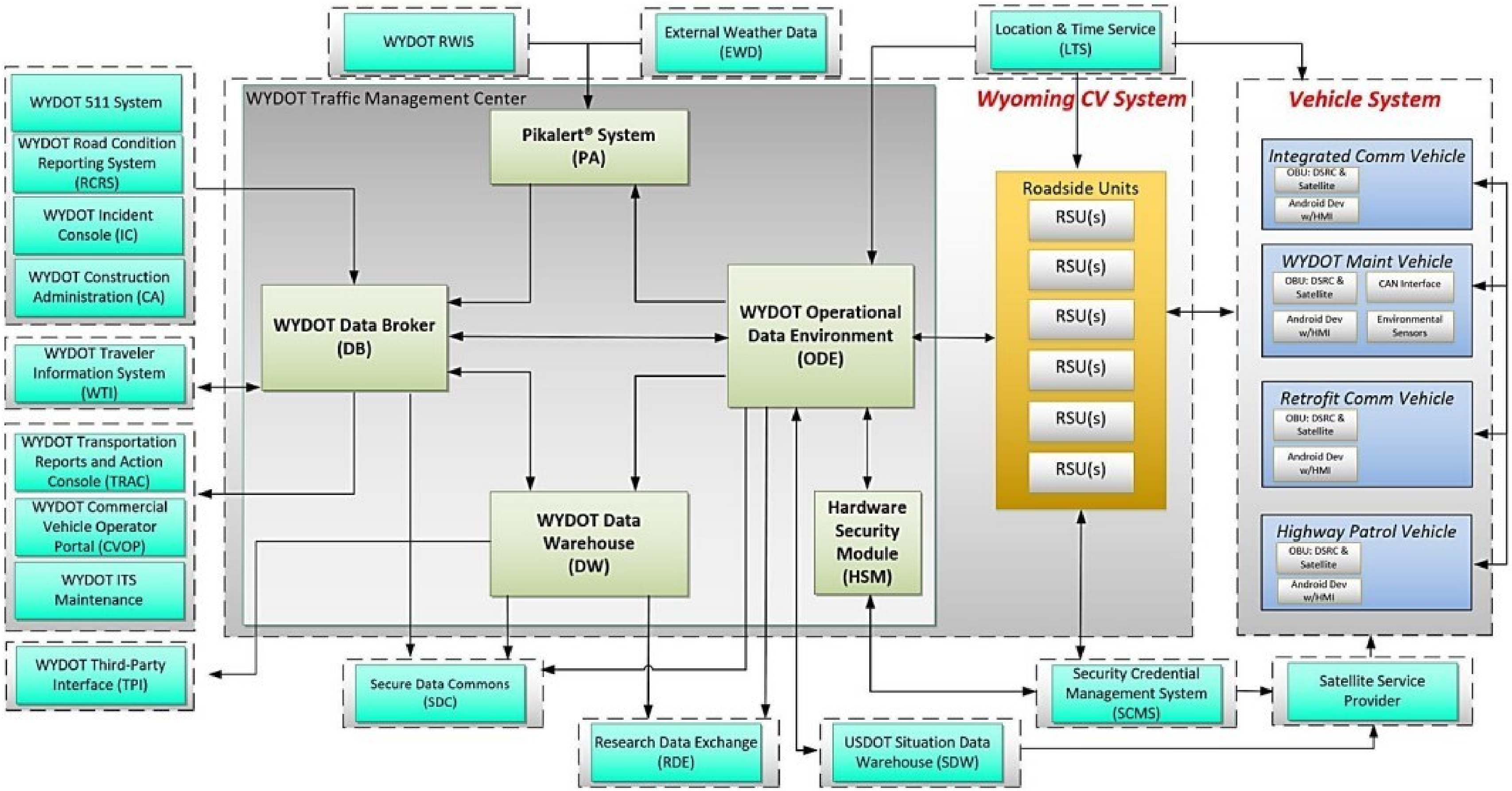
Deployment Goals and Objectives

WYDOT's objectives for the deployment were as follows:[3]

- Deploy and operate a set of vehicles equipped with OBU using DSRC connectivity. These vehicles included a combination of WYDOT snowplows, WYDOT fleet vehicles, WYDOT highway patrol vehicles, and private commercial fleet vehicles to broadcast J2735 BSMs and collect vehicle weather and road condition data for use in WYDOT's TMC. These vehicles also received roadway and traffic alerts wirelessly from the TMC so that drivers would have better information about current travel conditions to make better travel decisions.
- Deploy infrastructure devices (RSUs) with DSRC connectivity to transmit advisories and alerts to equipped vehicle traveling along I-80 in Wyoming.
- Leverage data provided by the equipped vehicles to develop and demonstrate a suite of V2V and V2I applications to support a variety of wide-area travel advisories and traffic management functions, including the following:
    - Setting and removing VSLs along the I-80 corridor.
    - Supporting 511 and other traveler information.
    - Supporting road weather advisories and freight-specific travel guidance through WYDOT Commercial Vehicle Operations Portal (CVOP).

System Components

The Wyoming CVPD was comprised of both infrastructure and vehicle subsystems. Figure 2 provides an overview of the system architecture associated with deployment. The following provides a brief description of the primary infrastructure and vehicle subsystems of the deployment.



Source: Wyoming Department of Transportation, 2017.

Figure 2. Diagram. System Architecture of Wyoming CVPD. [4]

Source: Wyoming Department of Transportation, 2022.

Figure 3. Map. RSU Locations on I-80. [(2)]

Infrastructure Subsystems

The infrastructure systems included all the components and back-office systems needed to generate and distribute advisories and alerts for CV pilot vehicles. Except for the RSUs, the bulk of the infrastructure subsystem components were located at WYDOT's TMC. Additionally, the Wyoming CVPD Team developed external interfaces to share the advisories and alerts with the public and commercial vehicle operators.

The following provide a brief description of the components of the Wyoming CVPD infrastructure subsystems:[(3)]

- RSUs—These are physical devices installed along I-80 to provide two-way communications (via DSRC) between equipped vehicles and WYDOT's TMC for the purposes of exchanging information. The Wyoming CVPD Team used a combination of both fixed and portable RSUs in the deployment. These devices also provided application support, data storage, and other support services (e.g., security certificate handling). WYDOT installed a total of 76 RSUs in the corridor. Figure 3 shows the location of where RSU were deployed along I-80.
- Operational data environment (ODE)—The ODE communicated with the RSUs to retrieve data collected from equipped vehicles. The ODE performed basic data quality checks on the data and then shared the information with other system components for analysis and distribution. The ODE was located in WYDOT's TMC.
- Hardware security module (HSM)—This "black box" provided security credentialing and certificate management services for WYDOT. The HSM was operated by a private company and provided security credentialing for the traveler information messages (TIMs) broadcast from the TMC.
- Pikalert® system—The Pikalert® system supported the integration and fusions of CV and non-CV weather data for the purposes of generating adverse weather alerts and advisories about driving conditions on I-80. The Pikalert® system was not developed as part of the Wyoming CVPD but is an existing alerting system developed by WYDOT for generating alerts and advisories from external weather sources.

- Data broker—The infrastructure system component was responsible for receiving and analyzing information from the ODE, Pikalert®, and other external system, and distributing it to other systems and services, including third-party data services such as FHWA's Secure Data Commons.
- Data warehouse (DW)—This component was responsible for storing various TMC- and CV-related data for use in conducting the Wyoming CVPD Team's performance evaluation. The DW was responsible for timestamping and geotagging log data from CV and non-CV sources collected, generated, and shared with the Wyoming CV System.

The Wyoming CVPD Team used 76 DSRC RSUs along I-80. The RSUs provided services for wave service announcements, TIM distribution, BSM logging, OBU log offloading via IPv6, OBU certificate top offs, and over-the-air updates for OBUs. Security credentialling was provided through a private secure credential management system (SCMS) for application certificates.

Vehicle Subsystem

WYDOT divided the deployment fleet into two groups: friendly fleet vehicles and partner CV fleet vehicles. Friendly fleet vehicles were those vehicles over which the Wyoming CVPD Team had more access and was able to collect identifiable information from the vehicles. Friendly fleet vehicles included WYDOT snowplows, stakeholder fleet vehicles, and WYDOT highway patrol vehicles. Because these vehicles are public or informed partner fleets, the Wyoming CVPD Team could track and collect detailed information from these vehicles. Partner CV fleet vehicles included all other vehicles, namely those from private stakeholders, who could not be tracked or accurately counted out of security and privacy concerns. Table 1 provides a breakdown of the number of vehicles in the deployment fleet.

Table 1. Number of CV Devices Installed as Part of Wyoming CVPD.

Vehicle Type	Deployment Category	Actual
WYDOT maintenance fleet (snowplows)	Friendly	53
WYDOT highway patrol	Friendly	66
State pool fleet	Friendly	18
Medium-duty friendly fleet	Friendly	21
Heavy-duty/commercial fleet	Partner CV fleet	167
Total equipped vehicles	**Not applicable**	**325**

Source: U.S. Department of Transportation Intelligent Transportation Systems Joint Program Office. (6)

Originally, WYDOT used two types of OBUs in its deployment—one a DSRC based, and the other satellite based. Both OBU types had the ability to perform the following functions:

- Broadcast BSMs (including trailer information in Part 2 of the message).
- Receive and display TIMs.
- Collect and send log data to the TMC.
- Sign and validate messages using USDOT's proof-of-concept SCMS pseudonym certificates.
- Receive and install over-the-air updates.
- Implement the Forward Collision Warning (FCW) application per the Society of Automotive Engineer's On-Board System Requirements for V2V Safety Communications (J2945/1) standard. (7)

All equipped vehicles in the deployment had the following core capabilities:(3)

- The ability to share and receive information via DSRC communications from other connected devices (vehicle and infrastructure based).
- The ability to broadcast J2735 BSMs.
- The ability to allow drivers to display alerts and advisories received by the vehicle while enroute.

While initial testing went well with both OBU devices, complications arose after WYDOT switched from USDOT's SCMS to a private SCMS provider. Because of these complications and because of the Federal Communications Commission's decision to reallocate the DRSC 5.9-GHz spectrum, the DSRC vendor decided in December 2020 that it would no longer support, warranty, develop, or repair its OBU and RSU devices. As a result, the Wyoming CVPD Team pivoted to using only the satellite based OBUs. With the satellite-based system, vehicles received inbound alerts while traveling anywhere in the corridor and would upload vehicle performance logs when they passed an RSU.

Onboard Applications

The Wyoming CVPD deployed four onboard applications to provide drivers with key information to help improve their safety. These applications include the following:

- Forward Collision Warning (FCW).
- Stationary Vehicle Alert (SVA).
- Infrastructure-to-Vehicle Situational Awareness (I2V–SA).
- Spot Weather Impact Warning (SWIW).

The Wyoming CVPD Team deployed a fifth application, Work Zone Warning, to provide approaching drivers with information about conditions that exist in work zones. This application used a portable RSU station deployed at the work zone location to transmit alerts to approaching CVs.

Table 2 provides a brief description of each of the deployment applications. (3)

Table 2. Applications Included as Part of the Wyoming CVPD.

Application	Description
FCW	Issues an alert if there is a threat of a front-end collision with another CV in the travel lane and direction. FCW will help drivers avoid and reduce the severity of front-to-rear vehicle collisions. The system does not take control of the vehicle to avoid a collision.
SVA	A specialized version of FCW in which a downstream vehicle is parked on the side of the road or an adjacent lane along I-80. The application alerts drivers to the situation and helps them avoid or mitigate a potential collision with the parked vehicle.
I2V—SA	Provides relevant road condition information including weather alerts, speed restrictions, vehicle restrictions, road conditions, incidents, parking, and road closures. The information is broadcast from RSUs and received by the CV.
Work Zone Warning	Communicates information to approaching vehicles about conditions at a work zone ahead. Approaching vehicles receive information about work zone activities or restriction information that could present unsafe conditions, such as obstructions in a vehicle's travel lane, lane closures, lane shifts, speed reductions, or vehicles entering or exiting the work zone.
SWIW	Enables localized road condition information, such as fog or icy roads, to be broadcast from a RSU and received by a CV.

Source: Wyoming Department of Transportation Connected Vehicle Pilot Website. [(1)]

System Operations

The following provides a brief description of the operational conditions under which the system was evaluated by the Wyoming CVPD.

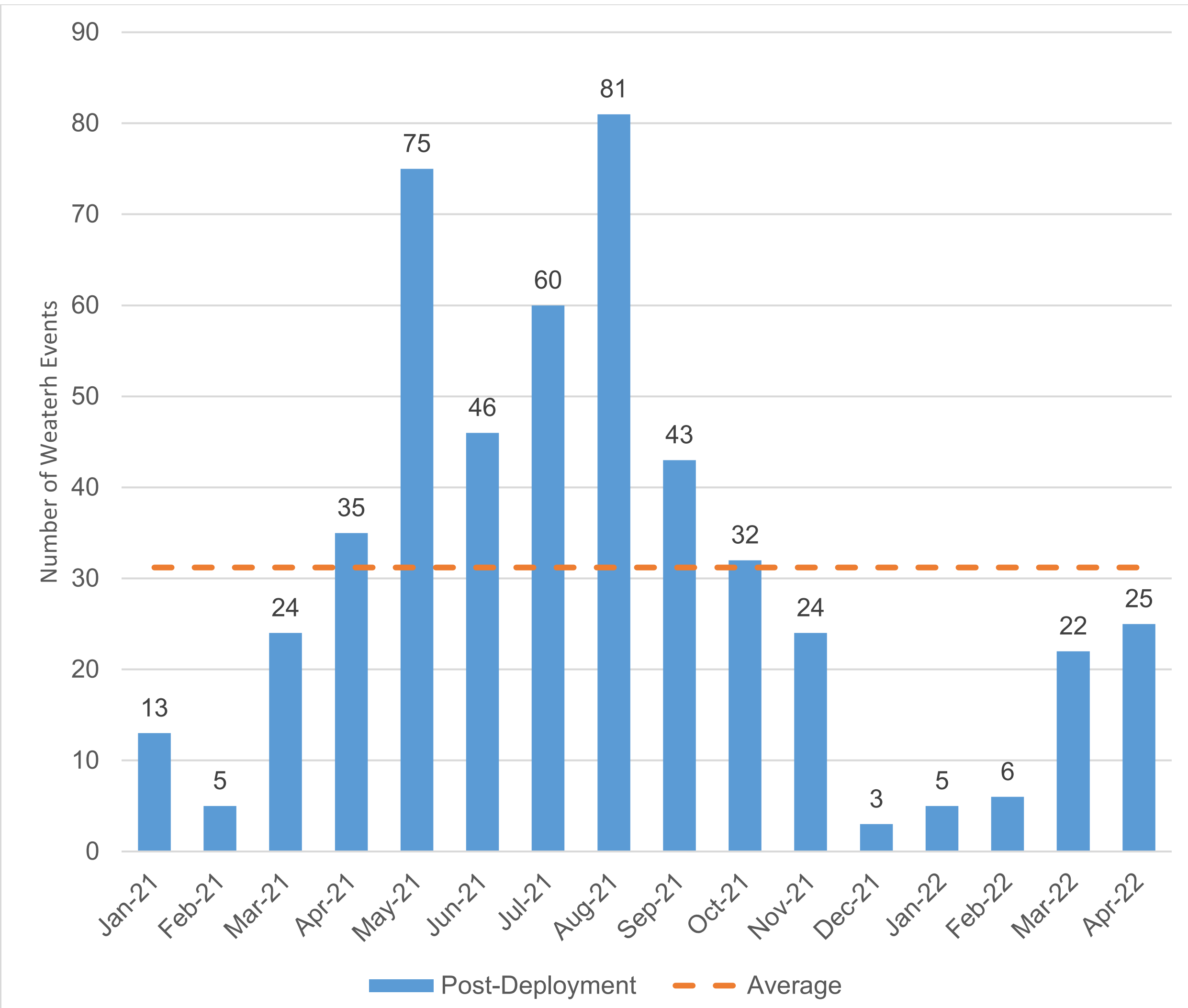
Baseline Conditions

The Wyoming CVPD Team collected pre-deployment data beginning in December 2016 through November 2017. [(3)] The purpose of this pre-deployment data collection effort was to create a baseline of the expected level of operations and system performance during severe weather events. The Wyoming CVPD Team also examined crash data before December 2016. During the baselining period, the Wyoming CVPD collected data only from traditional, non-CV data sources. No data from CVs were available because the CV technology had not yet been outfitted in the vehicles.

WYDOT reported that the 2016–2017 winter was one of the most severe on record, especially the number and intensity of strong wind events in the corridor.[(3)] The Wyoming CVPD Team reported 41 separate significant weather events on I-80 between December 2016 and May 2017.[(3)] These weather events resulted in WYDOT's extensive use of VSL systems and dynamic message signs, constant updates of the Wyoming traveler information system and the CVOP, and numerous road closures. Crashes numbered 1,310 in total, of which 225 trucks were blown over due to extreme strong winds. WYDOT also reported a total of nine fatalities during these weather events.

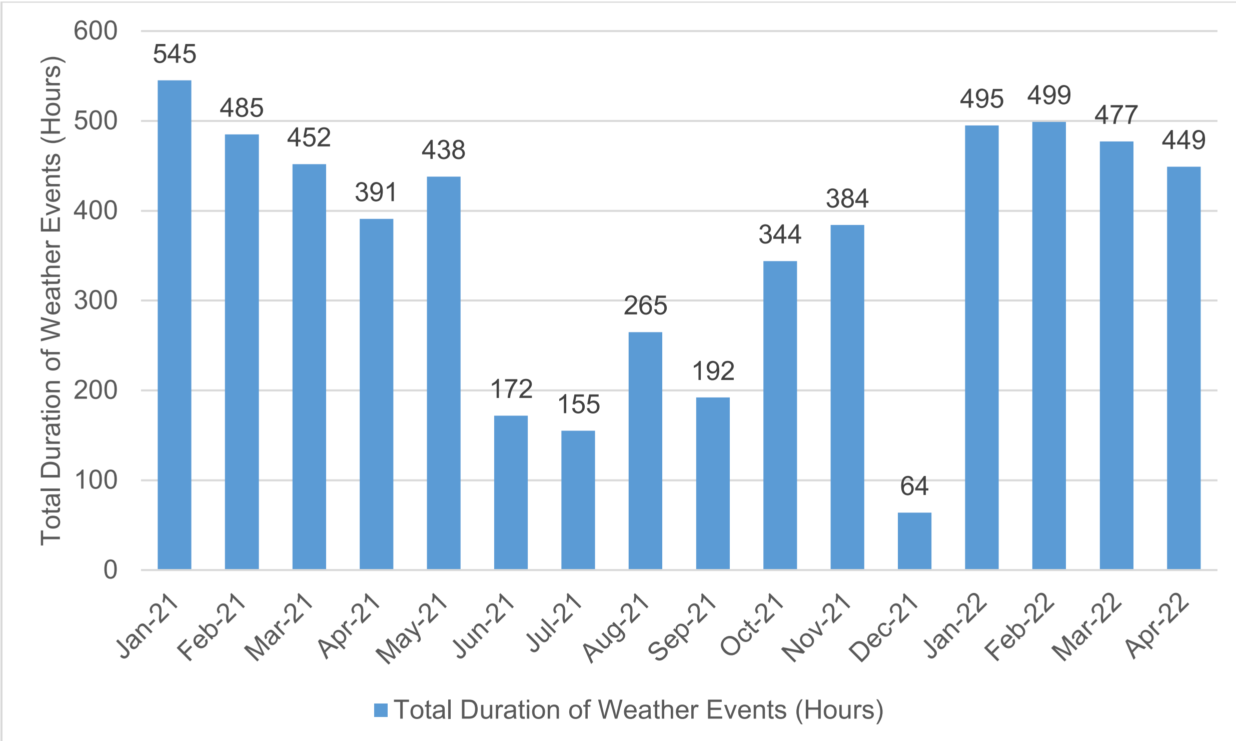
Post-Deployment Operations

The Wyoming CVPD entered the post-deployment evaluation phase (Phase3) in January 2021 and collected performance data until February 2022.(3) During the post-deployment period, WYDOT reported a total of 499 severe weather events, lasting a total of 5,807 hours.(3) The bulk of these events impacted at least half of the I-80 deployment corridor with the most severe storms (in terms of severity, complexity, and coverage) occurring during the winter. In February 2021 and January 2022, the I-80 corridor experienced only five major weather events, but their average duration was over 100 hours each. During the summer months, the I-80 corridor experienced significantly more severe weather events (between 45 and 85 events); these storms tend to have a relatively short duration (between 2.5 and 5 hours). Figure 4 shows the number of severe weather events occurring in the I-80 corridor during the post-deployment period, while Figure 5 shows the total duration that the corridor experienced inclement weather for each month. Figure 6 shows the average storm duration (in hours) per severe weather event.



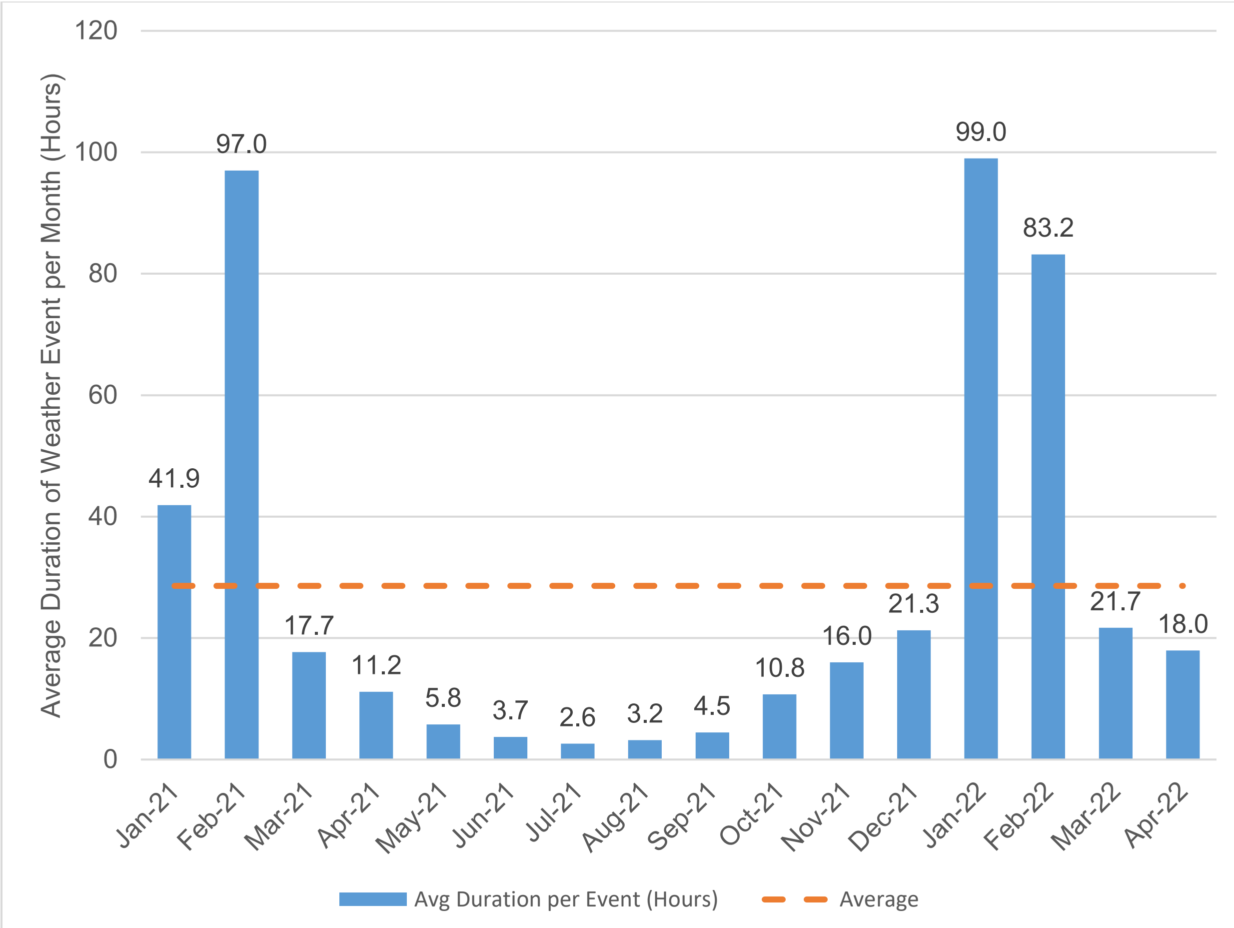
Source: Wyoming Department of Transportation, 2022.

Figure 4. Graph. Number of Weather Events in I-80 Deployment Corridor. (3)



Source: Texas A&M Transportation Institute based on data contained in Reference (3, 2022)

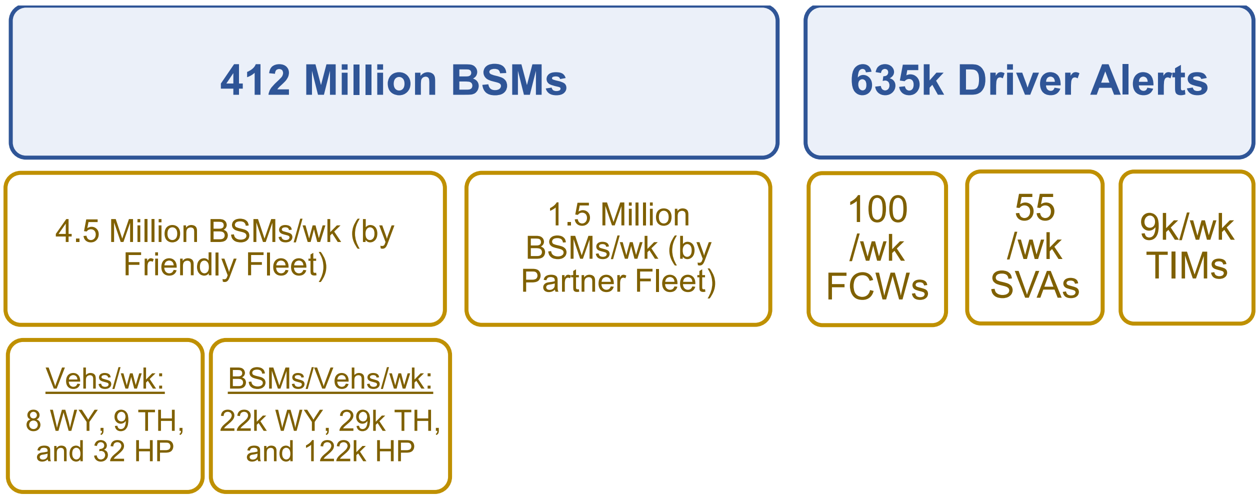
Figure 5. Graph. Total Duration of Severe Weather Storms in I-80 Deployment Corridor.



Source: Wyoming Department of Transportation, 2022.

Figure 6. Graph. Average Duration of Severe Weather Storms in I-80 Deployment Corridor. [3]

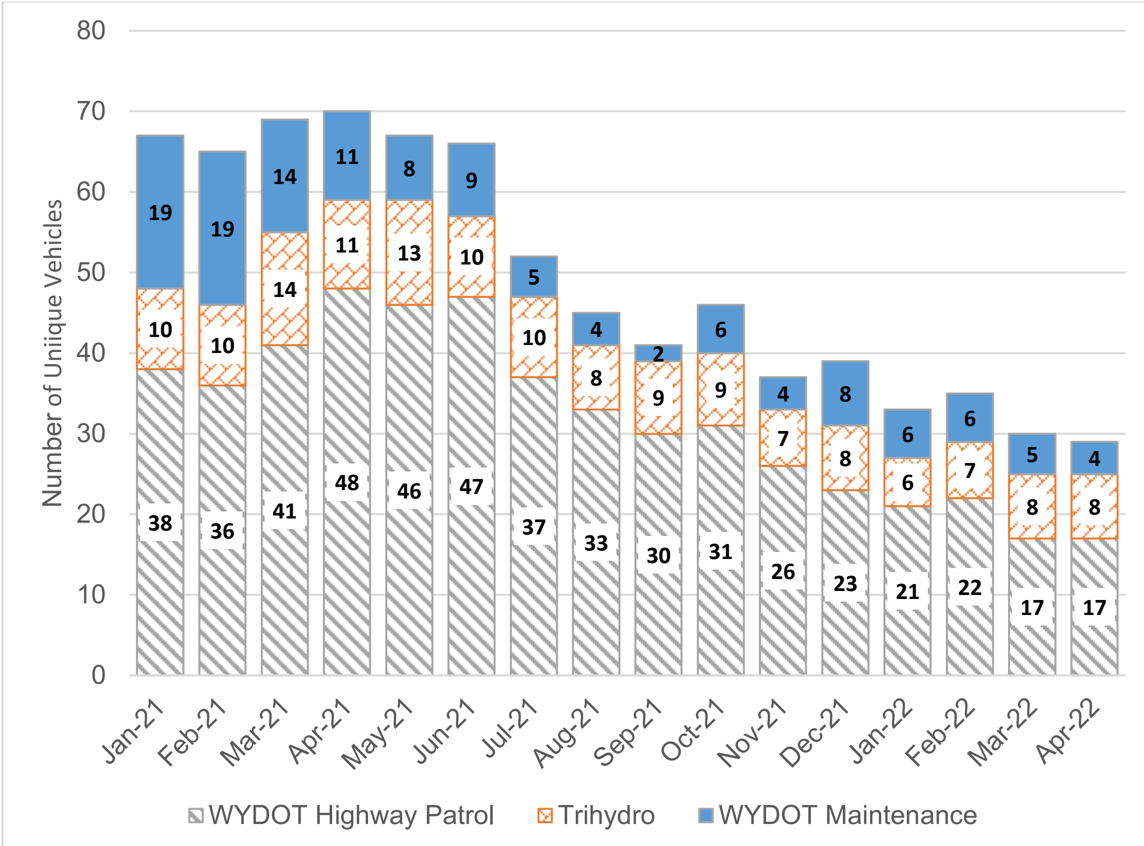
Figure 7 shows some basic operations statistics associated with CV operations in the I-80 corridor during the deployment periods. The Wyoming CVPD Team registered over 412 million BSMs and 635,000 driver alerts between January 1, 2021, and April 30, 2022. [3]



Source: Wyoming Department of Transportation, 2022.

Figure 7. Diagram. Summary of CV Operations in I-80 Deployment Corridor [3]

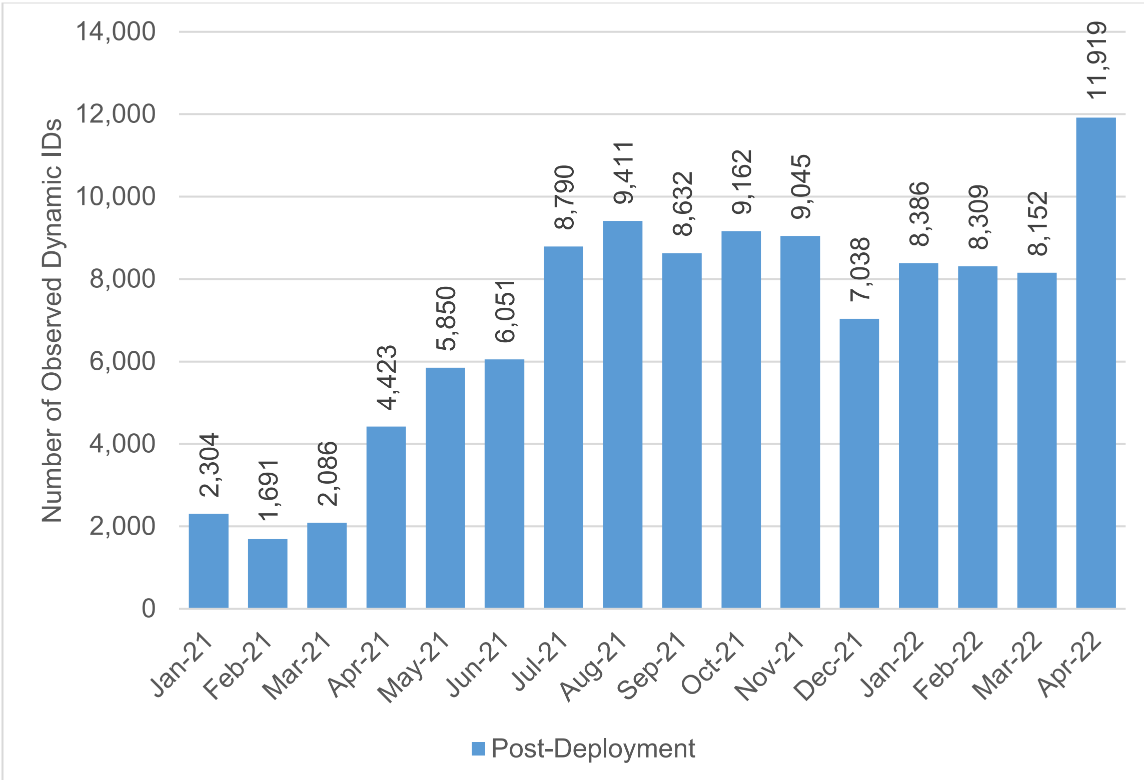
Figure 8 shows the number of friendly fleet CVs utilizing the I-80 deployment corridor between January 2021 and April 2022. [3] On average, the Wyoming CVPD Team observed 50 unique friendly fleet vehicles per month traveling on I-80 throughout the post-deployment period. The Wyoming CVPD Team reported that most of these vehicles were Wyoming highway patrol vehicles. The Wyoming CVPD reported significantly fewer WYDOT snowplows and stakeholder test vehicles during the same period, fluctuating between 2 to 20 vehicles per month.



Source: Wyoming Department of Transportation, 2022.

Figure 8. Graph. Number of Observed Friendly Fleet Vehicles on I-80 Deployment Corridor [3]

Figure 9 shows the number of dynamic vehicle IDs associated with partner fleet vehicles observed on I-80 each month during the post-deployment period. Because the vehicle IDs with partner fleet vehicles are dynamic (for security and privacy reasons), it is impossible to know the exact number of partner vehicles operating in the corridor between January 2021 and February 2022, but the figure shows an increased trend in the number of partner vehicles using the network during the post-deployment period.



Source: Wyoming Department of Transportation, 2022.

Figure 9. Graph. Number of Observed Partner Fleet Dynamic IDs in I-80 Deployment Corridor (3)

Chapter 3. Public Agency Efficiency Impact Assessment

Two primary objectives of the Wyoming CVPD were to improve WYDOT's situational awareness through better roadway conditions reporting and improve WYDOT's ability to generate alerts and advisories.

WYDOT hypothesized that improving the quality, quantity, and timeliness of road weather conditions information coming into WYDOT's TMC would in turn allow WYDOT TMC operators to issue alerts and warnings more quickly and accurately, which would ultimately produce significant safety, mobility, and environmental benefits. Using the performance measurements related to improving road weather condition reporting and information dissemination, TTI constructed a qualitative assessment of the public agency efficiency benefits associated with the Wyoming CVPD. This chapter presents the qualitative findings related to the extent to the deployment impacted the following:

- WYDOT's situational awareness of travel conditions in the deployment corridor.
- The quantity of road condition reports entering WYDOT's TMC.
- The coverage of road conditions reporting in the deployment corridor.
- The latency between road condition updates.
- The expansion of WYDOT's ability to disseminate road conditions and alerts beyond the deployment corridor.

Improved Situational Awareness

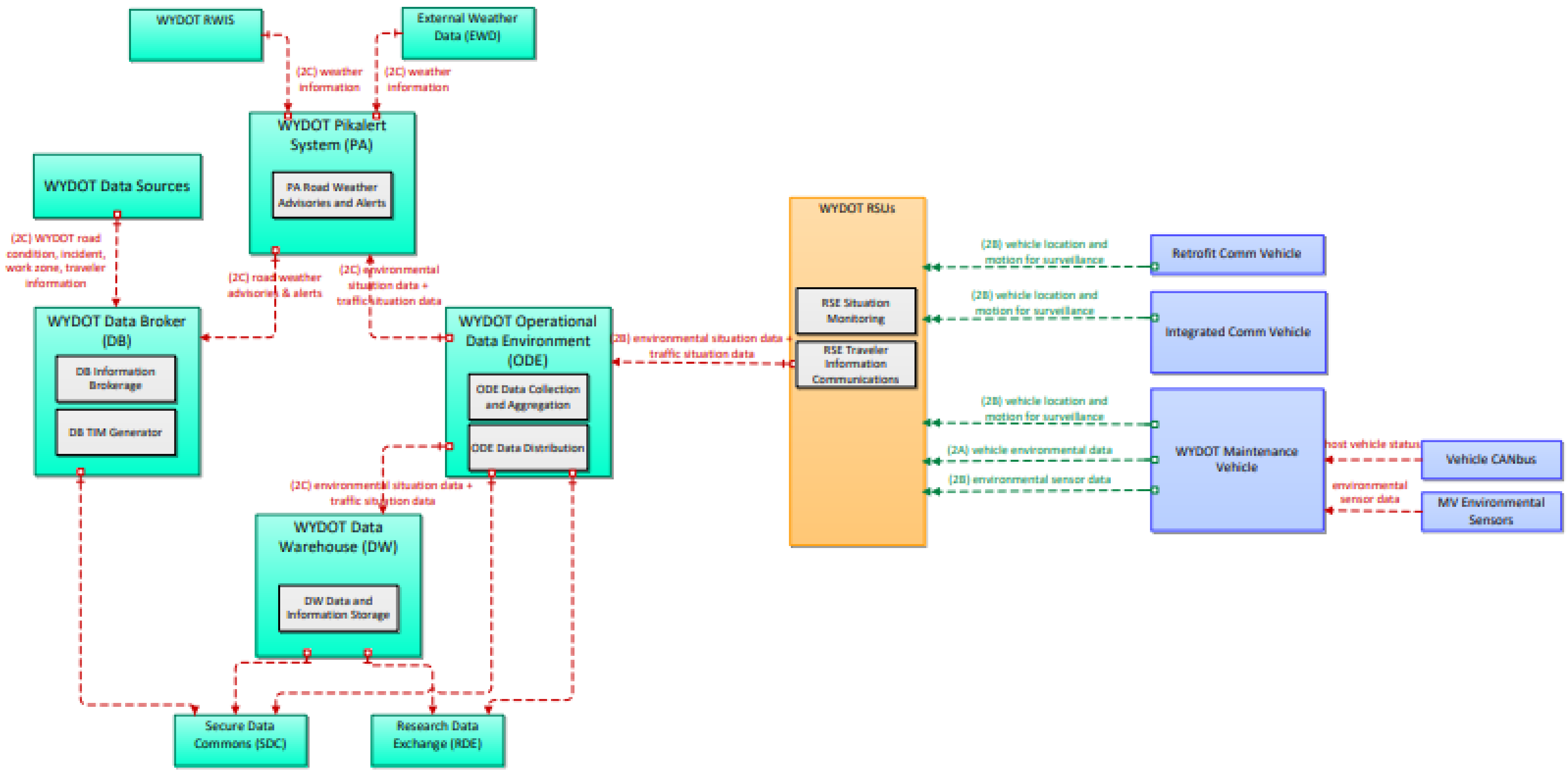
As part of the Wyoming CVPD, WYDOT implemented and enhanced the operation of their I2V Situational Awareness Application. This application ingests and fuses CV and non-CV data from various WYDOT applications to generate alerts and advisories about adverse travel conditions along I-80 with not only CV traveler information messages (TIMs) but also other traveler information systems. The I2V Situational Awareness application is a vital part of WYDOT transportation systems management and operations strategies for the entire State. It was vital that information used to generate these alerts and warning be accurate and timely and enhance the precision of their existing systems. Table 3 shows the sources of data that are used by the Data Broker which can be used by the I2V Situational Awareness application in generate road conditions and alerts.

Table 3. Input Data Sources Integrated into Wyoming CVPD Situational Awareness Application.

Source	Data Description
WYDOT 511 System	Provides information to the public regarding I-80's road weather and traffic conditions (e.g., road closure). The application is currently being updated to also share crowdsourced truck parking information with the CV Pilot.
WYDOT Road Condition Report System (RCRS)	An Android tablet-based application that resides in WYDOT snowplows which enables field personnel (e.g., snowplow operators) to report weather and roadway pavement conditions following WYDOT's 8 Code (roadway condition), 9 Code (atmospheric) and 10 Code (other road condition) system.
WYDOT Incident Console (IC)	Provides timestamped and geotagged incident information on incidents along I-80 obtained from the WHP and other sources (e.g., maintenance).
WYDOT Construction Administration (CA)	Provides timestamped and geotagged information of WYDOT's scheduled and unscheduled work-zone activities along I-80.This information includes dates and times of current and planned construction/work zone activities, work zone road surface conditions, expected delays, speed restrictions, lane restrictions, and other work zone related information.
WYDOT Traveler Information System (WTI)	Provides information related to the currently posted speed limit restrictions, and closure existing in the corridor.
Pikalert® System	Provides weather related information collected from CVs, WYDOT's Road Weather Information System, and 3rd party weather providers.

Source: Wyoming Department of Transportation, 2020

Figure 10 shows the data flows used by the I2V Situational Awareness application to generate Situational Awareness TIMs. CV data represents a new potential data stream that can be added to improve quality and timeliness of warning and alerts produced through WYDOT's TMC. Each equipped vehicle collects information about its trip in its Basic Safety Message. The Basic Safety Message includes not only standard elements of the J2735 BSM (e.g., the time, position, speed, and heading) but also other information which could be useful in determining the weather and road status information on I-80. As equipped vehicles pass in the vicinity of a RSU location, each equipped vehicle downloads its stored data the Operational Data Environment (ODE). Here, the data shown in Table 4 is extracted from the BSM and then passed to the Pikalert® system, where it is fused with weather and road condition information from other sources to generate a roadway hazard assessment. The results of this road hazard assessment process form the foundation of the various WYDOT traffic management applications to generate alerts and messages about the roadway operating conditions. When a new road hazard is detected, the TMC operator is notified. Once the hazard alert has been verified by the operator, the hazard alert is then passed to the Data Broker. The Data Broker is responsible for processing all incoming warnings and messages provided by these data sources, notifying the TMC operators of new warnings and alerts, determining the affected area, and generating TIMs to be broadcast through the different applications, including CV.



NOTE: Vehicle CANBus integration is no longer part of this Pilot.

Source: Wyoming Department of Transportation, 2020.

Figure 10. Diagram. Data Flow for CV Data into WYDOT's I2V Situational Awareness Application. [5]

Table 4. Weather Elements Added by CV into WYDOT's Situational Awareness Application [5]

Data Name	Type	Units	Description
Air Temperature	Float	Degree Celsius	Observed air temperature
Surface Temperature	Float	Degree Celsius	Observed surface temperature
Humidity	Float	Percent	Observed relative humidity
Wiper Speed	Float	Hertz	Number of swipes of wipers across windshield per unit time
Stability	Integer	NA	If available via BSM, the Anti-lock braking system, traction, or stability control status of the vehicle
Speed	Float	Meters per second	Vehicle speed
Yaw Rate	Float	Degrees per second	If available via BSM, the rate of change of vehicle yaw
Headlights	Integer	NA	If available via BSM, the on/off status of vehicle headlights, parking lights, and fog lights.
Heading	Flat	Degree	If available, vehicle's heading.

Source: Wyoming Department of Transportation, 2020.

One purpose of the Wyoming CVPD was to demonstrate the value of adding CV data to help improve WYDOT's situational awareness of travel conditions in the deployment corridor. The CV data can help fill in some of the gaps between roadway segments, giving operators better insight into the operational status of segments of roadway where data currently doesn't exist. WYDOT could potentially increase the number of roadway segments receiving updated road status information each time a CV vehicle uses the corridor.

For this analysis, the Wyoming CVPD Team identified 499 weather events from January 2021 to April 2022. The Wyoming CVPD Team divided the deployment corridor into a total of 64 reporting sections (32 reporting sections in each direction of travel). The Wyoming CVPD Team extracted the number of reporting sections from the raw data for each storm event. The number of events ranged from a low of 2 sections for a strong wind event to a high of all 64 sections for several corridor-wide events. [3]

The Wyoming CVPD Team also extracted the hours associated with each weather event. The hours per weather event logged were based on when the TMC received a report and not the total number of hours the event took place (start and end dates/times). The Wyoming CVPD Team recorded events ranging in duration from 1 hour for a strong wind event to 293 hours for a major winter storm in February 2021. [3]

The WYDOT TMC collects and stores all field maintenance reported road conditions by day/time and location. During inclement weather conditions, WYDOT's operating procedure is for maintenance personnel to report road conditions for each maintenance section every 2 hours or when conditions change. [3,8] The pre-deployment baselining indicated that maintenance personnel average about 4.3 reports per section per day during incident weather. WYDOT speculated that is value was lower than expected because, in many cases, maintenance personnel did not always feel that a report was needed because conditions had not changed. Part of WYDOT's CVPD was to equip maintenance vehicles with technology to allow drivers to report road condition information (and other issues) more easily during winter weather conditions. WYDOT's expected that the quantity of road conditions reports, and the coverage area of the reports would increase during the CVPD. WYDOT also expected that latency of reports would decrease because of the deployment.

Improved Quantity of Road Condition Reports

To assess the extent to which the deployment impacted the quantity of road condition reports, the Wyoming CVPD Team used the number of road condition reports. Changes in the number of road condition reports received per section per day is a measure of the extent to which equipped vehicles provided WYDOT with more information about travel conditions on I-80. As all maintenance dispatching occurs out of WYDOT's TMC, higher number of roadway conditions reports received per section per day would imply that WYDOT operators had more timely and frequent information on which to issue alerts and warnings.

Table 5 shows a comparison of the average number of road condition reports per section per day during moderate and severe weather events from post-deployment periods and the baseline. The table shows that the number of road condition reports per section per day increased dramatically during the post-deployment period. (3) For example, the average number of reports per section per day increased from 4.3 condition reports in the baseline to 16.9 in the post-deployment periods, an increase of 12.6 reports per section per day. Table 5 also shows that the minimum number of reports per section per day increased from 1.4 in the baseline period to 7.2 in the post-deployment, an increase of 5.8 reports per section per day. The maximum number of reports per section per day also increased from 12.0 in the baseline period to 27.9 reports per section per day, an increase of 15.9 reports per section per day. These values represent significant increases in the number of road condition reports coming into the TMC for use in generating alerts and warnings disseminated through WYDOT's systems.

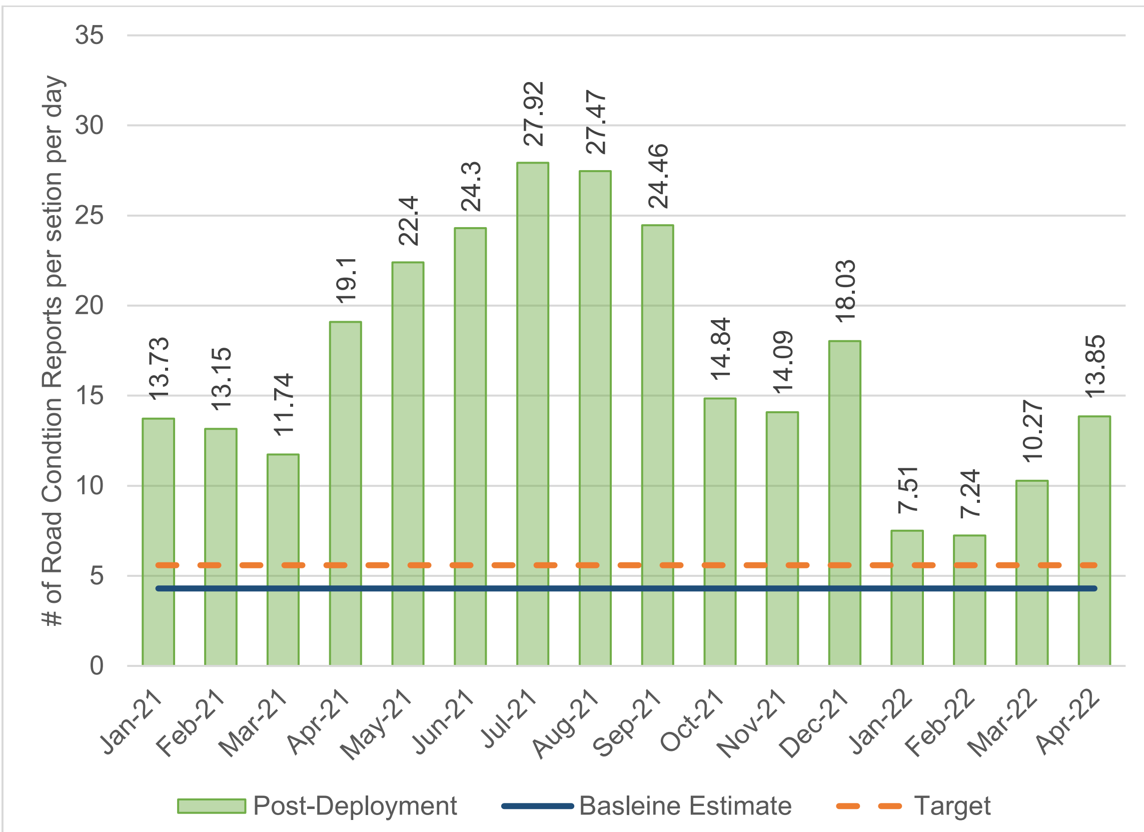
Figure 11 shows the average number of road condition reports per section per day by month in the post-deployment periods. This number shows a substantial number of road condition reports per section per day during the summer months. The Wyoming CVPD Team indicated that the large number of reports during the summer months was because there were fewer major weather events that closed the entire section of roadway during the summer months compared to the winter months. When the roadway is open, more vehicles can travel through the corridor providing reports.

Table 5. Comparison of the Number of Road Condition Reports Received at TMC Pre- and Post-Deployment.

Descriptive Statistic	Number of Road Condition Reports Received—Baseline*	Number of Road Condition Reports Received—Post-Deployment**	Change in the Number of Road Condition Reports Received	Percent Change
Mean	4.3	16.9	+12.6	+293.0
Median	3.6	14.5	+10.9	+302.8
Minimum	1.4	7.2	+5.8	414.3
Maximum	12.0	27.9	+15.9	+132.5

*December 2016 through November 2017. *Reference (8)* ** January 2021 through April 2022. *Reference (3)*

Source: Texas A&M Transportation Institute, 2022.



Source: Wyoming Department of Transportation, 2022.

Figure 11. Graph. Number of Road Condition Reports per Section per Event in the Post-Deployment Period. (3)

It should be noted that the number of road condition report per section per event exceeded the pre-deployment average (4.3 reports per section) and the deployment target (5.3 reports per section) in every month.

Increased Coverage by Road Condition Reports

To assess the extent to which the CVPD increased the coverage of road conditions network, the Wyoming CVPD Team examined the number of road sections that had at least one report per hour during significant weather events. The Wyoming CVPD Team expected the number of sections of I-80 with at least one road condition report per hour to increase substantially through the deployment of CV technology such as snowplow tablets transmitting road reports. (9) Also, because CV-equipped vehicles measure and transmit data about roadway conditions they experience, WYDOT fuses this data with other sensor data to gain a clearer understanding of the existing travel conditions in the corridor. WYDOT's rationale for looking at this performance measure was that CV technologies allowed it to obtain reports about road conditions from more sections of the roadway as vehicles traversed I-80. Without the CV technologies, WYDOT must rely on widely spaced road weather sensors or other reporting mechanisms that may not provide the same level of granularity of information as the CV technology. Using CV technologies would minimize the dependence on maintenance vehicles to traverse the network to generate a road condition report. More road sections having at least one report per hour means that the CV vehicles were able to provide more road conditions coverage in the corridor. (3)

Table 6 shows a comparison of the number of road segments with at least one road condition report per hour. The table shows that by integrating CV technologies into its system, WYDOT was able to expand its ability to monitor road conditions on its network. In the post-deployment period, WYDOT increased the number of roadway sections that had at least one condition reports per hour up from 5.4 sections in the baseline period to 6.4 sections in the post-deployment period. (3).

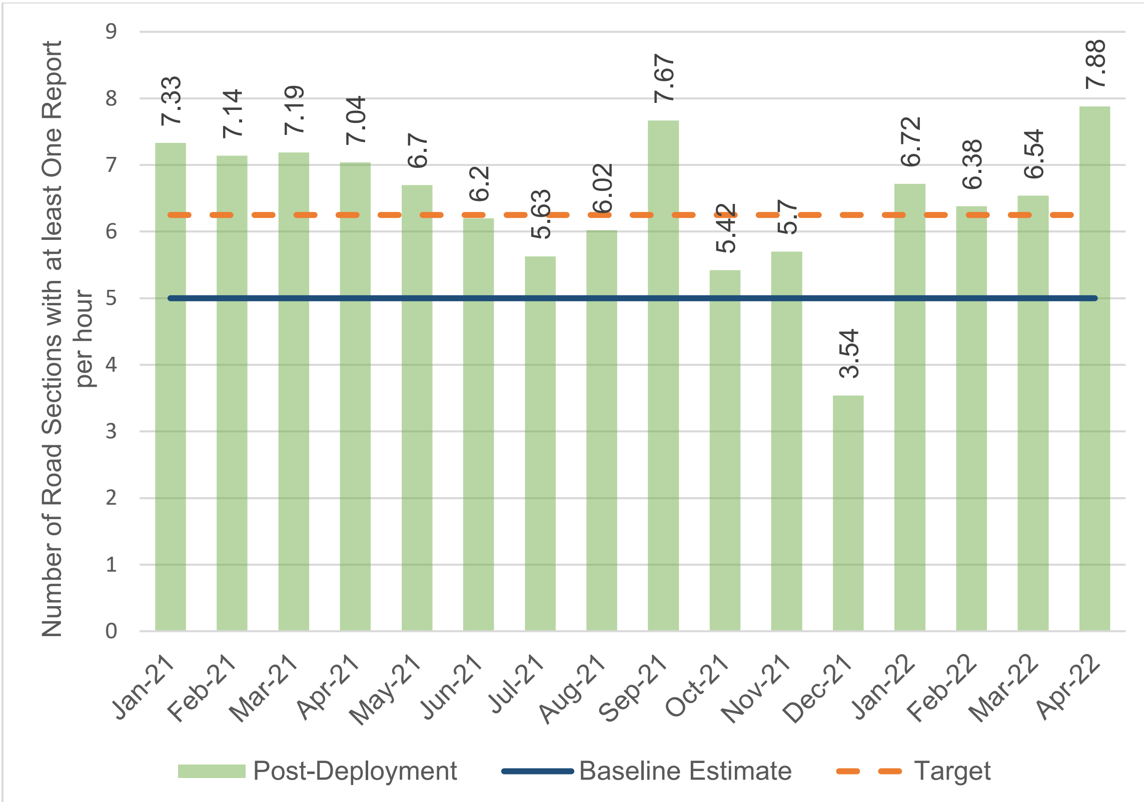
Table 6. Comparison of Number of Sections with Least One Report per Hour Pre- and Post-Deployment.

Descriptive Statistic	Baseline*	Post-Deployment**	Change	Percent Change
Mean	5.0	6.4	+1.4	+25.9
Median	4.5	6.6	+2.1	+46.7
Minimum	1.4	3.5	+1.9	+135.7
Maximum	10.5	7.8	−2.7	-25.7

*December 2016 through November 2017. Reference (8) ** January 2021 through April 2022. Reference (3)

Source: Texas A&M Transportation Institute, 2022.

Figure 12 shows the average number of road sections receiving at least one road condition report per hour for each month in the post-deployment period. The figure shows that during most month, the number of sections having at least one report per hour was above the baseline mean and WYDOT's performance targets. During the both winter seasons, the I-80 corridor experienced severe weather storms which lasted for couple days. The Wyoming CVPD Team speculated that these storms caused road closures that impacted the number of CVs that operated within the corridor and, therefore, increasing the average refresh time of road reports. (3)



Source: Wyoming Department of Transportation, 2022.

Figure 12. Graph. Average Number of Road Sections Receiving At Least One Road Condition Report per Event. [3]

Reduced Latency Between Road Condition Reports

Timeliness of information is critical in managing traffic operations during weather events. TMC operators and maintenance personnel need timely information to ensure their responses are appropriate and to properly allocated resources and personnel. In deploying the CV technology, WYDOT expected to improve the timeliness of their information by reducing the time lag (or latency) between road conditions updates.

To assess the extent to which the CVPD reduce information latency, the Wyoming CVPD Team examined the average refresh time. Average refresh time is the amount of time that elapses between vehicle-based road condition reports. Less time between road condition reports means that TMC operators have more frequent updates from vehicles that have traversed a section. A reduction in refresh time would indicate a positive public agency efficiency impact. Wyoming DOT's goal is for road condition reports in each section to be updated (refreshed) when conditions change. Currently, this is accomplished by DOT maintenance personnel as they are plowing and treating the roadways. During the CV Pilot those data will be enhanced with better equipped snowplows with road reporting tablets. [9]

Table 7 provides a comparison of the average refresh time between road condition reports per section from the post-deployment period to the baseline period. The table shows that on average, the time between road segment reports decreased from just under four hours in the baseline condition to just over three hours in the post-deployment conditions. [3] This meant that TMC operators were able get information about changing travel conditions quicker. This reduction in update time allowed operators to be more responsive to changing operational conditions.

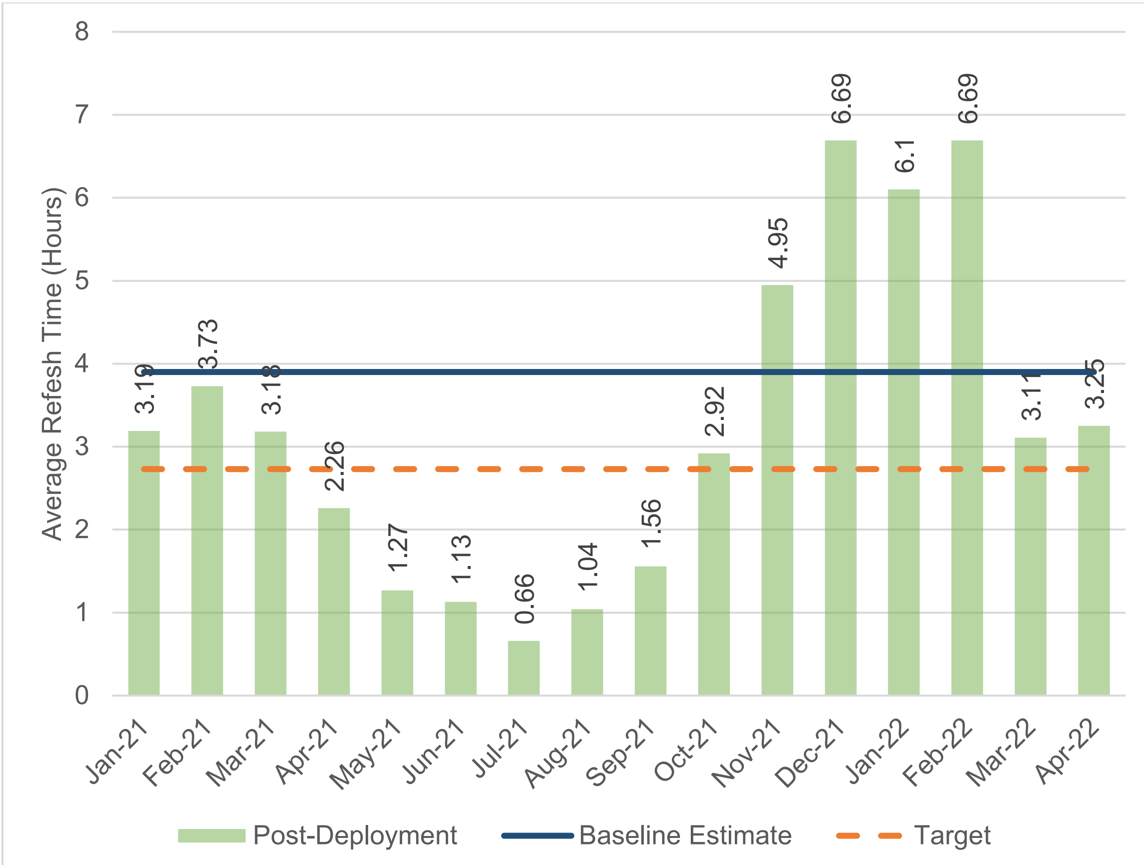
Table 7. Comparison of Road Conditions Reports Latencies Pre-and Post-Deployment.

Descriptive Statistics	Time between Road Condition Updates Baseline* (Hours)	Time between Road Condition Updates Post-Deployment** (Hours)	Change in Time between Road Conditions Report (Hours)	Percent Change
Mean	3.9	3.2	−0.7	-17.9
Median	3.7	3.1	−0.6	-16.2
Minimum	0.7	0.7	0	0
Maximum	7.8	6.7	−1.1	-14.1

*December 2016 through November 2017. *Reference (8)* ** January 2021 through April 2022. Reference *(3)*

Source: Texas A&M Transportation Institute, 2022.

Figure 13 shows the average time between road condition reports after implementing the system. The average time between road section updates during severe weather conditions was higher during the winter months. The Wyoming CVPD Team attributed this increase in time between reports to the frequency and severity of winter storms during these months keeping traffic from using I-80.[3] The Wyoming CVPD Team reported that the I-80 corridor experienced several significant severe weather storms that caused I-80 to be closed over multiple days. These road closures impacted the number of CVs that operated within the corridor, increasing the time between updates. [3]



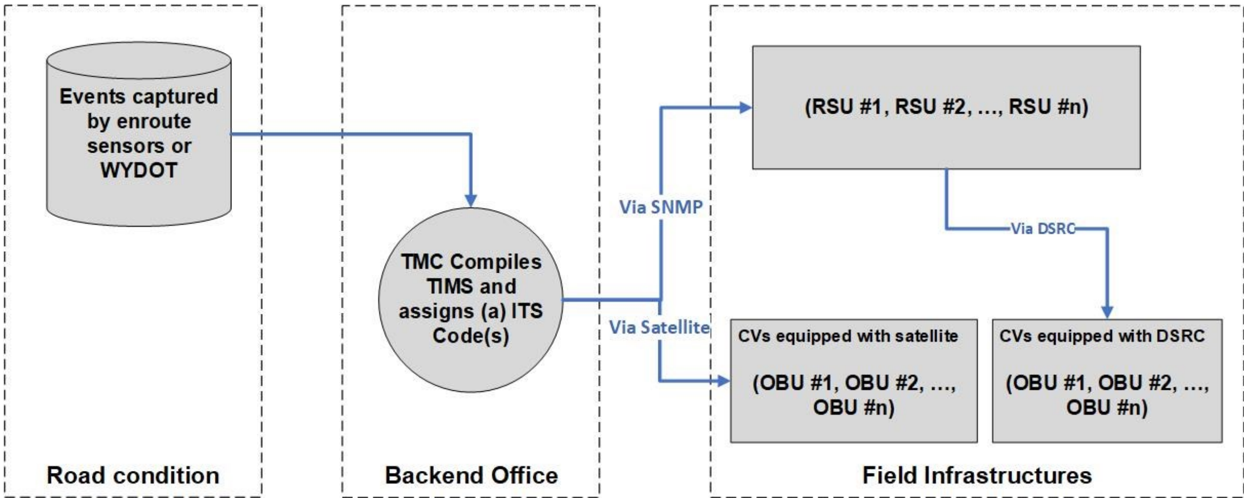
Source: Wyoming Department of Transportation, 2022.

Figure 13. Graph. Average Time between Road Condition Updates (Hours) per Segment by Month in the Post-Deployment Period. [(3)]

Enhanced Information Dissemination

In this deployment, WYDOT disseminated information about road condition reports through TIMs. TIMs disseminate different types of message content by using a collection of Integrated Taxonomic Information System (ITIS) codes. Each ITIS code conveys a standard phrase or specific content.[(3)] For more information on the development TIMs, the reader should consult the Society of Automobile Engineers' *V2X Communications Message Set Dictionary.*[(10)]

Figure 14 shows the process the Wyoming CVPD used to generate TIMs. The Wyoming CVPD used two means of disseminating roadway conditions alerts to CV: the first being through a DSRC connection via an RSU and the second via satellite transmission. For the Wyoming CVPD, all CVs were equipped to receive TIMs through both satellite and DSRC communications. [(3)] Each vehicle received TIM alerts, when it passed an RSU. They also received TIMs at any time when they could connect with a satellite.



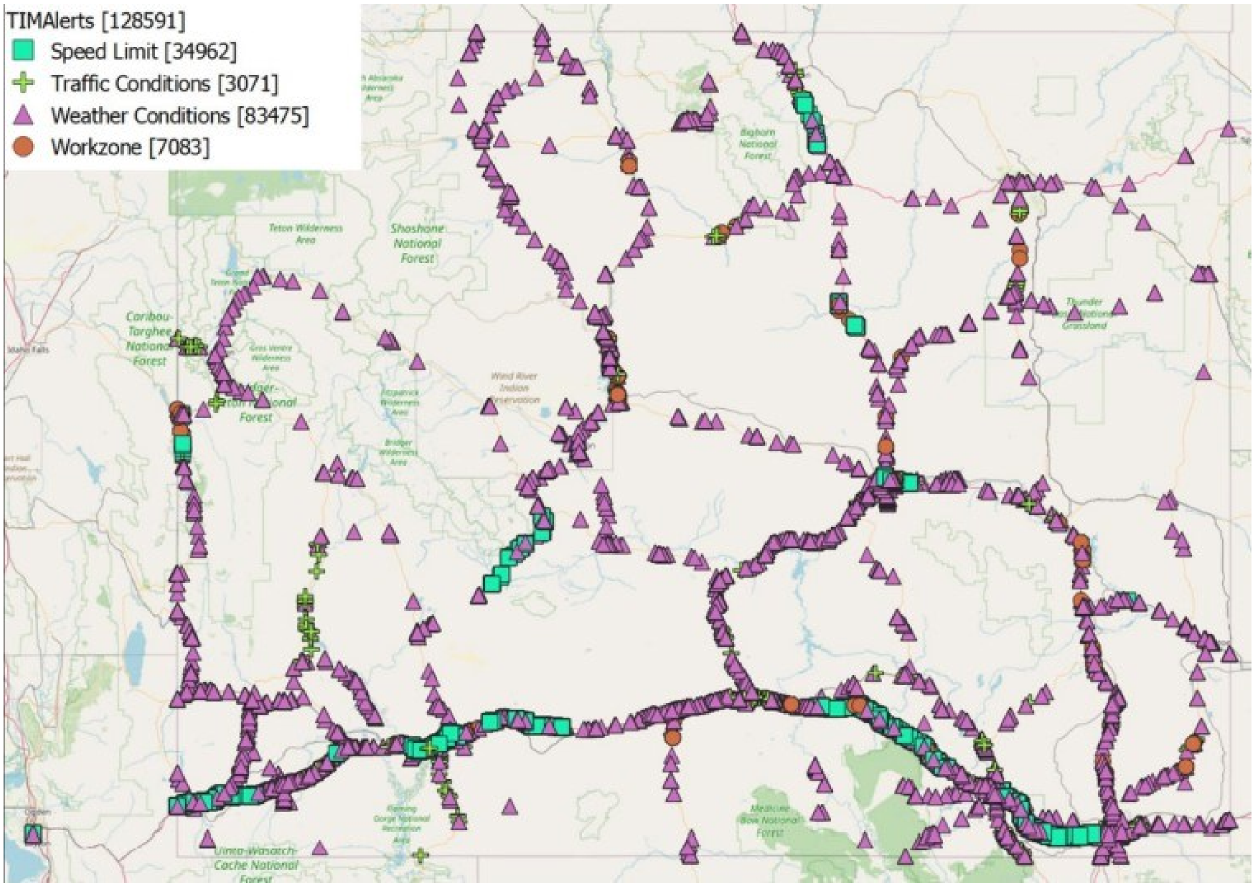
Source: Wyoming Department of Transportation, 2022.

Figure 14. Diagram. Process for Generating TIMs in Wyoming CVPD. [3]

The Wyoming CVPD Team hypothesized that deploying CV technologies would enhance WYDOT's ability to disseminate traveler information and road condition reports to equipped vehicles in the corridor. In the deployment, the Wyoming CVPD Team equipped all fleet vehicles with the ability to receive TIMs from both RSUs (via DSCR) and satellite communications. This was accomplished using a dual mode OBU capable of receiving and processing transmitted message via both DSRC and satellite communications simultaneously. Data collected by the Wyoming CVPD Team revealed that both means of disseminating messages were essential equivalent. [3]

The Wyoming CVPD Team collected anecdotal information about how quickly alerts and warning could reach equipped vehicles. [3] The Wyoming CVPD Team provided a case study assessment using a head-on collision that closed all lanes in both directions for nearly 3 hours. Operators in the TMC were first notified of the collision at approximately 3:25 pm. Within a minute of the TMC receiving its first report, the RSU closest to the incident began broadcasting TIM alerts about the incident instructing travelers in the area to be prepared to stop. The intent of this message was to prevent subsequent multi-vehicle chain reaction collisions associated with the first crash. As the event continued, additional TIMs were broadcasted to keep travelers informed of the changing road conditions, as different lanes and directions were reopened. While the number of equipped vehicles entering the collision area was low, the analysis did show that vehicles were able to receive correct information about the incidents as far as 5-miles away from the incident location. The case study showed that the Situational Awareness application generated over 52 speed limit alerts, 531 incident alerts, and 7186 "prepare to stop" alerts associated with this single incident. [3]

Using satellite as a means of disseminating TIMs to CVs has allowed WYDOT to extend their ability to reach CVs outside I-80 deployment corridor as well. [3] Because satellite communications allow TIMs to flow to CV anywhere there is satellite coverage (as opposed to requiring a vehicle to pass in vicinity of an RSU to receive TIM alerts), WYDOT retooled the original design of the application to allow CVs to receive TIM alerts and warning on any state or federal roadway throughout the entire State. This retooling involved switching the original applications to a Geographic Information System (GIS) platform. This allows WYDOT to generate targeted alerts and information for equipped vehicles located in specific geofenced areas. WYDOT also had to standardize their route naming convention used by different branch of WYDOT. As a result of these changes, WYDOT can now push out target alerts and information to any equipped vehicles on any state or federal highway throughout the state. Figure 15 shows the locations of all the TIM alerts that equipped vehicles received from January through April 2022.



Base maps for the figures above curtesy of the Open Street Maps project (© OpenStreetMap contributors).
Copyright information available at https://www.openstreetmap.org/copyright,

Source: Volpe Transportation National Transportation Systems Center, 2022

Figure 15. Map. Geographic Locations of All TIM Alerts Received by CVs from January through April 2022. [11]

As a byproduct of the deployment, WYDOT was also able to use the data structures and information exchanges developed to support to the deployment for other purposes as well. [3] At the suggestion of WYDOT, one of the deployment stakeholders developed a Traveler Information Alexa Skill. The Skill queries the Situational Data Exchange (SDX) to extract road conditions for and produce alert messages. The Skill can also provide drivers with road conditions information from their current locations to their destination city. The Skill queries the SDX for all TIM messages contained along the existing route to the drivers destination. Results are then filtered for relevant results and read back to the user.

Chapter 4. Summary of Findings and Conclusions

Two of the primary objectives of the Wyoming CVPD were to (a) improve road weather reports received by the TMC and (b) improve the ability of the TMC to generate alerts and advisories.

WYDOT hypothesized that the quantity of road reports and the coverage would increase during the CVPD and that the latency between reports would decrease. Using records for 499 weather events from January 2021 to April 2022, the Wyoming CVPD Team examined the extent to which the CVPD improved the quality, coverage, and timeliness of road condition reports during the deployment. The following is a summary of their findings:

- The quantity of road condition reports coming into the TMC increased from 4.3 reports per section of I-80 per day during weather events in the baseline conditions to 16.9 reports per section per day in the post-deployment period. An increase in the number of road condition reports will allow WYDOT operators to be more responsive to changing travel conditions.
- The CVPD improved WYDOT's coverage of road conditions reports in the deployment corridor. The average number of road sections that had at least one road condition report per hour during weather event increased from 5.0 in the baseline condition to 6.4 in the post-deployment period. Increasing the coverage of the network using CV technologies would reduce the dependency of using maintenance vehicles to traverse the segment to generate road condition reports. This means that with higher market penetrations, WYDOT would be able to detect more quickly when road conditions were beginning to deteriorate or improve.
- The latency, express as average refresh time in hours, between road condition reports per section during weather events dropped from 3.9 hours to 3.2 hours. Reducing the frequency between updates helps TMC operators better match traffic management strategies to changing operational and weather conditions.

The data generated by the Wyoming CVPD vehicles became an additional source information for WYDOT's existing traffic management system, which uses travel condition and road weather information from multiple sources to assist TMC operators manage WYDOT's traffic management assets (VSL signs, DMS, road closure gates, etc.). Having better quality, quantity, and timeliness of road condition information allowed TMCs operators to better manage those traffic management assets through the following:

- Increasing the accuracy and quality of road condition information that TMC operators could use to adjust VSL and other traffic management assets in response to changing weather conditions.
- Expanding the coverage in the network where information is available to make real-time adjustments to traffic management strategies.
- Reducing the time lag between status updates on travel conditions on the roadway network.

- Increasing the frequency of updates to DMS and other traveler information system messaging to reflect evolving travel conditions during significant weather events.
- Sending targeted weather alert messages to vehicle entering specific segments of the deployment corridor.
- Directing maintenance resources to locations requiring attention.
- Enhancing the credibility of WYDOT's weather-related messaging by ensuring that messaging reflects the conditions observed by drivers.

WYDOT also hypothesized that CV technologies would improve its ability to disseminate changing road condition information. In the deployment, all the equipped vehicles had the ability to receive traveler information message (TIMs) alerts and warnings via both Dedicated Short-Range Communications (DSRC) and satellite communications. Both technologies were shown to have comparable performance in disseminating alerts and warnings to equipped vehicles.

As a results of the deployment, WYDOT has expanded its ability to provide traveler information not only in the corridor, but throughout the state. Using the data structures, data exchanges, and processes developed in the CVPD, WYDOT extended their ability to disseminate traveler information messages via satellite to include all state and federal highways throughout the state. WYDOT extended their information dissemination capabilities by developing an Alexa Skill that can also produce alerts and warnings using the data provided by WYDOT's Situational Awareness applications.

References

1. Wyoming Department of Transportation Connected Vehicle Pilot Website. Wyoming Department of Transportation. Available at https://wydotcvp.wyoroad.info/. Accessed November 19, 2021.
2. Connected Vehicle Pilot Deployment. Program Overview. U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office. Available at https://www.its.dot.gov/pilots/overview.htm. Accessed June 5, 2022.
3. Garcia, V., N Ureña Serulle, K. Kelarestaghi, R. Young, D. Gopalakrishna, T. English, S. Zumpf, and M. Ahmed. *Connected Vehicle Pilot Deployment Program Phase 3. Final System Performance Measurement and Evaluation—WYDOT Connected Vehicle Pilot.* U.S. Department of Transportation, ITS Joint Program Office. Washington, DC. March 21, 2022. (Draft)
4. English, T., N Ureña Serulle, D. Stephens, D. Gopalakrishna, V. Garcia, and R. Ostroff. *Connected Vehicle Pilot Deployment Program: Phase 2 System Architecture Document—WYDOT CV Pilot.* FHWA-JPO-17-467. U.S. Department of Transportation, ITS Joint Program Office. Washington, DC. May 2018. Available at https://rosap.ntl.bts.gov/view/dot/36649. Accessed May 11, 2022.
5. Zumpf, S., T. English, D. Stephens, D. Gopalakrishna, N Ureña Serulle, V. Garcia, and R. Ostroff. *Connected Vehicle Pilot Deployment Program, System Design Document—Wyoming*. FHWA-JPO-17-468. U.S. Department of Transportation, ITS Joint Program Office. Washington, DC. As Built July 27, 2020. Available at https://rosap.ntl.bts.gov/view/dot/36241. Accessed May 11, 2022.
6. CV Device Deployment Status. Connected Vehicle Pilot Deployment Program. Intelligent Transportation Systems Joint Program Office. U.S. Department of Transportation. Available at https://its.dot.gov/pilots/status.htm. Accessed November 16, 2021.
7. On-Board System Requirements for V2V Safety Communications. J2945/1_201603. Society of Automotive Engineers. Available at https://www.sae.org/standards/content/j2945/1_201603/. Accessed May 11, 2022.
8. Kitchener, F., R Yong, M. Ahmed, G. Yang, S. Gaweesh, T. English, V. Garcia, A. Ragan, N. Ureña Serulle, and D. Gopalakrishna. *Connected Vehicle Pilot Deployment Program Phase 2, Final System Performance Report, Baseline Condition—WYDOT CV Pilot*. FHWA-JPO-17-474. U.S. Department of Transportation, ITS Joint Program Office. Washington, DC. Revised July 2018. Available at https://rosap.ntl.bts.gov/view/dot/36646. Accessed May 11, 2022.
9. Kitchener, F., R. Young, M Ahmed, G. Yang, S. Gaweesh, D Gopalakrishna, V. Garcia, A. Ragan, T. English, S. Zumpf, N. Ureña Serulle, and E. Hsu. *Connected Vehicle Pilot Deployment Program Phase 2, Performance Measurement and Evaluation Support Plan—ICF/Wyoming.* FHWA-JPO-16-290. U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office. Washington, DC. June 2016. Available at https://rosap.ntl.bts.gov/view/dot/31400. Last accessed June 20, 2022.
10. V2X Communications Message Set Dictionary. J2735_202007. Society of Automotive Engineers. 2020. Available at https://www.sae.org/standards/content/j2735_202007. Accessed May 11, 2022.

11. Chupp, W. A. Lam, and W. Najm. *Connected Vehicle Pilot Deployment Program Limited Analysis of the Wyoming Department of Transportation Connected Vehicle Pilot Safety Applications*. U.S. Department of Transportation, Volpe National Transportation Center. June 2022.

U.S. Department of Transportation
ITS Joint Program Office – HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free “Help Line” 866-367-7487

www.its.dot.gov

FHWA–JPO–22–950

U.S. Department of Transportation