Connected Vehicle Pilot Deployment Program Independent Evaluation

Mobility Impact Assessment—Wyoming

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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 conducted a qualitative assessment of the mobility impacts of the deployment. There was little evidence to suggest that the deployment had any direct or indirect impact on mobility; however, this finding was expected because the primary focus of the deployment was on improving safety and information dissemination during severe weather events.

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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:(2)

- Deploying around 76 roadside units that could receive and broadcast messages using dedicated short-range communications 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 capable of receiving alerts and broadcasting 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 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 transportation management center 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 (511, dynamic message signs, and others).

Based on the data available at the time this report was prepared, there is no conclusive evidence to indicate the Wyoming CVPD had any impact on mobility on I-80, either directly or indirectly. There is little evidence to support that the Wyoming CVPD impacted speed compliance with the posted speed limit or speed variability. There are also insufficient data to suggest the CVs complied any better with posted speed limits. Case study analysis did indicate that under certain situations, drivers of CVs took appropriate action after receiving alerts, but because no data were available from a control group, it is impossible to conclude that the action the drivers took was a direct response to receiving the alert as opposed to their normal reactions to the circumstances. However, none of this was unexpected by the Wyoming CVPD Team or the Texas A&M Transportation Institute Evaluation Team for the following reasons:

- The focus of the deployment was on improving safety and demonstrating the feasibility and applicability of using CV technology to improve information dissemination during severe weather events. In most cases, the weather itself was responsible for the degradation in mobility, and WYDOT's emphasis is preventing collisions during these situations.

- The level of market penetration was extremely low (325 vehicles were equipped with CV technologies)—almost half of which were “friendly” fleet partners such as WYDOT snowplows, maintenance vehicles, and highway patrol vehicles. During severe weather conditions, the mission of these vehicles is to ensure the safety of other travelers, not optimizing their mobility.

The Wyoming CVPD was successful, however, at demonstrating how data from CV technologies can be integrated with other WYDOT systems to improve situational awareness. These successes are discussed in WYDOT’s *Connected Vehicle Pilot Deployment Program Phase 3: Final System Performance Measurement and Evaluation—WYDOT Connected Vehicle Pilot*. [(2)]

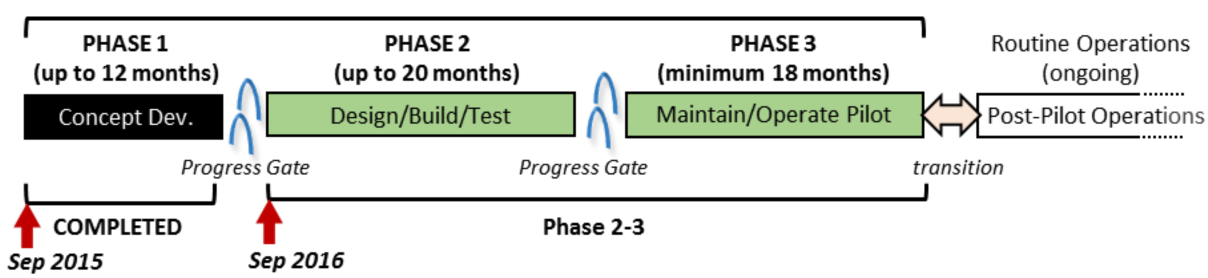
Another key success of the project was demonstrating the value of using satellite communications for disseminating traveler information. Through the CVPD, WYDOT was able to develop a partnership with a major vehicle satellite communication provider. After resolving several technical issues, WYDOT made it possible for CV drivers to receive traveler information messages while traveling on any State or Federal highway instead of just I-80. This function has allowed WYDOT to gather additional interest from fleet partners to receive weather and travel alert messages statewide.

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. 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:[3]

- 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. [4] 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 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. (1)

At a high level, the scope of deployment included implementing the following:(2)

- 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 broadcasting 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 the 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 mobility impacts assessment (MIA) 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 sites.
- The Volpe National Transportation Systems Center's safety impact assessments.
- Site-generated dashboards and lessons-learned logbooks.

This report focuses solely on the MIA associated with the deployment. Other reports have been produced to summarize the independent evaluation of the safety, environmental, and public agency efficiency 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, 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 direct and indirect impacts of the deployment on mobility in the I-80 corridor, based on the data provided by the Wyoming CVPD Team.
- Chapter 4 summarizes the key successes and lessons learned 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*. (5)
- *Connected Vehicle Pilot Deployment Program: System Design Document (SDD)—Wyoming CV* Pilot. (6)

Deployment Goals and Objectives

WYDOT's original objectives for the deployment were as follows:(2)

- Deploy and operate a set of vehicles equipped with OBUs 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 vehicles 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's Commercial Vehicle Operator Portal (CVOP).

Because of technical and deployment issues associated with using a DSRC-based OBU, WYDOT modified their deployment to use satellite-based OBUs for providing equipped vehicles with in-vehicle alerts from the WYDOT's TMC.

System Components

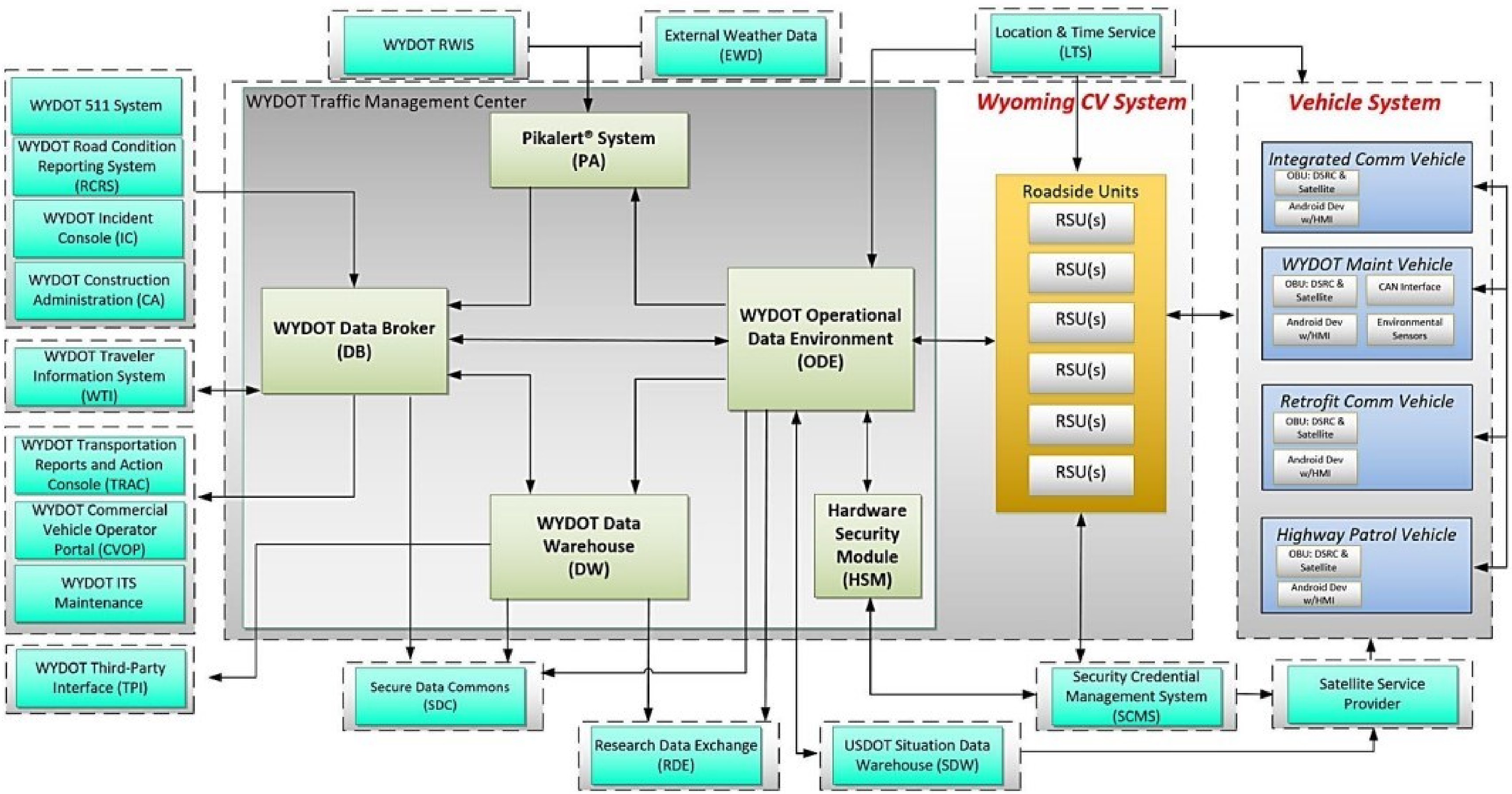
The Wyoming CVPD was comprised of both infrastructure and vehicle subsystems. Figure 2 provides an overview of the system architecture associated with deployment. Following is a brief description of the primary infrastructure and vehicle subsystems of the deployment.

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 provides a brief description of the components of the Wyoming CVPD infrastructure subsystems:[(2)]

- 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 locations where RSUs 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 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 an 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.



Source: Wyoming Department of Transportation, 2017

Figure 2. Diagram. System Architecture of Wyoming CVPD [5]

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 was provided through a private secure credential management system (SCMS) for application certificates.

Source: Wyoming Department of Transportation, 2021

Figure 3. Map. RSU Locations on I-80

Vehicle Subsystem

WYDOT divided the deployment fleet into two groups: friendly fleet vehicles and partner CV fleet vehicles. Friendly fleet vehicles were vehicles over which the Wyoming CVPD Team had more access and from which the team was able to collect identifiable information. Friendly fleet vehicles included WYDOT snowplows (WY), stakeholder fleet vehicles (TH), and WYDOT highway patrol vehicles (HP). Because these vehicles are public or informed partner fleets, the CVPD Team could track and collect detailed information from these vehicles. Partner CV fleet vehicles included all other vehicles, namely those from private stakeholders, which 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 [(4)]

Because of these complications and because of the Federal Communications Commission's decision to reallocate the DSRC 5.9-GHz spectrum, WYDOT's DSRC device 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 a combination DSRC- and satellite-based OBUs. With the combination OBUs, vehicles received inbound alerts while traveling anywhere in the corridor and still upload vehicle performance logs when they passed an RSU.

All equipped vehicles in the deployment had the following core capabilities:(2)

- The ability to broadcast and receive SAE J2735 Basic Safety Messages (BSs) via DSRC from other connected devices (vehicles and RSUs).
- The ability to receive alerts and traveler information messages (TIMs) from the infrastructure via both DSRC and satellite communications.
- A device (display screen) allowing drivers to disseminate alerts and advisories received by the vehicle while enroute.

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 drivers.

Table 2 provides a brief description of each of the deployment applications. More information about the design of the applications is available in *Connected Vehicle Pilot Deployment Program Phase 3: Final System Performance Measurement and Evaluation—WYDOT Connected Vehicle Pilot*. (2)

Table 2. Applications Included as Part of Wyoming CVPD [2]

Application	Description
FCW	Issues an alert if there is a threat of a front-end collision with another CV in the vehicle's travel lane and direction 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 parted on the side of the road or an adjacent lane along I-80. The application provides alerts to drivers of 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 an RSU and received by a CV.

Source: Wyoming Department of Transportation, 2017.

System Operations

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

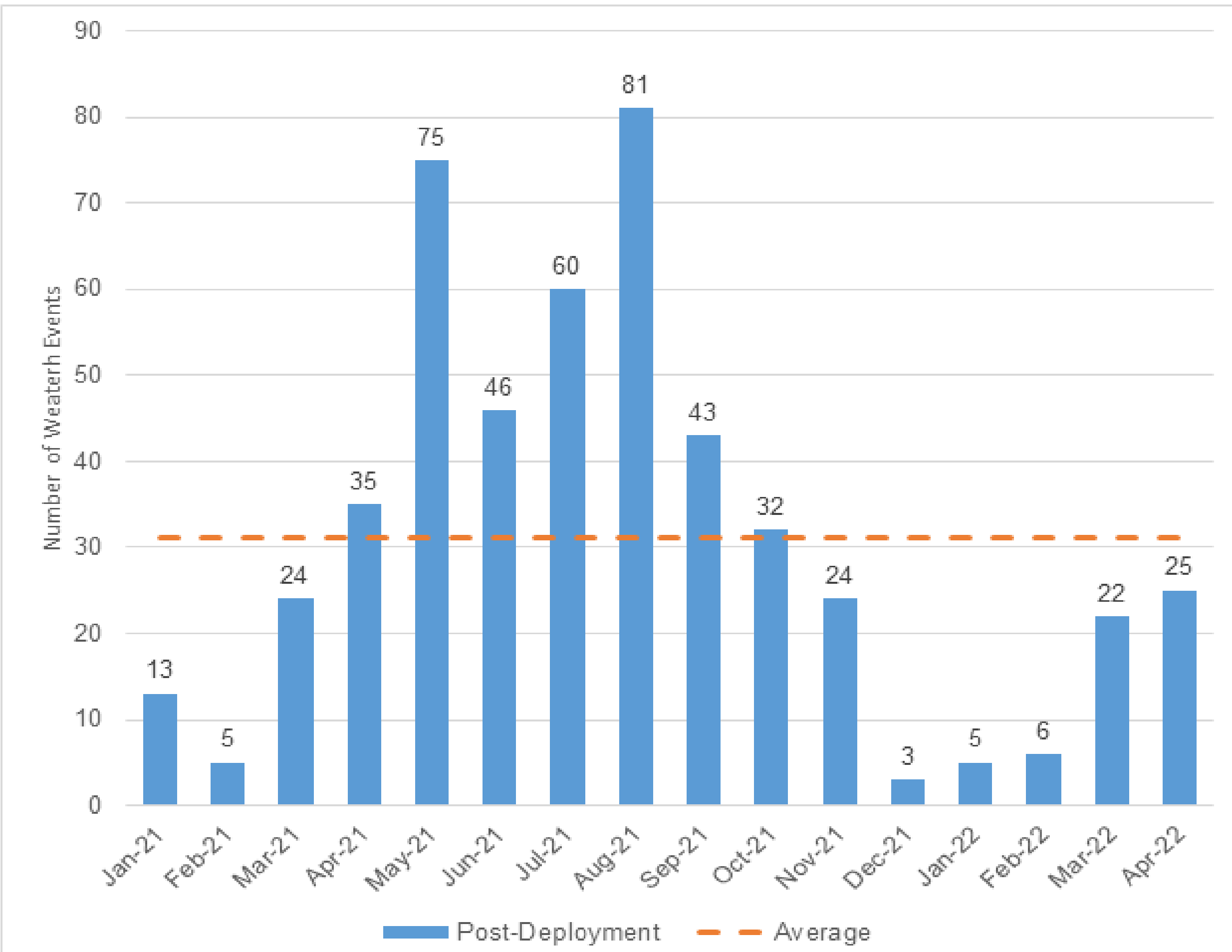
Baseline Conditions

The Wyoming CVPD Team collected pre-deployment data beginning in December 2016 through November 2017.[2] The purpose of this pre-deployment data collection effort was to create a baseline for 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.[2] The Wyoming CVPD Team reported 41 separate significant weather events on I-80 between December 2016 and May 2017.[2] 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 9 fatalities during these weather events.

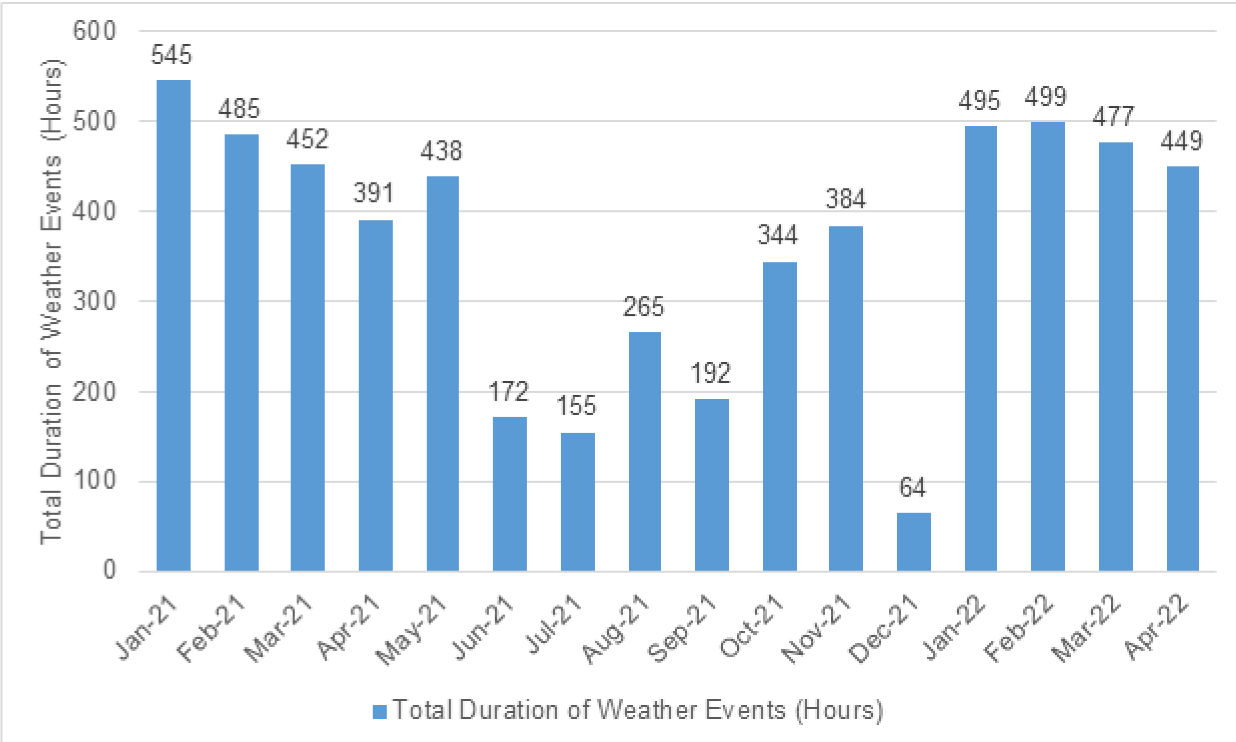
Post-Deployment Operations

The Wyoming CVPD entered the post-deployment evaluation phase (Phase 3) in January 2021 and collected performance data until April 2022.(2) During the post-deployment period, WYDOT reported a total of 499 severe weather events, lasting a total of 5,807 hours.(2) 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 5 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 short durations (between 2.5 hours 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 6 shows the average storm duration (in hours) per severe weather event. Figure 6 shows the average storm duration (in hours) per severe weather event.



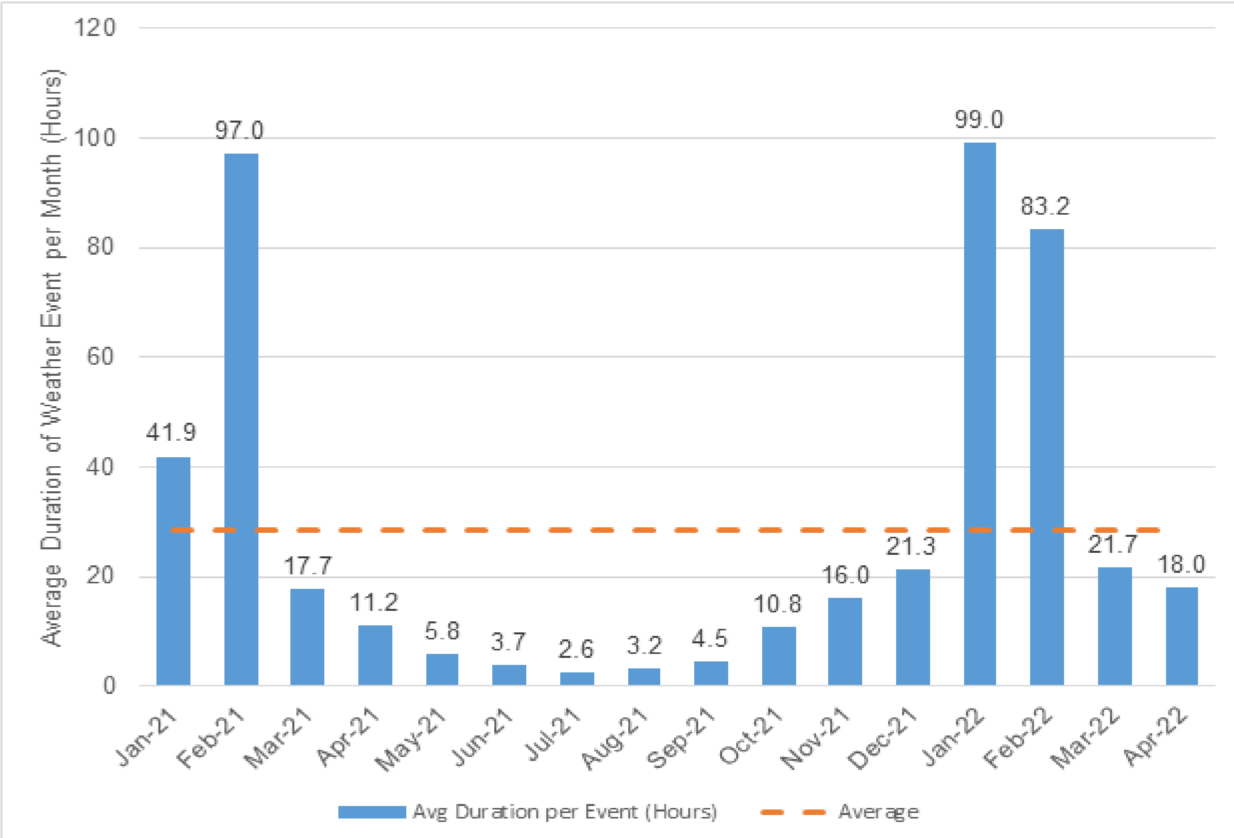
Source: Wyoming Department of Transportation, 2022

Figure 4. Chart. Number of Weather Events in I-80 Deployment Corridor—January 2021 through April 2022(2)



Source: Texas A&M Transportation Insitute based on data contained in Reference (2)

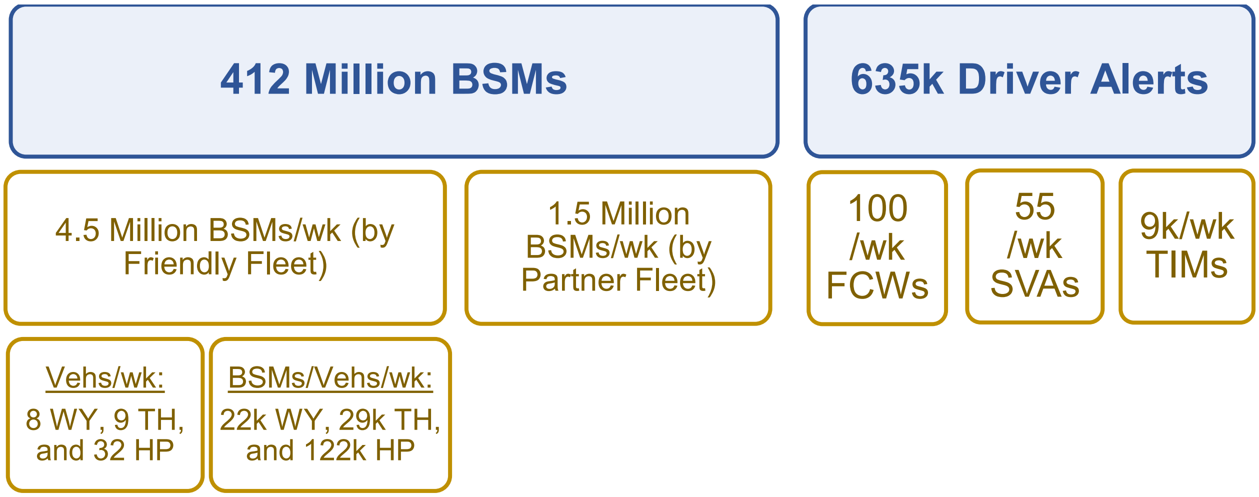
Figure 5. Bar Chart. Total Duration of Severe Weather Storms in I-80 Deployment Corridor.



Source: Wyoming Department of Transportation, 2022

Figure 6. Bar Chart. Average Duration of Severe Weather Storm in I-80 Deployment Corridor (2)

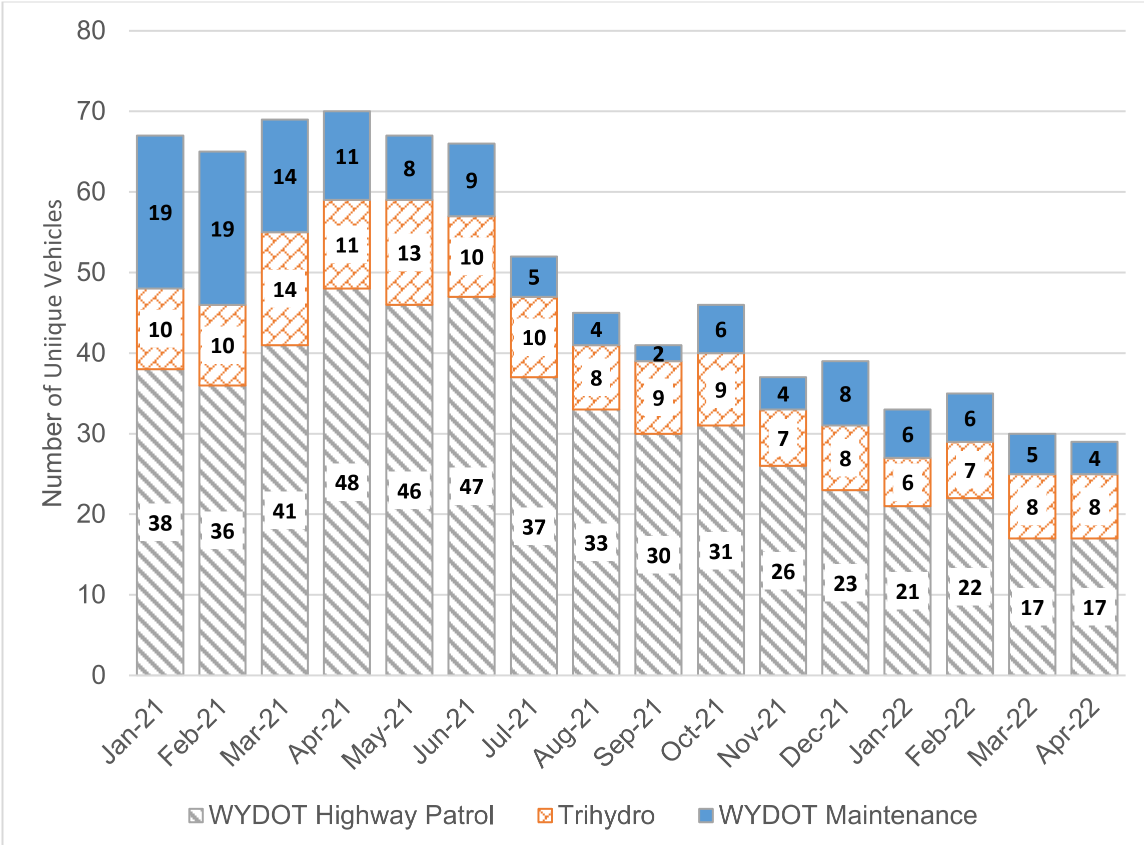
Figure 7 shows some basic operations statistics associated with CV operations in the I-80 corridor during the deployment periods. The Wyoming CVPD Team registered over 412 million BSMs and 635,000 driver alerts between January 1, 2021, and April 30, 2022.



Source: Wyoming Department of Transportation, 2022

Figure 7. Diagram. Summary of CV Operations in I-80 Deployment Corridor—January 2021 through April 2022[2]

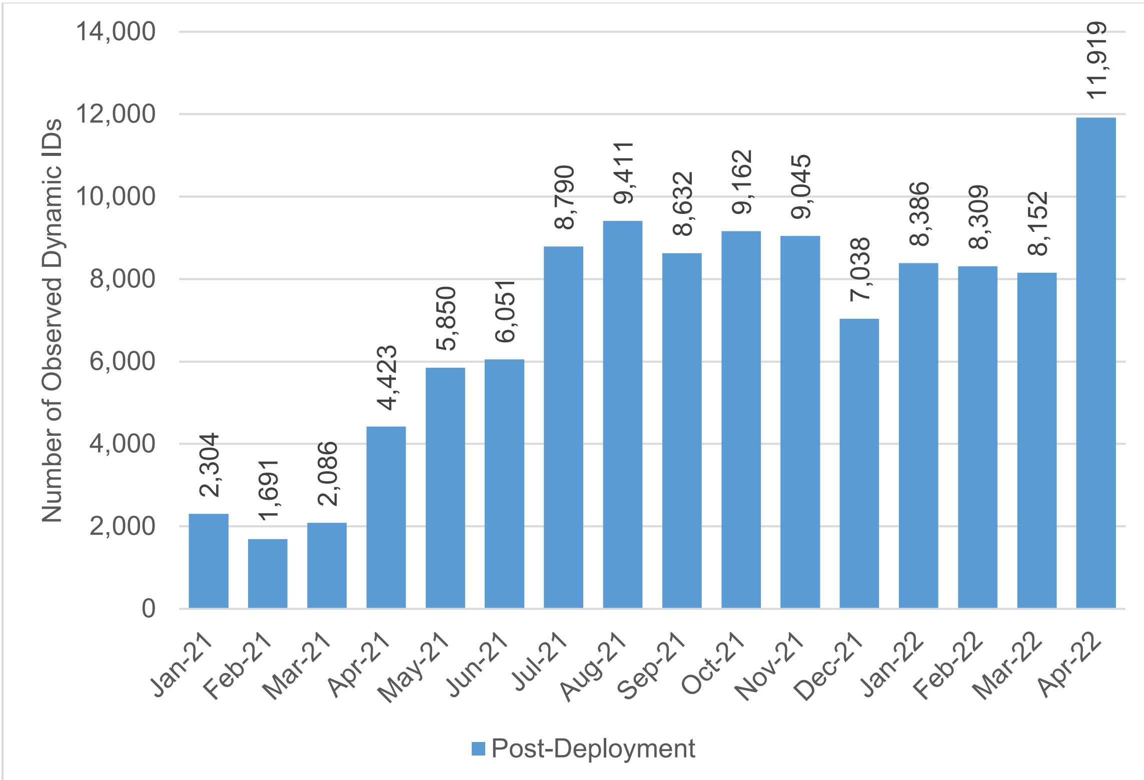
Figure 8 shows the number of friendly fleet CVs using the I-80 deployment corridor between January 2021 and April 2022. [1] On average, the Wyoming CVPD Team observed 50 unique friendly fleet vehicles per month traveling on I-80 throughout the post-deployment period. The Wyoming CVPD Team reported that most of these vehicles were Wyoming highway patrol vehicles. The monthly breakdown shows that most of the Friendly CVs were highway patrol vehicles with the minimum of 17 vehicles (in March and April 2022) and maximum of 48 vehicles in April 2021. The Wyoming CVPD reported significantly fewer WYDOT snowplows and stakeholder test vehicles during the same period, fluctuating between 2 and 20 vehicles per month.



Source: Wyoming Department of Transportation, 2022

Figure 8. Chart. Number of Observed Friendly Fleet Vehicles in I-80 Deployment Corridor—January 2021 through April 2022[(2)]

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 unique partner vehicles operating in the corridor between January 2021 and April 2022, but the figure shows the trend of an increase in the number of partner vehicles using the network during the first six months of the deployment (January 2021 through June 2021), and then becoming relatively constant to the end of the deployment (July 2021 through April 2022).



Source: Wyoming Department of Transportation

Figure 9. Chart. Number of Observed Partner Fleet Dynamic IDs in I-80 Deployment Corridor—January 2021 through April 2022[(2)]

Chapter 3. Mobility Impact Assessment

Table 3 shows the performance measures collected by the Wyoming CVPD Team. Even though the scope of the deployment focused on the "system's impact on accurate and timely reports on road weather condition, information dissemination, and safety,"(2) TTI conducted a qualitative assessment of the impacts of the deployment on mobility using these performance measures. Measures of mobility impacts were divided into two categories: direct and indirect. Direct performance measures are a direct quantification of how the deployment reduced congestion or improved mobility. Examples of direct measures of mobility include items such as travel times, travel speeds, travel time reliability, etc. Indirect measures of mobility include performance measures, which might contribute indirectly to less congestion and improved mobility (e.g., reduction in crashes or crash rates). The following reports the results of this qualitative assessment.

Table 3. Performance Measures Collected by Wyoming CVPD Team (2)

Deployment Objective	Performance Measure
Road weather condition reporting	• Number of road condition reports • Number of road sections with at least one report • Average refresh time of road reports
Information dissemination	• Percentage of TIMs received by at least one RSU • Percentage of TIMs received by at least one OBU on I-80 through satellite • Percentage of TIMs received by at least one friendly vehicle from RSUs • Percentage of TIMs received by at least one OBU, through either satellite or RSU
Safety outcomes	• Total vehicles traveling at no more than 5 mph over the posted speed • Total vehicle traveling within +/–10 mph of the posted speed • CV speed compliance compared to non-CVs • CV-involved initial or secondary crashes • Reduction of total and truck crash rates within a work zone area • Reduction of total and truck crash rates in the corridor • Reduction of critical total and truck crash rates in the corridor
CV driver behavior compliance	• CVs that likely took action following receipt of an alert • CVs that likely took action following receipt of a V2V alert

Source: Wyoming Department of Transportation, 2022

Assessment of Direct Mobility Impacts

WYDOT has deployed variable speed limits (VSL) on portions of I-80 to reduce speeds during adverse weather conditions. WYDOT expects the CV technology to lead to greater adherence to the posted speed limits due to increased awareness of the posted speed limits on their variable speed limit signs and to increase the uniformity of speeds in the deployment corridors. Improve speed compliance and uniformity is expected to help to reduce primary and secondary crashes during adverse weather conditions and congestion. [7] By implementing more uniform driver behavior and uniform speeds, drivers are less likely to drive erratically, reducing the likelihood of crashes. Furthermore, more uniform speeds and decreased headways and help traffic flows more smoothly and efficiently, which can improve trip travel time reliability. Reduced speeds can also help reduce the severity of incidents that might occur.

From the performance metrics supported by the Wyoming CVPD Team, TTI identified the following performance measures produced as the direct measures of mobility impacts of the Wyoming CVPD:[2]

- Vehicles traveling at no more than 5 mph over the posted speed (compared before and after the CV pilot).
- Vehicle traveling with +/–10 mph of the posted speed (compared before and after the CV pilot).
- Speed of CVs closer to the posted speed when compared to non-CVs.
- Percentage of CVs that likely took action following receipt of an alert.

This analysis includes a “before and after” comparison of key performance measures. The “before” condition is represented by the baseline conditions, the data for which was collected during 2016 and 2017. The “after” condition represents data collected during the post-deployment evaluation period, which runs from January 2021 through April 2022. The following provides TTI’s assessment of the direct impacts of the deployment on mobility.

The Wyoming CVPD Team used eleven storm categories to analyze the speed behavior differences in different weather conditions. The Wyoming CVPD Team identified these eleven storm categories using weather and speed-related data from the baseline period, such as the relative humidity, wind speed, road surface temperature, road surface condition, and visibility condition as recorded at the closest RWIS to each speed sensor. The Wyoming CVPD Team aggregated with data into two to four categories using threshold values based on speed behavior analyses. This aggregation process of the baseline data resulted in 216 unique storm variable combinations. More details about the selection of these weather variables, the threshold values used in each of these variables, and the analyses that determined the final event storm categories can be found in WYDOT’s *Connected Vehicle Pilot Deployment Program Phase 2 Final System Performance Report, Baseline Conditions—WYDOT CV Pilot.* [8]

It is important to note that the WYDOT CVPD Team identified two storm categories labeled as “Mixed Conditions.” These storms categories contained a variety of different storm events that were found to have similar speed distributions. However, the Mixed Conditions 1 category was comprised of 19 unique storm variable combinations, whereas Mixed Condition 2 was comprised of 31 unique storm variable combinations. Because of this, the Wyoming CVPD Team was unable to provide a succinct weather description to assigned to these storm types.

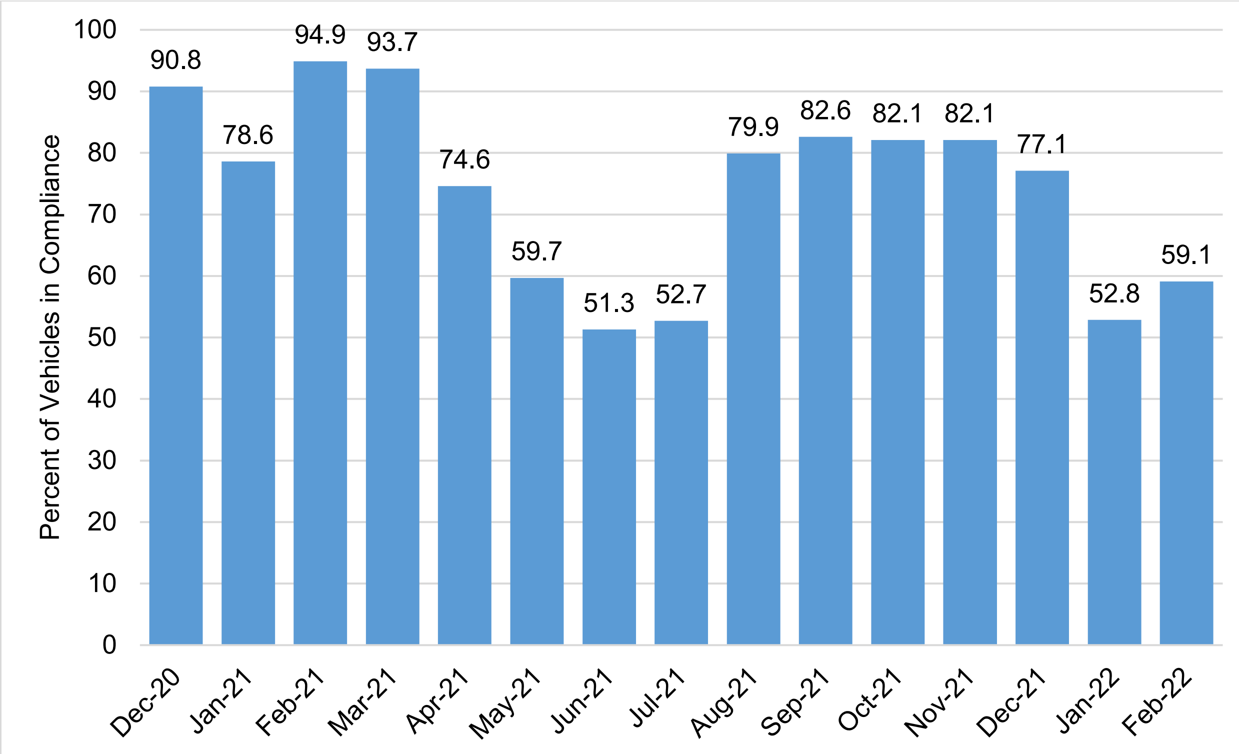
Vehicles Traveling at No More than 5 mph over Posted Speed

The Wyoming CVPD Team compared speed compliance in the post-deployment period to that observed in the baseline. For this analysis, the Wyoming CVPD Team defined a vehicle to be compliant with the speed limit if its measured travel speed was no more than 5 mph above the posted speed limit.(2) Under ideal conditions, the posted speed limit in most of the corridor was 85 mph; however, WYDOT can dynamically alter the speed limits in some sections of I-80 based on weather conditions through its VSL system. Depending upon the severity of the conditions, WYDOT can reduce the speed limits in some sections of I-80 to as low as 35 mph through its VSL system. For this analysis, WYDOT considered speed limit compliance to be a critical factor in lowering collision rates during severe weather conditions.

To analyze speed limit compliance, the Wyoming CVPD Team measured speed data from radar sensors deployed as part of the VSL system.(2) The sensors measured the individual speed of all vehicles, equipped and unequipped. The Wyoming CVPD Team merged speed data with measured weather condition data at the time of the speed observations and then aggregated speed compliance by different storm categories, based on measures such as relative humidity, wind speed, road surface temperature, road surface condition, and visibility.

Figure 10 shows the percentage of vehicles measured to be compliant with the posted speed limits for all weather conditions by month in the post-deployment period. The figure shows that during the post-deployment period, monthly compliance rates varied from a high of almost 95 percent to a low of slightly better than 51 percent. Speed limit compliance tended to be higher during winter months (December, January, February, and March) than summer months (May, June, and July) when weather conditions are more consistent and pristine.

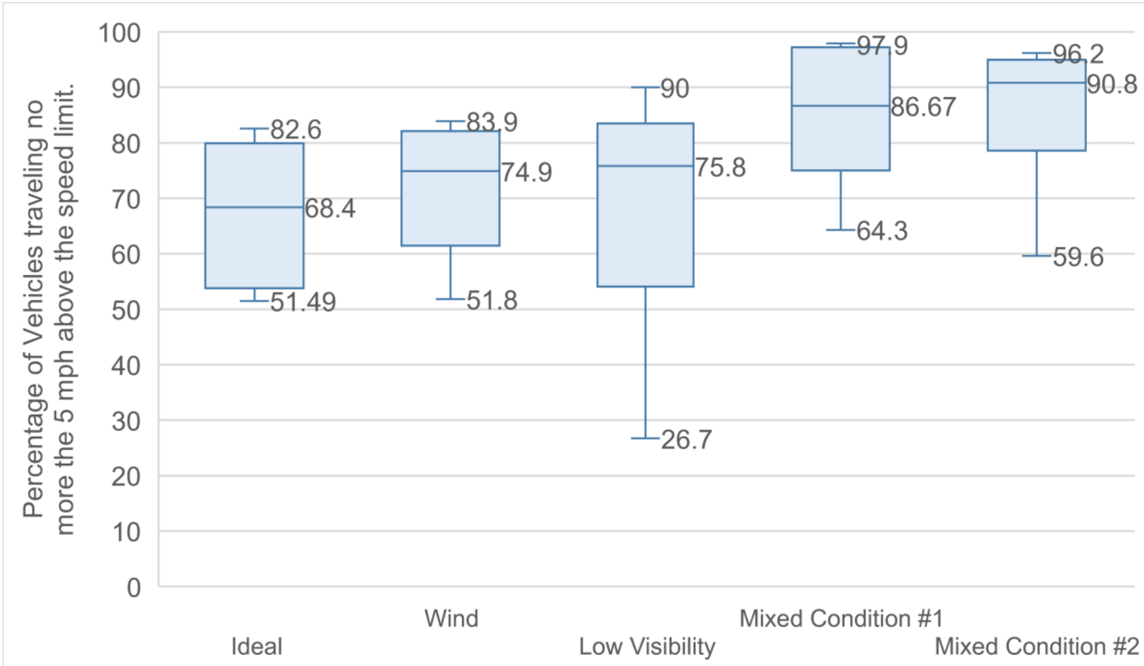
Figure 11 shows the compliance rates for different weather conditions, aggregated across all months in the post-deployment period. The median compliance rate during wind and limited visibility conditions were slightly higher (76 percent and 78 percent, respectively) compared to ideal conditions (around 70 percent). The median monthly compliance rate was higher during mixed storm conditions.



Data available through February 2022.

Source: Texas A&M Transportation Institute based on data from Reference 2, 2022

Figure 10. Chart. Percent of Vehicles in Compliance during All Weather Conditions (Post Deployment)

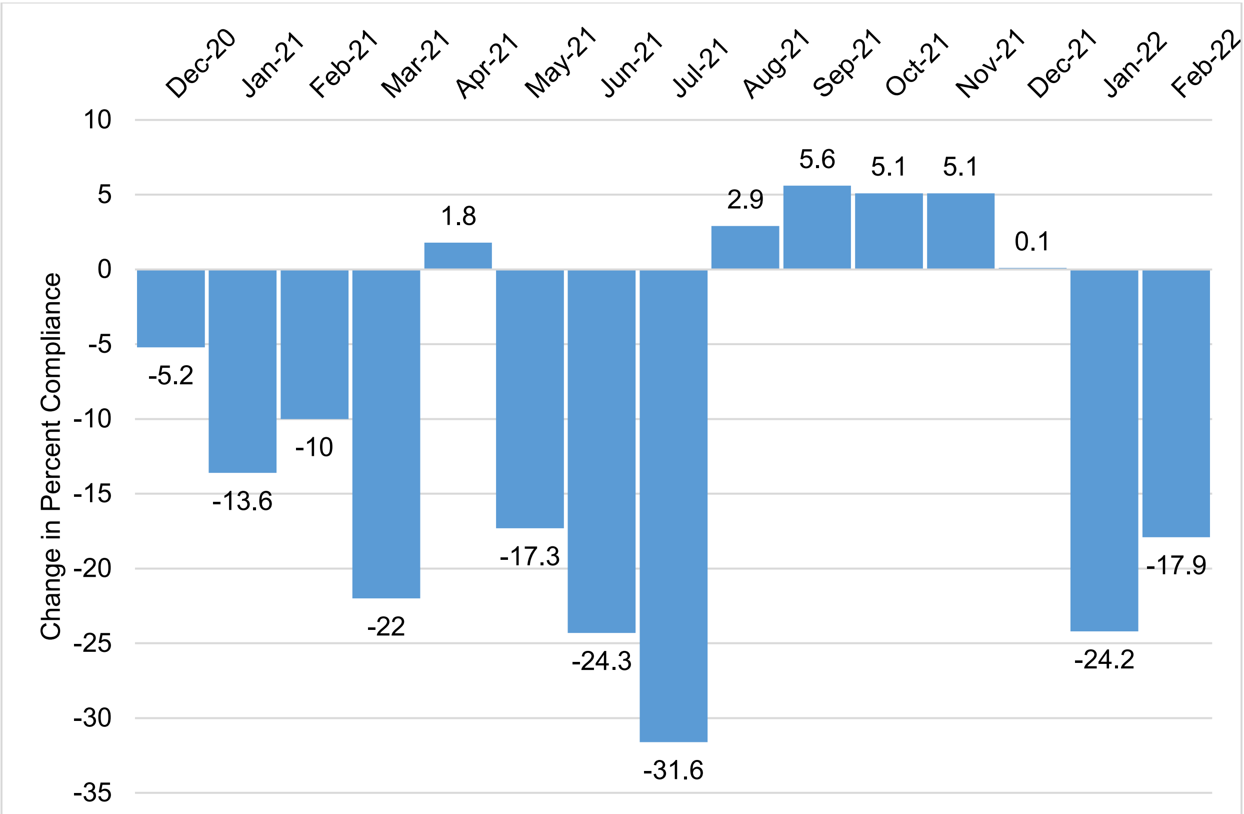


Source: Texas A&M Transportation Institute based on data from Reference 1, 2022

Figure 11. Chart. Post-Deployment Compliance Rates during Different Weather Conditions

The Wyoming CVPD Team compared the percentage of vehicles in compliance with the speed limits from the post-deployment periods (with active CV applications) to the compliance percentages from the baseline conditions.(2) Figure 12 shows the results of this comparison, aggregated across weather events, while Table 4 shows the comparison for different storm categories. A negative change in compliance implies that more vehicles were observed traveling faster than 5 mph above the speed limit in the post-deployment period compared to the baseline conditions. The Wyoming CVPD Team reported that overall speed compliance decreased from 86.1 percent in the baseline to 65.7 percent in the post-deployment period, an 20 percent reduction in the compliance rate.(2) The greatest reduction in the percentages of drivers traveling less than 5 mph above the posted speed limit occurred during ideal, windy, and low visibility conditions. Speed compliance was slightly better (a positive difference in percentage of vehicle traveling no more than 5 mph over the speed limit) during the two mixed weather conditions. The Wyoming CVPD Team reported slightly better compliance (as measured by a positive change between the baseline and deployment percentage of vehicles traveling no mor than 5 mph above the speed limit) during both mixed storm categories—approximately 5 percent better conformance to the post speed limit.

A significant proportion of the observations shown in Table 4 occurred during ideal weather conditions (over 93 percent in the post-deployment and 87 percent in the baseline conditions). Because the CV alerts are issued only under adverse weather conditions, and because WYDOT's VSL system is active only during adverse conditions, TTI removed the observations under ideal weather conditions from analysis. Table 5 shows the results of the analysis with the ideal weather conditions are removed. After removing observations under ideal weather conditions, the results show that overall speed compliance was 14 percent lower during post-deployment period compared to the baseline condition.



Source: Texas A&M Transportation Institute based on data from Reference 2, 2022

Figure 12. Chart. Change in Percentage of Vehicles Traveling no more than 5 mph Over Posted Speed Limit

Table 4. Comparison of Baseline and Post-Deployment Speed Compliance Rates by Storm Category

Storm Category	Number of Vehicle Observations (Baseline)*	Percent Compliant (Baseline)	Number of Vehicle Observations (Post-Deployment) **	Percent Compliant (Post-Deployment)	Change in Compliance Rate (Percent)
Ideal	40,524,982	86.3	356,787,174	65.4	– 20.9
Wind	3,430,866	87.4	13,286,077	73.3	– 14.1
Low Visibility	147	64.2	6,926,073	55.0	– 9.2
Mixed Conditions 1	197,985	79.1	6,963	82.6	3.5
Mixed Conditions 2	2,241,121	80.1	4,594,541	85.0	4.9
Total	**46,395,101**	**86.1**	**381,600,828**	**65.7**	**– 20.3**

*January 2017 through November 2017 **December 2020 through February 2022

Source: Wyoming Department of Transportation, 2022

Table 5. Comparison of Baseline and Post-Deployment Speed Compliance Rates—Storm Conditions Only

Storm Category	Number of Vehicle Observations (Baseline)*	Percent Compliant (Baseline)	Number of Vehicle Observations (Post-Deployment) **	Percent Compliant (Post-Deployment)	Change in Compliance Rate (Percent)
Wind	3,430,866	87.4	13,286,077	73.3	– 14.1
Low Visibility	147	64.2	6,926,073	55.0	– 9.2
Mixed Conditions 1	197,985	79.1	6,963	82.6	3.5
Mixed Conditions 2	2,241,121	80.1	4,594,541	85.0	4.9
Total	**5,870,1119**	**84.3**	**24,813,654**	**70.4**	**– 14.0**

*January 2017 through November 2017 **December 2020 through February 2022

Source: Wyoming Department of Transportation, 2022

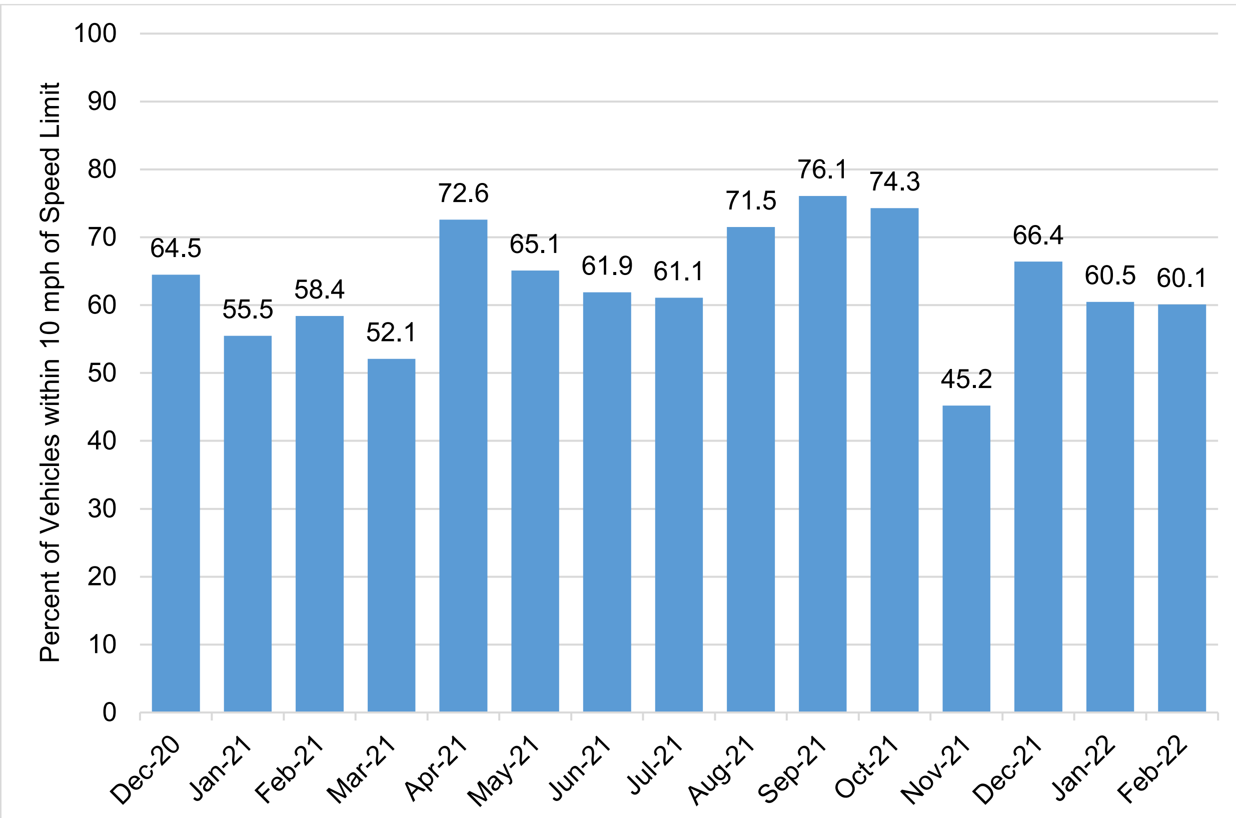
One should not the large difference between the total number of observations between the baseline and post-deployment periods. For the inclement weather conditions, the number of observations was approximately 4 times higher in the post-deployment periods (24.8 million) compared to the baseline period (5.9 million). When including the ideal conditions, the number of observations in the post deployment period was approximately 8 times higher than that in the baseline conditions (381 million to 46 million). Such large differences in sample sizes can significantly distort changes in percentage in compliance. Given such large differences in sample sizes, one should note though that percentage of vehicle in compliance with compliance with the speed limit remained relatively high (approximately 80 percent) during the most severe weather conditions. One should also note that these compliance rates are for the entire traffic stream and not just the CV. Additional analysis below shows that CV comprised only 2 percent of the vehicle stream in the post-deployment period, and therefore had likely little influence on the overall compliance rates of the entire traffic stream.

Vehicle Traveling within +/–10 mph of Posted Speed

The Wyoming CVPD Team also examined changes in speed variability between the baseline and post-deployment periods. [(2)] For this analysis, the Wyoming CVPD Team examined the number of vehicles traveling within +/–10 mph of the posted speed limit. WYDOT selected this performance measure as a measure of excessive speeding—drivers selecting to travel 10 mph or more above the posted speed limit. Likewise, vehicles traveling slower than 10 mph below the speed limit become a potential hazard for rear-end and sideswipe collisions. WYDOT hypothesized CVs would improve the speed selection behavior of equipped drivers, given that the in-vehicle devices would alert them of current speed limits.[(2)] WYDOT also hypothesized that the improvement in back-office TMC operations would improve the timeliness and accuracy of the entire traveler information system, leading to a reduction in speed variation.[(2)]

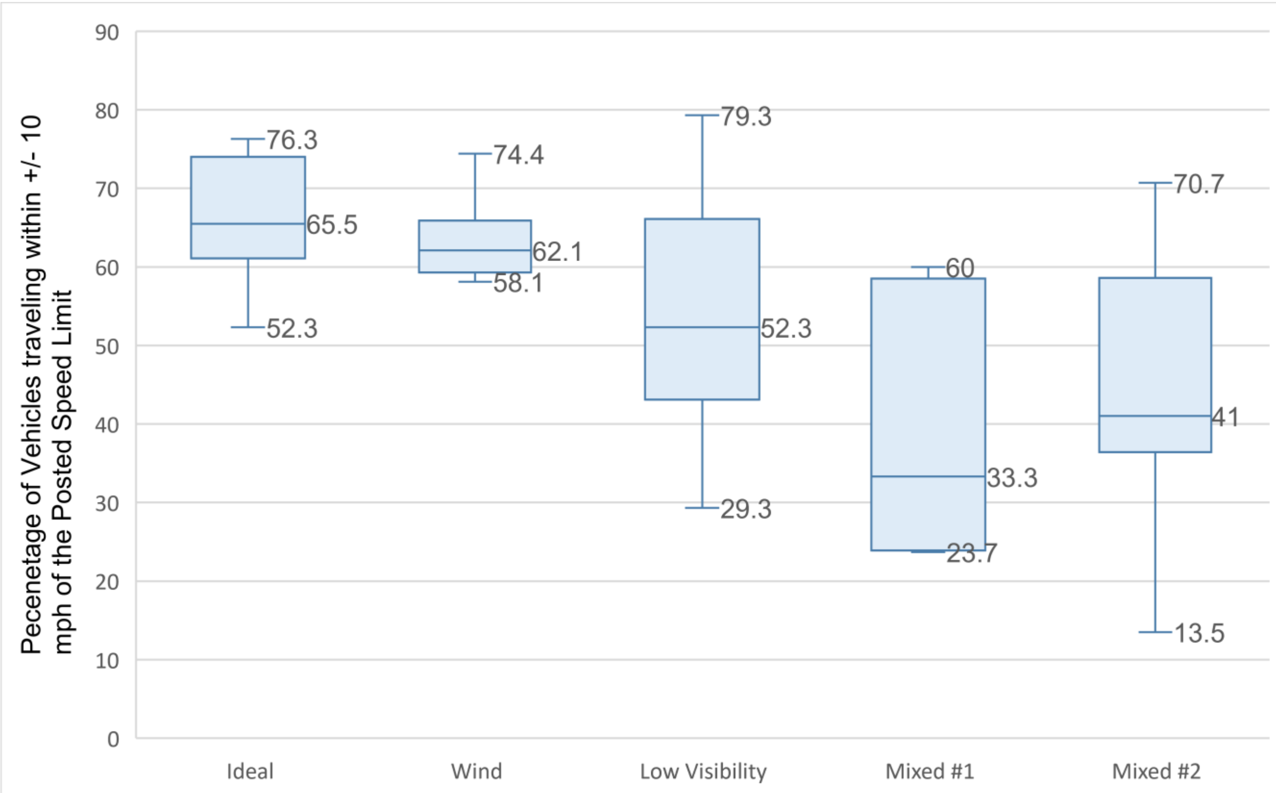
Figure 13 shows the number of vehicles traveling within 10 mph of the posted speed limit across all the months in the post-deployment conditions. The figure shows the percentage of vehicles traveling near the speed limits were constant throughout the year, hovering around 60 to 65 percent for vehicles within 10 mph of the posted speed limit.

Figure 14 shows the distribution of monthly percentages of vehicles traveling within 10 mph of the posted speed limit in the post-deployment period for different types of weather categories. For ideal and high-wind conditions, the median percent of vehicles traveling within 10 mph of the posted speed limit was 65.5 percent and 62.1 percent, respectively, nearly the same.(2) The Wyoming CVPD Team reported a smaller proportion of the vehicles traveling within 10 mph of the posted speeds in more severe weather categories.(2) In the limited visibility storm category, the median percentage of vehicles traveling within 10 mph of the speed limit dropped to 52.3 percent. For the two mixed storm categories, the median percentage of vehicles traveling within 10 mph of the posted speed limit dropped to 33.3 percent and 41 percent. This decrease suggests that more drivers were operating speeds outside the 10-mph range of the speed limit. The Wyoming CVPD Team did not report whether vehicles were traveling faster or slower than the speed limit. It is not known if this observation is related to how representative the speed limits of the VSL signs were to the operating conditions at the time.



Source: Texas A&M Transportation Institute based on data from Reference 2, 2022

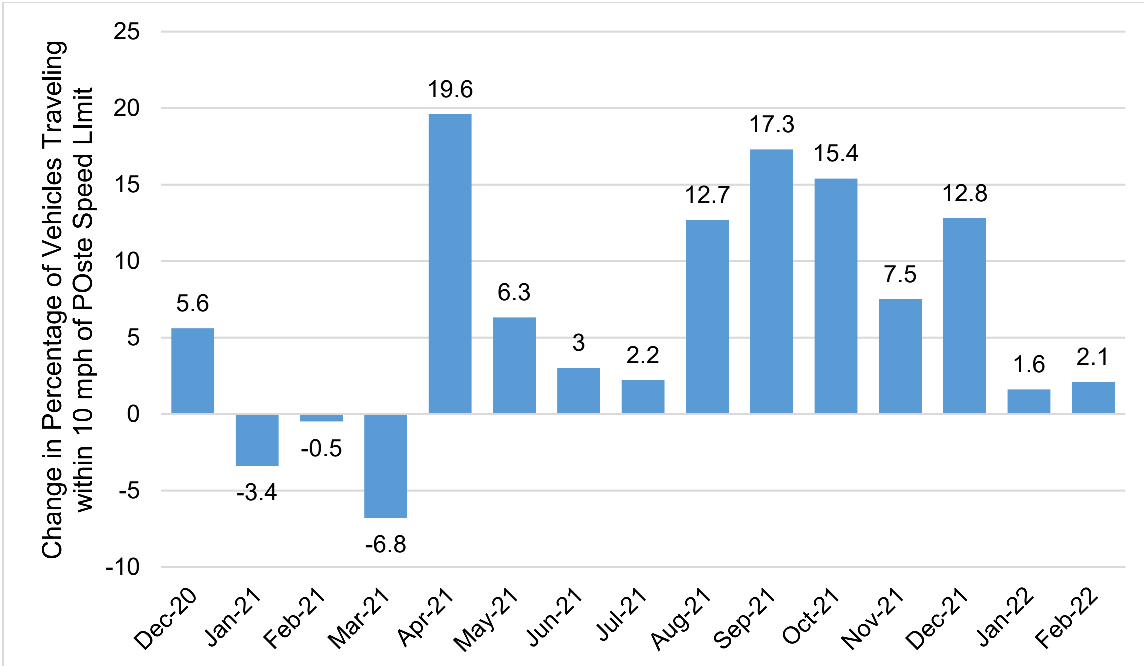
Figure 13. Chart. Percent of Vehicles Traveling within 10 mph of Posted Speed Limit—All Conditions (Post Deployment)



Source: *Texas A&M Transportation Institute based on data from Reference 2, 2022*

Figure 14. Chart. Percent of Vehicles Traveling within 10 mph of Posted Speed Limit during Different Weather Conditions

The Wyoming CVPD Team also examined how the percentage of vehicles traveling within 10 mph of the posted speed limit in the post-deployment period compared to the baseline observations.[(2)] Figure 15 shows the change in percentage of vehicles within the 10-mph range of the speed limit aggregated across all weather conditions. A positive change in percentage would imply that more vehicles were observed within the 10-mph range around the speed limit during the post-deployment period compared to the baseline. The figure shows that in general, more vehicles traveled within 10 mph of the posted speed limit in the post-deployment period, compared to the baseline.



Source: Texas A&M Transportation Institute based on data from Reference 1, 2022

Figure 15. Chart. Change in Percentage of Vehicles Traveling within 10 mph of Posted Speed Limit in Post-Deployment Compared to Baseline Conditions

Table 6 shows a comparison of the baseline and post-deployment percent of vehicles to be within 10 mph of the posted speed limit for different storm event categories. The table shows lower percentages of vehicles traveling within 10 mph in the post-deployment period than in the baseline for all storm categories except low-visibility storms. For this category of storm, the percentage of vehicles traveling within the 10-mph buffer around the speed limit showed a 2.3 percent improvement. The Wyoming CVPD Team reported that overall speed conformity to the post speed limit (as measured by the percentage of vehicle traveling within +/- 10 mph of the speed limit) changed from 70.7 percent to 66.4 percent, an 4.3 percent reduction, across all weather conditions.(2) Table 7 shows a similar comparison with the ideal weather conditions removed. This shows that the level of conformity to the speed limit was approximately the same (around 60 percent) in all adverse weather conditions, except for the under limited visibility. Again, the disparity in sample sizes between the post-deployment period and the baseline condition could be the source in the observed reduction on conformity. The Wyoming CVPD Team also hypothesized that this change may occurred because of an absence of storm conditions in the baseline period that resulted in particularly low percentages of vehicles being within the 10-mph buffer.(2)

Table 6. Comparison of Baseline and Post-Deployment Speed Buffer by Storm Category

Storm Category	Number of Vehicle Observations (Baseline)*	Percent of Vehicles within 10-mph Buffer of Speed Limit (Baseline)	Number of Vehicle Observations (Post-Deployment) **	Percent of Vehicles within 10-mph Buffer of Speed Limit (Post-Deployment)	Change in Vehicle within 10-mph Buffer of Speed Limit
Ideal	33,619,787	71.6	356,787,174	66.9	– 4.7
Wind	2,618,285	66.7	13,286,077	62.5	– 4.2
Low visibility	134	58.5	6,926,073	60.2	1.7
Mixed Condition 1	137,739	55.1	6,963	37.5	– 17.6
Mixed Condition 2	1,694,709	60.6	4,564,541	51.6	– 9.0
Total	**38,070,654**	**70.7**	**381,570,828**	**66.4**	**– 4.3**

*January 2017 through November 2017 **December 2020 through February 2022

Source: Wyoming Department of Transportation, 2022

Table 7. Comparison of Baseline and Post-Deployment Speed Buffer —Storm Conditions Only

Storm Category	Number of Vehicle Observations (Baseline)*	Percent of Vehicles within 10-mph Buffer of Speed Limit (Baseline)	Number of Vehicle Observations (Post-Deployment) **	Percent of Vehicles within 10-mph Buffer of Speed Limit (Post-Deployment)	Change in Vehicle within 10-mph Buffer of Speed Limit
Wind	2,618,285	66.7	13,286,077	62.5	– 4.2
Low visibility	134	58.5	6,926,073	60.2	1.7
Mixed Condition 1	137,739	55.1	6,963	37.5	– 17.6
Mixed Condition 2	1,694,709	60.6	4,564,541	51.6	– 9.0
Total	**4,450,867**	**64.0**	**14,840,510**	**59.9**	**– 4.1**

*January 2017 through November 2017 **December 2020 through February 2022

Source: Wyoming Department of Transportation, 2022

Comparison of Speed Compliance by CVs to Non-CVs

The Wyoming CVPD Team also compared the speed limit compliance of CV-equipped vehicles versus that of non-equipped.(2) For this analysis, the Wyoming CVPD team defined compliance with the speed limit as a measured speed of no more than 5 mph above the posted speed limit. To conduct this comparison, the Wyoming CVPD Team compared the speeds of the CVs as reported in the BSM data as vehicles traveled in front of a corridor speed sensor to the speeds of non-CVs as reported by the roadside radar speed sensor. To ensure that the CVs and non-CVs had similar road and weather conditions, the Wyoming CVPD Team used only non-CV speed observations around the CV observations in the analysis. The Wyoming CVPD Team established a window of 2 minutes and 30 seconds before and after the CV observation as a reasonable time to ensure vehicles experienced similar conditions. Given the relatively low number of CVs in the traffic stream, the Wyoming CVPD Team expected the sample size of CVs would be much lower than the number of non-CVs. Table 8 shows the number of CV and non-CV speed events by month used by the Wyoming CVPD Team in this comparison.

Table 9 shows the results of the speed limit compliance percentages of CVs and non-CVs by month and for the total analysis period. The table shows the percentage of CV compliance compared to non-CVs has been improving over time. The table shows that overall speed limit compliance was 5.8 percent higher for CVs over non-CVs.

Table 8. Number of CV and Non-CV Speed Events by Month [2]

Analysis Month	Number of CV Events	Number of Non-CV Events	Percent of CVs in Traffic Stream
December 2020	0	627	1.8
January 2021	49	3,171	1.5
February 2021	82	2,625	3.1
March 2021	244	12,960	1.9
April 2021	158	7,886	2.0
May 2021	157	2,031	7.7
June 2021	314	39,399	0.8
July 2021	216	8,235	2.6
August 2021	209	1,065	19.6
September 2021	205	3,171	6.5
October 2021	109	899	12.1
November 2021	239	13,729	1.7
December 2021	369	14,193	2.5
January 2022	241	2,265	10.6
February 2022	175	8,223	2.1
Total	**2,778**	**120,782**	**2.3**

Source: Wyoming Department of Transportation, 2022

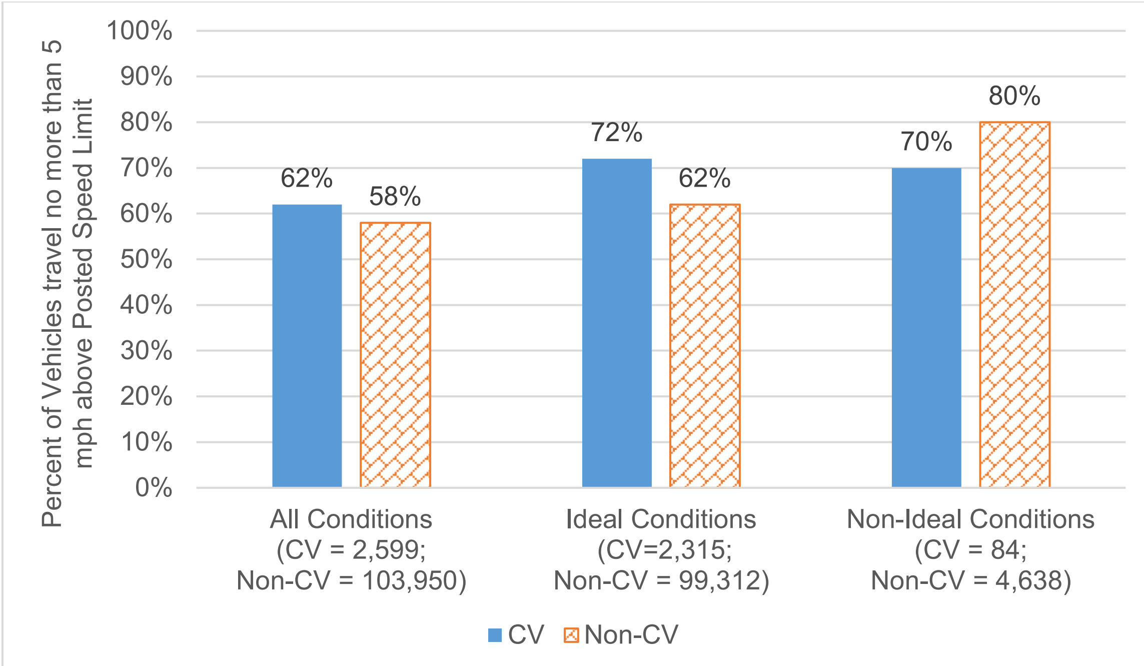
Table 9. Comparison of CV and Non-CV Speed Limit Compliance by Month (2)

Analysis Month	Percent of CVs Compliant	Percent of Non-CVs Compliant	Compliance Difference (CV vs. Non-CV)	Percent of Compliance Difference
December 2020	72.7	83.6	–10.8	–14.9
January 2021	69.4	77.2	–7.8	–11.2
February 2021	81.7	77.0	4.7	5.7
March 2021	39.1	55.5	–16.4	–42.1
April 2021	72.2	76.0	–3.8	–5.3
May 2021	52.2	61.7	–9.4	–18.0
June 2021	45.4	45.6	–0.2	–0.4
July 2021	32.9	37.0	–4.1	–12.6
August 2021	87.6	72.5	15.1	17.2
September 2021	78.5	82.7	–4.2	–5.4
October 2021	80.7	80.6	0.1	0.1
November 2021	93.3	86.3	7.0	7.5
December 2021	86.2	78.0	8.2	9.5
January 2022	61.4	51.6	9.8	16.0
February 2022	61.1	53.2	8.0	13.0
Total	**66.3**	**60.6**	**5.7**	**8.5**

Source: Wyoming Department of Transportation, 2022

The Wyoming CVPD Team provided histograms showing the difference between observed and posted speed for connected and non-connected vehicles for the 15-month post-deployment period under different operating conditions.(2) These histograms show the distribution of speed relative to the posted speed limit in 5 mph bins. The histograms were based on 103,950 observed non-connected vehicles and 2,599 connected vehicles.

Figure 16 shows a comparison of the percentage of CVs traveling less than 5-mph above the speed limit to non-CVs under different operating conditions. The figure shows that 72 percent of the CVs were in compliance with the speed limit (traveling less than 5 mph above the speed limit) under ideal conditions compared to 62 percent of non-CVs. Under non-ideal travel conditions, 70 percent of the CVs were observed to comply with the speed limit compared to 80 percent of non-CVs.

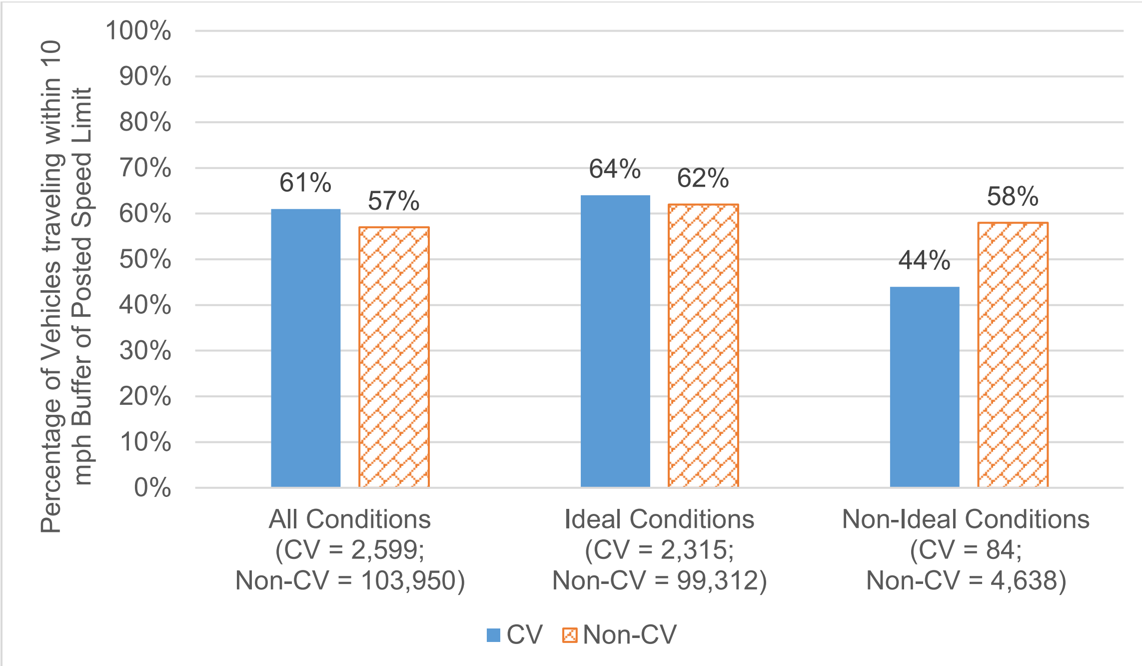


Source: Texas A&M Transportation Institute based on data from Reference (2).

Figure 16. Bar Chart. Comparison of Percent of CVs and Non-CVs in Compliance with Posted Speed Limits under Different Operating Conditions.

Figure 17 shows a comparison of the percentage of CVs and non-CVs traveling within a 10-mph buffer around the posted speed limit under different operating conditions. Under ideal conditions, CVs and non-CVs shows approximately the same level of conformity around the posted speed limit. Under non-ideal conditions, however, fewer CVs were observed traveling within a 10-mph buffer of the speed limit. A review of the data provided by the Wyoming CVPD team shows a substantial percentage of CV (25 percent) traveling either 30 mph below or above the posted speed limit.

It should be noted that they Wyoming CVPD Team reported that most of the observations were found to be during ideal conditions with only 84 observations (5%) for connected vehicles and 4,638 observations (4%) for non-connected vehicles occurring during non-ideal conditions. This disparity in the amount of CV versus non-CV data is most likely the source of the difference in compliance and conformity to the speed limit.



Source: Texas A&M Transportation Institute based on data from Reference (2).

Figure 17. Bar Chart. Comparison of Percentage of CVs and Non-CVs Traveling with a 10mph Buffer of the Posted Speed Limit under Different Operating Conditions.

CVs that Likely Took Action Following Receipt of Alert

The purpose of provide fleet operators with alerts to encourage drivers to perform an action that might improve safety (reduce speeds, come to a stop, change lanes) or improve mobility (e.g., change routes, delay or cancel a trip) during inclement weather. In terms of mobility, the most important actions that a driver could take would be one that moved the trip to less congested time or route not impacted by weather conditions.

The TTI CVPD Team identified the percentage of CVs that likely acted upon an alert as a measure of mobility associated with the deployment. WYDOT expected that the alerts produced by the CV technology would elicit behavioral changes from CV operators. (2) These expected behaviors include parking the vehicle, reducing speed, coming to a stop safely, or exiting I-80 altogether.

To assess drivers' actions in response to receiving a CV alert, the Wyoming CVPD Team used a case study approach. The team evaluated driver reactions to alerts received during the following events:(2)

- High wind alerts for a wind event on June 22, 2021.
- Work zone alerts for a construction zone during June 2021.
- Winter storm event on February 2, 2022.

Using this case study approach, the Wyoming CVPD Team found the following:(2)

- On June 22, 2021, a high wind event occurred that impacted operations on the I-80 corridor, particularly in the southeast portion. The Wyoming CVPD Team analyzed the high-wind driver alerts from that day and found that 18 alerts had been issued to vehicles traveling on I-80. After eliminating WYDOT maintenance and highway patrol vehicles from the dataset, the Wyoming CVPD Team analyzed 10 events where messages were received. From these 10 events, the Wyoming CVPD Team found that four vehicles (40 percent) took no action, four vehicles (40 percent) reduced their speed, and two vehicles (20 percent) stopped. Detailed analysis of the BSM data, particularly the yaw acceleration, showed that wind was significantly impacting truck performance at the time the driver took action.

- The Wyoming CVPD Team analyzed the alerts associated with a single work zone on I-80 during the entire month of June 2021. This particular work zone involved detouring all traffic to the eastbound lanes using a median crossover after compressing traffic into a single lane of flow in each direction. After eliminating highway patrol and WYDOT maintenance vehicles from the dataset, the Wyoming CVPD Team found 16 events where at least one work zone alert was broadcast to a vehicle approaching or within the work zone. From these 16 events, the Wyoming CVPD Team found that in 7 instances (44 percent) the driver took no action, 8 instances (50 percent) the driver reduced speed, and 1 event (6 percent) the vehicle exited the freeway after receiving the construction alert.
- The Wyoming CVPD Team also identified one winter weather event occurring on February 2, 2022, to use in a case study; however, at the time TTI drafted this report, the Wyoming CVPD Team had not completed its analysis of the event.

The Wyoming CVPD Team also examined the driver responses to two V2V applications: FCW and SVA. Using a sample of FCW alerts collected for the first 15 days of February 2022, the Wyoming CVPD Team found the following:(2)

- Five days (1st, 2nd, 4th, 5th, and 12th) had no FCW alerts, while February 3 had 39 alerts.
- Thirty-six alerts (40 percent) occurred off the I-80 main lanes.
- Of the remaining 53 alerts, further analysis by the Wyoming CVPD Team shows that many of these alerts were clustered spatially and temporally, indicating that they came from related events where multiple alerts were produced.

In the end, the Wyoming CVPD Team identified 10 unique, multi-message events. All but one of these events involved highway patrol vehicles. A detailed analysis of these events showed the following:(2)

- Five events involved two highway patrol vehicles, and the FCWs were issued when one of the vehicles approached and then later followed another patrol vehicle.
- Four events involved a single patrol vehicle, but the BSM data did not show another CV nearby. The Wyoming CVPD Team is investigating these events further.
- One event involved two partner fleet vehicles where a faster-moving vehicle approached a slower-moving one and then passed the vehicle. In this event, the driver’s action was to reduce the speed of the vehicle.

Because the Wyoming CVPD evaluation plan did not involve the use of a controlled vehicle and because of the limited amount of vehicle interactions, it is impossible to tell if the alert caused the driver’s actions or if the driver would have taken the same action even if the driver had not received the alert in all of the cases analyzed. As a result, there is insufficient evidence to know the effects of drivers receiving alerts on travel behavior.

Assessment of Indirect Mobility Impacts

The Wyoming CVPD Team reported the following safety-related impacts associated with the deployment:(2)

- No crashes involving CVs (friendly or partner) were reported to WYDOT.
- The average number of vehicles involved in all crashes was approximately 1.4 vehicles per crash. This number represented an increase of 7.3 percent in the post-deployment period, compared to the baseline period. After accounting for secondary collisions, the average number of vehicles involved in all crashes increased by 2.9 percent.
- The average number of vehicles involved in a crash was slightly higher for truck crashes than all crashes. The average number of vehicles involved in truck crashes was 1.48 without accounting for secondary crashes and 1.55 when accounting for secondary crashes. These numbers represent a decrease of approximately 3.2 and 7.7 percent, respectively, compared to the baseline conditions. The Wyoming CVPD Team noted that truck crashes had a greater propensity to include multiple vehicles.
- The post-deployment results showed an increase in the percentages of work-zone-related crashes but a reduction in crash rates, likely resulting from an increased number of work zone vehicle miles traveled during the post-deployment due to extensive construction activity that year.

Modeling of Mobility Impacts

The Wyoming CVPD Team developed a VISSIM microscopic simulation model of a 23-mile segment of the Cheyenne-Laramie VSL corridor (mileposts 317–340). The Wyoming CVPD Team selected this segment of I-80 because it included the most challenging traffic situation (e.g., high altitude, severe weather events, and steep vertical grades). The Wyoming CVPD Team uploaded the basic corridor network from the standard map data in VISSIM; then, the team added the roadway geometric data, including number of lanes, roadway segment lengths and grades, location of lane additions and drops, etc. Since the WYDOT CVPD focused on truck safety, the team defined three vehicle categories: regular cars, non-connected trucks, and connected trucks. The Wyoming CVPD Team altered the model parameters of the connected trucks using the results from its driver behavior studies (2) to represent the different operating characteristics of the connected trucks from non-equipped trucks.

The Wyoming CVPD Team used the model to assess surrogate safety-related performance measures (e.g., time to collision and post-encroachment time); no information on the estimated impacts of deploying CV technologies on mobility was included in the analysis.

More information on how the Wyoming CVPD Team used the simulation model in its analysis is available in WYDOT's *Connected Vehicle Pilot Deployment Program Phase 3: Final System Performance Measurement and Evaluation—WYDOT Connected Vehicle Pilot*. (2)

For those looking to assess surrogate safety performance measures for their own locations, please review the FHWA documents listed below. These documents discuss and evaluate the trajectories output from some microsimulation models and how some microsimulation models may not reflect realistic vehicle performance in near crash conditions. Obtaining actual vehicle trajectories will more than likely be needed to validate whether the trajectories produced by the models are reflecting the actual real-world performance.

- Active Transportation and Demand Management. Website. Federal Highway Administration. (Available at https://ops.fhwa.dot.gov/atdm/research/index.htm).
- Active Transportation and Demand Management (ATDM) Trajectory-Level Validation State of the Practice Review. (Available at https://rosap.ntl.bts.gov/view/dot/32715).
- A Framework for Validating Traffic Simulation Models at the Vehicle Trajectory Level. (Available at https://rosap.ntl.bts.gov/view/dot/34271).
- Proof of Concept for Trajectory-Level Validation Framework for Traffic Simulation Models (Available at https://rosap.ntl.bts.gov/view/dot/34397).
- Trajectory Investigation for Enhanced Calibration of Microsimulation Models. (Available at https://www.fhwa.dot.gov/publications/research/operations/21071/index.cfm).

User Perceptions of Mobility Impacts

No information related to user perceptions of the impacts and effects of any of the applications on safety or mobility was included in WYDOT's *Connected Vehicle Pilot Deployment Program Phase 3: Final System Performance Measurement and Evaluation—WYDOT Connected Vehicle Pilot*.[2]

Chapter 4. Key Successes and Lessons Learned

Summary of Findings

There is no conclusive evidence to indicate the Wyoming CVPD had any impact on mobility on I-80, either directly or indirectly. There is little evidence to support that the Wyoming CVPD impacted speed compliance with posted speed limit or speed variability. There are also insufficient data to suggest the CVs complied any better with posted speed limits. Case study analysis did indicate that in certain situations, drivers of CVs took appropriate action after receiving alerts, but because there were no data available from a control group, it is impossible to conclude that the action the drivers took was a direct response to receiving the alert as opposed to their normal reactions to the circumstances. However, none of this was unexpected by the Wyoming CVPD Team or the TTI Evaluation Team for the following reasons:

- The focus of the deployment was on improving safety and demonstrating the feasibility and applicability of using CV technology to improve information dissemination during severe weather events. In most cases, the weather itself is responsible for the degradation in mobility, and WYDOT's emphasis is preventing collisions during these situations.
- The level of market penetration was extremely low (325 vehicles were equipped with CV technologies)—almost half of which were friendly fleet partners such as WYDOT snowplows, maintenance vehicles, and highway patrol vehicles. During severe weather conditions, the mission of these vehicles is to ensure the safety of other travelers, not optimizing their mobility.

The Wyoming CVPD was successful, however, at demonstrating how data from CV technologies can be integrated with other WYDOT systems to improve situational awareness. These successes are discussed in WYDOT's *Connected Vehicle Pilot Deployment Program Phase 3: Final System Performance Measurement and Evaluation—WYDOT Connected Vehicle Pilot*. (2)

Another key success of the project was the demonstration of the value of using satellite communications for disseminating traveler information systems. Through the CVPD, WYDOT was able to develop a partnership with a major vehicle satellite communication provider. Satellite coverage is available in 100 percent of the I-80 corridor traveled by commercial fleet vehicles. Because of the success of using this technology in the deployment, WYDOT saw the opportunity to expand its ability to provide TIM alerts on all state and federal highways in Wyoming. In October 2019, the application development team began work with WYDOT to create a representational-site-transfer-enabled microservice that would allow WYDOT's existing application to easily create and distribute TIMs to the data exchange, where the satellite providers could pull the messages and distribute them over their satellite infrastructure. After resolving several technical issues, WYDOT made it possible for CV drivers to receive TIMs while traveling on any state or federal highway instead of just I-80. This function has allowed WYDOT to gather additional interest from fleet partners to receive weather and travel alert messages statewide.

The Wyoming CVPD pilot has also made significant contributions to the standard development processes. For example, through the Wyoming CVPD Team's efforts, the SAE J2735 trailer definitions and BSM Part 2 for trailers has been standardized, and the information used to define work zones has been incorporated into SAE J2945/4 road safety application specifications. The team has also worked with SCMS managers on improving misbehavior detection and ending entity protections.

Lessons Learned

The Wyoming CVPD Team kept an extensive lessons-learned log throughout the deployment—over 65 lessons with many very technical entries. The following is a summary of several of the high-level lessons learned deemed important by the TTI Evaluation Team. More information on the detailed lessons learned is available in *Connected Vehicle Pilot Deployment Program Phase 3: Final System Performance Measurement and Evaluation—WYDOT Connected Vehicle Pilot*. (2)

- Use existing standards as a part of the system architecture and design process. Also, standards are subject to interpretation by technology vendors and application developers. It is critical to ensure a common understanding and interpretation of the standards. Configuration issues can also compromise accurate delivery of information to applications.
- Do not underestimate the importance (and time requirements) of testing. Deployers need to ensure that they reserve enough time in the schedule adequately for testing, both the test planning process and the execution of the testing. Testing should come in every aspect of the system being deployed, and testing should reoccur to ensure that end-to-end functionality is not impacted by firmware upgrades and modifications.
- Partnerships between different disciplines are critical. Deployers will encounter many technical issues, and adequate documentation may be lacking for some applications. When this occurs, having access to knowledgeable individuals with specialized expertise may be needed to overcome some technical challenges.
- Installation of CV technologies is not the same for commercial fleet vehicles as it is for automobiles. Commercial fleet vehicles have different information and antenna requirements. Testing of antenna placement is critical to ensure the coverage range is maintained. Standards development processes are lacking around truck-related issues. Driver preferences may not always mesh with the capability of the technology. Many fleet operators lease vehicles and equipment and may need to go back to the original owner to approve installation. The quality of the installations can be impacted by the vehicle's original condition.
- Keep deployment documentation up to date. As the deployment progresses, it is important for developers to keep as-built documentation current to reflect changes in productions. Have a plan available for addressing errors and installation issues. To the extent possible, include health monitoring and self-error checking and reporting in systems to alert operators of malfunctions.
- Quality control of automated messages should be monitored, especially around the accuracy of TIMs. TIMs may not be received correctly by vehicles; the messages themselves may not match what was sent by the TMC. Agencies will need to rely on friendly eyes to ensure message quality is maintained. Agencies also need processes to collect a standard set of information for reporting errors to developers. Having an active, knowledgeable reporting team was the most critical element in identifying and resolving inaccurate/erroneous TIMs.

- Include redundancy to recover from poor equipment and issues with maturity of applications. The use of a second technology to ensure the continuity of data flow to the deployment vehicles was critical to the success of the deployment.
- In terms of work zone information, it is important to have a cultural shift with contractors to provide more accurate information about work zone locations and duration. Agencies need processes to ensure that information pushed out directly to vehicles is timely and accurate.

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