Connected Vehicle Pilot Deployment Program Independent Evaluation:

Mobility, Environmental, and Public Agency Efficiency (MEP) Refined Evaluation Plan—Wyoming

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16. Abstract

This report presents a refined evaluation plan documenting the approaches that the Texas A&M Transportation Institute Evaluation Team, as the independent evaluator for the United States Department of Transportation (USDOT) Joint Program Office Connected Vehicle Pilot Deployment Program, will use to evaluate the mobility, environmental, and public agency efficiency (MEP) cost-benefit impacts of the Wyoming Department of Transportation Connected Vehicle Pilot Deployment. The refined plan builds on the approaches outlined by Noblis. This plan focuses solely on the analyses related to quantifying the MEP benefits. The details of the MEP approach will be provided in other plan documents such as the survey interview/stakeholder acceptance plan, the data management plan, and the analysis, modeling, and simulation plan. All of these plans will be integrated into a single comprehensive evaluation plan. This refined evaluation plan document serves as the foundation for the development of the detailed plans. Topics covered in this document an overview and summary of the performance measurement plan proposed by the Wyoming deployment team, key USDOT goals and objectives for the deployment, potential confounding factors and risks that may affect the evaluation.

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List of Acronyms

Acronym	Definition
AAA	American Automobile Association
AASHTO	American Association of State Highway and Transportation Officials
AIS	Abbreviated Injury Scale
AMS	Analysis, Modeling, and Simulation
BSM	Basic Safety Message
CMEM	Comprehensive Modal Emissions Model
CMM	Capability Maturity Model
CV	Connected Vehicle
CVOP	Commercial Vehicle Operator Portal
CVPD	Connected Vehicle Pilot Deployment
DMS	Dynamic Message Sign
DN	Distress Notification
DSRC	Dedicated Short-Range Communication
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
I2V	Infrastructure-to-Vehicle
IE	Independent Evaluator
IRB	Institutional Review Board
ITIS	Integrated Transport Information System
ITS	Intelligent Transportation System
MEP	Mobility, Environmental, and Public Agency Efficiency
MOVES	Motor Vehicle Emission Simulation
NPMRDS	National Performance Management Research Data Set
OBE	On-Board Equipment

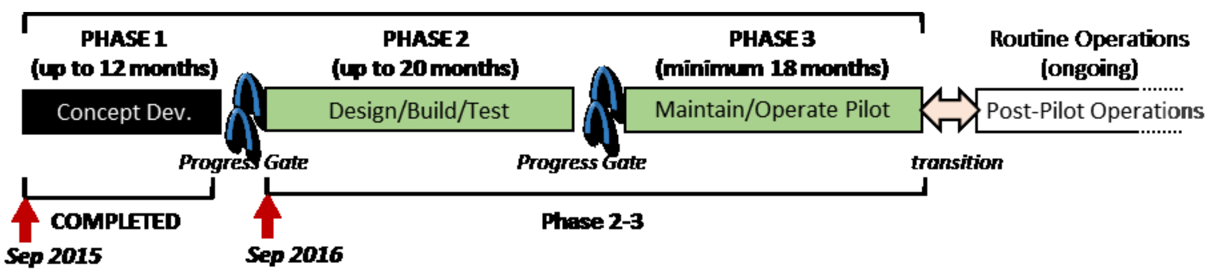
Acronym	Definition
OBU	On-Board Unit
PII	Personally Identifiable Information
PM	Performance Measure
RDE	Research Data Exchange
RSE	Roadside Equipment
RSU	Roadside Unit
RWIS	Road Weather Information System
SA	Situational Awareness
SAE	Society of Automotive Engineers
SMEP	Safety, Mobility, Environmental, and Public Efficiency
SWIW	Spot Weather Impact Warning
TAMU	Texas A&M University
TIM	Traveler Information Message
TMC	Transportation Management Center
TMDD	Traffic Management Data Dictionary
TSMO	Transportation Systems Management and Operations
TTI	Texas A&M Transportation Institute
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VSL	Variable Speed Limit
WYDOT	Wyoming Department of Transportation
WZW	Work Zone Warning

Chapter 1. Introduction

The United States Department of Transportation (USDOT) connected vehicle (CV) research program is a multimodal initiative that aims to enable safe, interoperable, networked wireless communications among vehicles, transportation infrastructure, and travelers' personal communications devices. The USDOT and others are sponsoring CV research to leverage the potentially transformative capabilities of wireless technology to make surface transportation safer, smarter, and better for the environment. Concurrent federal research efforts have developed critical cross-cutting technologies and other enabling capabilities required to integrate and deploy applications. Descriptions of the relevant research products, developed by the component CV research programs, can be found at http://www.its.dot.gov/pilots. The programs seek to identify, develop, and deploy applications that leverage the full potential of trusted communications among CVs, travelers, and infrastructure to better inform travelers, reduce environmental impacts, enhance current operational practices, and transform surface transportation systems management.

On September 14, 2015, the Connected Vehicle Pilots Deployment (CVPD) Program initiated the pilot deployments of CV applications that synergistically capture and use new forms of CV, mobile device, and infrastructure data to improve multimodal surface transportation system performance and enable enhanced performance-based systems management.

The three selected sites (Wyoming Department of Transportation [WYDOT], New York City Department of Transportation, and Tampa Hillsborough Expressway Authority) have completed the concept development phase (Phase 1) and have initiated the design/build/test phase (Phase 2). Figure 1-1 illustrates the life cycle of a CV pilot deployment.



Source: USDOT

Figure 1-1. The Three Phases of a Connected Vehicle Pilot Deployment

The CVPD Program seeks to spur innovation among early adopters of CV application concepts. The USDOT expects the pilot deployments to integrate CV research concepts into practical and effective elements, enhancing existing operational capabilities. The pilot deployments will include site-tailored collections of applications that address specific local needs while laying a foundation for additional local/regional deployment, and they will provide transferable lessons learned for other prospective deployers across the nation. The intent of the pilot deployments is to encourage partnerships of multiple stakeholders (e.g., private companies, State and local agencies, transit agencies, commercial vehicle operators, and freight shippers) to deploy applications utilizing data captured from multiple sources (e.g., vehicles, mobile devices, and infrastructure) across all elements of the surface transportation system (i.e., transit, freeway, arterial, parking facilities, and tolled roadways). The sites will demonstrate improved performance in one or more of the following areas: safety, mobility, public agency efficiency, or environmental impact. Pilot deployers will identify a set of key quantitative performance measures (PMs) and implement a system that supports continuous monitoring of observed data capable of quantifying the measures. The USDOT expects the CVPDs expected to become part of a permanent CV capability that is fully integrated into routine operational practice at the pilot site—and create a foundation for expanded and enhanced deployments. The deployers will identify and implement institutional and financial models that will enable long-term sustainability without the need for dedicated federal funding.

An evaluation of a project or a program is essential to discover how well it attains its goals. An *independent* evaluation by a third party who does not have a vested interest or stake in the project will eliminate potential bias in the findings. The USDOT has sponsored an independent evaluation of the CVPDs to help assess whether the pilots were effective in achieving their goals of transformational safety, mobility, public agency efficiency, and environmental improvements; what lessons can be used to improve the design of future projects; and how resources should be applied in the future. In parallel, the independent evaluation will help the sites in identifying the impacts of their pilot deployments by complementing the sites' performance measurement effort; determining if their actions achieved desired objectives; and, ultimately, extracting lessons that can be used to improve the continued operation of their deployments.

The sites' performance measurement activity will be limited to their study areas, project goals, and corresponding PMs. The independent evaluator (IE), on the other hand, will not only conduct a comprehensive evaluation of the deployments as implemented but also the following:

- Assessing short-term and long-term impacts of the deployments (by looking at various levels of market penetration of CV technology).
- Conducting a national-level evaluation of CV deployment, which is an assessment of potential impacts of CV technology and applications when deployed on a national scale (based on an extrapolation of findings from the three pilot sites).
- Conducting a program-level evaluation of the CV Pilots Program to inform the Government if the CV Pilots Program was able to achieve its vision cost effectively.

Purpose of the Report

The intent of this report is to update the preliminary evaluation plan developed by Noblis in October 2016. This report reflects the latest thinking by the Texas A&M Transportation Institute Connected Vehicle Pilot Deployment (TTI CVPD) Evaluation Team relative to approaches and data that will be used to assess the mobility, environmental, and public agency efficiency (MEP), as well as the cost-benefit impacts associated with the Wyoming CVPD. The report also identifies additional data collection activities that the TTI CVPD Evaluation Team may need to perform to complete the both the safety and mobility assessment of the Wyoming CVPD. The report provides the foundation for the overall evaluation approach. The TTI CVPD Evaluation Team will develop other reports to provide the details of the planned evaluation. These include the following:

- Stakeholder Acceptance/Satisfaction Evaluation Plan—this plan describes the processes and procedures for collecting and analyzing feedback and lessons learned from stakeholders, specifically decision makers, deployment operators, and managers.
- Survey/Interview Guides—this plan describes the process and procedures that the TTI CVPD Evaluation Team will use to collect, process, and analyze data related to user satisfaction.
- Site-Specific Data Plan—this plan describes the processes and procedures the TTI CVPD Evaluation Team will follow to collect, protect, manage, and disseminate data collected as part of evaluation.
- Site-Specific Analysis, Modeling, and Simulation (AMS) Plan—this plan describes the processes and procedures that the TTI CVPD Evaluation Team will follow for modeling and assessing the MEP impacts associated with the deployment.
- Site-Specific Acquisition, Installation, and Test Plan—this plan describes the processes and procedures that the TTI CVPD Evaluation Team will follow to procure, install, and test any additional data collection or system needed by the team.
- Site-Specific Participant Training and Evaluation Outreach Plan—this plan describes the processes and procedures that the TTI CVPD Evaluation Team will use to train, test, and recruit test participants if needed for the evaluation.
- Site-Specific Comprehensive Evaluation Plan—this plan provides a final summary of all the other plans developed to support the evaluation. The Comprehensive Evaluation Plan is a further refinement of this plan.

Organization of Report

This report is organized as follows:

- Section 2 provides an overview of the Wyoming CVPD including a description of the deployment corridor and the applications planned as part of this deployment.
- Section 3 lists USDOT goals and objectives for the deployment as well as the goals, objectives, hypotheses, and anticipated PMs that underpin the hypotheses.
- Section 4 provides a description of the potential confounding factors and risks that may affect the evaluation.
- Section 5 provides an overview of the approaches that will be used to conduct the assessment planned by the TTI CVPD Evaluation Team and an overview of the benefit-cost analysis.
- Section 6 provides an overview of the data that will be collected by both the Wyoming CVPD Team as well as the TTI CVPD Evaluation Team.
- Section 7 discusses the role of observation-based data analysis in the overall evaluation of the Wyoming CVPD.
- Section 8 discusses the role of simulation in the overall evaluation of the Wyoming CVPD.
- Section 9 discusses the role of survey-based evaluation in the overall evaluation of the Wyoming CVPD.

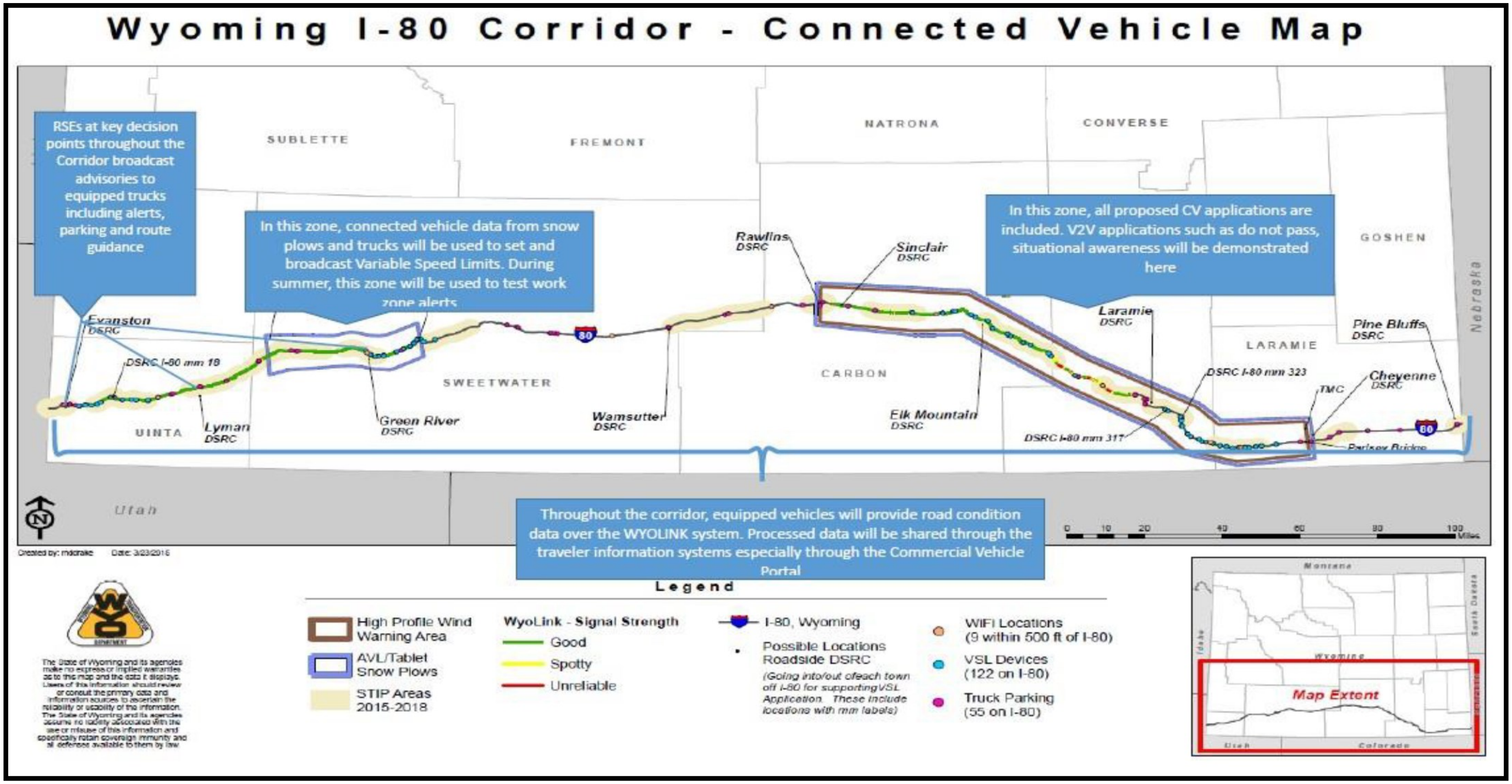
Chapter 2. Overview of Wyoming CV Pilot Deployment

This chapter describes the pilot deployment site, deployer's site goals and objectives associated with the deployment, and set of applications chosen by the local stakeholders to meet objectives, and it summarizes the metrics and data that the Wyoming CVPD Team will use to measure and monitor the performance of the deployment. The data and measures outlined in this section are only a subset of a broader collection of objectives, hypotheses, and measures associated with the USDOT evaluation presented in the USDOT Evaluation Goals, Objectives, Hypotheses, and Performance Measures section.

WYDOT is one of the first CVPD selected to showcase the value and spur the adoption of CV technology in the United States. As described in the following subsections, the Wyoming CVPD aims to reduce the impact of adverse weather on truck travel in the Interstate 80 (I-80) corridor by deploying several CV applications to mitigate existing transportation challenges.

Site Description and Transportation Issues

The proposed site is the length of I-80 in the State of Wyoming (see Figure 2-1). This corridor is about 402 mi long and reaches its maximum elevation of 8,640 ft above sea level at Sherman Summit, near Buford. As a result of the high elevation, the corridor is particularly subject to winter weather events, most commonly between October and April. Weather events typical to the corridor are ice- and snow-covered road surfaces, poor visibility, and high-wind events (i.e., wind speeds exceeding 30 mph and wind gusts exceeding 70 mph) that often lead to truck blow-overs. These truck blow-overs often result in road closures that tend to have significant economic impacts due to lost revenue. Between 2002 and 2012, over 3,472 high-wind crashes were observed. Annual average daily traffic along I-80 in Wyoming exceeds 11,000 vehicles per day. Along parts of I-80 in southern Wyoming, freight traffic comprises 30 to 55 percent of the traffic stream. Seasonal truck percentages can be as high as 70 percent. Additional challenges to freight traffic along I-80 are the lack of adequate service and parking locations as well as lack of alternate routes [1]. As a result, there is a need to develop and implement strategies to mitigate the dangers associated with truck travel on I-80 during adverse weather conditions. Figure 2-1 shows the scope of the Wyoming CVPD.



Source: Wyoming CVPD Concept of Operations, 2016 **[2]**

Figure 2-1. Wyoming CVPD Site

Goals and Objectives

The overall vision of the WYDOT CVPD is to address the safety needs of commercial vehicle operators in the State of Wyoming, as summarized below from the Wyoming CVPD Concept of Operations document [1]:

- Reduce the number of truck blow-over incidents and adverse weather-related incidents (including secondary incidents) on the I-80 corridor to improve safety and reduce incident-related delays.
- Improve emergency management on the I-80 corridor through early identification of conditions and improved messaging and communication.
- Improve freight drivers' ability to locate truck parking locations along the corridor. This objective is safety related since it allows drivers to find safer parking locations in designated areas and to meet hours-of-service regulatory requirements.
- Improve freight traveler information on construction activities in the corridor. This objective is related to both the safety of the construction zones and the increased efficiency of the freight logistics through improved information for the scheduling of freight movements through the corridor.

Description of Deployment

The Wyoming CVPD consists of five main components. Each component is described below briefly. For detailed descriptions, please refer to the Wyoming CVPD Concept of Operations document [1].

Vehicles

Four categories of vehicles will play a role in the pilot. The first two categories of vehicles are referred to as equipped vehicles since they will have on-board equipment (OBE) installed or modified as part of the pilot (see Table 2-1). These two vehicle categories are the WYDOT fleet vehicles (e.g., snowplows, highway patrol vehicles, and other State-owned vehicles) and connected trucks (i.e., trucks owned by commercial vehicle operators participating in the pilot). The vehicle OBE provides the vehicle-based processing, storage, and communications functions necessary to support CV operations. The radio(s) supporting vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications are a key component of the vehicle OBE. The OBEs are also capable of generating a Society of Automotive Engineers (SAE) Standard J2735 Basic Safety Message (BSM). This communication platform is augmented with processing and data storage capability that supports the CV applications. Also, the OBE will include an interface with the vehicle database (e.g., controller area network, local interconnect network, Ethernet/IP, FlexRay, and media oriented systems transport) that may enable communication between the vehicle OBE and other vehicle systems to support CV applications. The OBE also contains capabilities to monitor vehicle systems to support maintenance of the vehicle itself and includes sensors that monitor environmental conditions such as road condition and surface weather information. The remaining two categories of vehicles do not have any equipment installed as part of the project. However, impact evaluation requirements may require temporary data collection from these vehicles as well. These include private passenger vehicles and trucks that are connected to fleet management centers but are not equipped with an OBE.

Table 2-1. CV-Equipped Vehicles

Vehicle Type	Estimated Number
Snowplows	60
Highway Safety Patrol	40
TriHydro and Other Miscellaneous Vehicles	20
Fleet Vehicles—Large Commercial Vehicle Companies	150–200
Fleet Vehicles—Small/Medium Commercial Vehicle Companies	100
Total Equipped Vehicles	*370–420*

Source: WYDOT CV Pilot Application Deployment Plan [3]

WYDOT has planned for a two-phase deployment of CVs for this pilot. The first phase includes the WYDOT fleet vehicles (snowplows, highway safety patrol, TriHydro, etc.) and is scheduled for a winter 2018 deployment. The second phase includes the commercial vehicles participating in the pilot deployment; these vehicles are scheduled to be deployed in 2019. This phased approach will allow WYDOT to work out any technical issues before the commercial vehicle implementation; however, it will also increase the measurement period for PMs. This increased measurement period should provide WYDOT and the IE the ability to correct for data anomalies.

Roadside Infrastructure

The Wyoming CVPD Team will be using two major categories of roadside equipment (RSE) as part of this deployment:

- WYDOT Traditional Intelligent Transportation System (ITS)—this physical object includes traffic detectors, environmental sensors, Highway Advisory Radio, dynamic message signs (DMSs), closed-circuit television cameras, and video image processing systems. Variable speed limit (VSL), lane management systems, and barrier systems that control access to transportation infrastructure such as roadways are also included. This object also provides environmental monitoring including sensors that measure road conditions, surface weather, and vehicle emissions. Work zone systems including work zone surveillance, traffic control, driver warning, and work crew safety systems are included as well. This category also includes speed monitoring devices like loop detectors and nonintrusive radar detectors, as well as size and weight monitoring systems that gather truck weight and size information while in motion. While 511 is not a roadside infrastructure, it is included as part of the traditional ITS infrastructure maintained by WYDOT.
- WYDOT RSE—this object describes the RSE that will be deployed as part of the system. RSE represents the CV roadside devices that are used to send messages to, and receive messages from, nearby vehicles using dedicated short-range communication (DSRC) or other alternative wireless communication technologies. Communications with adjacent field equipment and back-office centers that monitor and control the RSE are also supported. This device operates from a fixed position and may be permanently deployed or a portable device that is located temporarily in the vicinity of a traffic incident, road construction, or special event. It includes a processor, data storage, and communications capabilities that support secure communications with passing vehicles, other field equipment, and centers.

Table 2-2 provides a summary of the RSE devices that the Wyoming CVPD Team plans to use in this deployment.

Table 2-2. Summary of Devices for Deployment

WYDOT—Devices	Estimated Number
Roadside Unit (RSU)	75
WYDOT Fleet Subsystem On-Board Unit (OBU)	100
Integrated Commercial Truck Subsystem OBU	150
Retrofit Vehicle Subsystem OBU	20–30
Basic Vehicle Subsystem OBU	100–150
Total Equipped Vehicles	*400*

Source: WYDOT CV Pilot Application Deployment Plan [3]

Centers

The Wyoming CVPD will also take advantage of three main centers. They include the following:

- WYDOT Transportation Management Center (TMC)—The TMC is planned to be the hub of operations for the CV pilot, collecting information from the WYDOT fleet and partnering fleet management centers. The TMC supports the integration and fusion of CV and non-CV data to developing warnings and advisories. The TMC also provides traveler information services back to the general public and fleet management centers via various means.
- Fleet Management Centers—the partnering fleet management centers will both receive and send real-time information to the WYDOT TMC about their firm's truck operations and corridor conditions. These centers (and associated personnel) are responsible for the dispatching and management of commercial vehicle fleets (e.g., traditional fleet managers) and freight equipment assets. There may be many people in a large trucking organization or a single person (owner driver) in the case of single vehicle fleets. The fleet management centers provide instructions and coordination for commercial vehicles and freight equipment and receive the status of the vehicles and freight equipment in the fleets that they manage.
- Data Warehouse—a data warehouse capability is planned for the pilot to collect, manage, and make available the data collected as part of the pilot for performance management and evaluation. The data warehouse is a data distribution service that collects, processes, and distributes CV data; connects data producers with data consumers; and facilitates data sharing in the Connected Vehicle Exchange. It focuses on data that are relevant for a period beyond the immediate (10 minutes or more, roughly), and it distributes those data to interested parties using a publish-and-subscribe mechanism. It stores data for a period long enough to satisfy the utility of those data. It may discard data when they are no longer relevant. The data warehouse supports performance measurement dashboards and the impact assessment.

Personnel

Key personnel involved in this pilot include the following:

- WYDOT TMC Weather Operator—the WYDOT TMC weather operator represents the on-site weather support service that exists in the WYDOT TMC. The function provides weather, hydrologic, and climate information and warnings of hazardous weather. It provides an analysis of atmospheric weather observations and derives forecasts that are an ensemble of the National Weather System, private-sector providers, and various research organizations. The service provides formatted weather data products suitable for online processing and integration with other ITS data products.
- WYDOT TMC Operations Personnel—this group represents the WYDOT ITS personnel that operate a traffic management center. These personnel interact with traffic control systems, traffic surveillance systems, incident management systems, and work zone management systems. They provide operator data and command inputs to direct system operations to varying degrees depending on the type of system and the deployment scenario.
- WYDOT Maintenance Field Personnel—this group represents the people that perform maintenance and construction field activities including vehicle and equipment operators, field supervisory personnel, field crews, and work zone safety personnel. Information flowing from the maintenance and construction field personnel will include those system inputs specific to maintenance and construction operations, such as information regarding the status of work zones or maintenance actions. The field personnel are also monitored within the work zone to enhance work zone safety.
- WYDOT Highway Patrol Personnel—this group represents the personnel that perform incident management and enforcement-related activities on I-80. Information flowing from highway patrol personnel will include those inputs specific to incident management, commercial vehicle enforcement, and emergency management.

Communications Infrastructure

A secure WyoLink Radio Network exists throughout the corridor. WyoLink is a statewide digital trunked very-high-frequency P-25 compliant public safety communications system. The system is used for voice traffic and secondarily for low-speed mobile data communications; it provides radio service to public safety entities at all levels (city, county, State, and Federal agencies as well as commercial emergency medical responders and hospitals). The WyoLink system is maintained by WYDOT's Telecommunications Program.

Point-to-point wireless microwave communications are used to communicate between WyoLink radio sites, which also support a parallel IP backhaul communication system used by ITS. Using point-to-multipoint wireless communications to extend from the backhaul system to roadside service points, WYDOT has also been able to set up a network of roadside Wi-Fi hotspots along the I-80 and I-25 corridors. Using low-cost antennas, WYDOT has been able to achieve Wi-Fi signal range of more than a mile in some locations. DSRC communications between RSE and vehicles and cellular linkages between fleet management centers are included in the communications infrastructure as well.

The proposed CV system will collect and integrate road data, weather data, traffic data, work zone information, parking availability, and accident information from a variety of sources (e.g., connected trucks, WYDOT fleets, fixed infrastructure sensors) to generate safety and road condition messages that will be shared among CVs in real time and stored in the data warehouse. For detailed information on the WYDOT CV Pilot system, please refer to the Concept of Operations document [1].

CV Applications

The Wyoming CVPD Team will be implementing six truck-related CV applications for this CV pilot site. The focus of these applications is on reducing truck-related crashes as well as mitigating their impacts. The following provides brief descriptions for each of the seven applications. For detailed descriptions of the CV applications, please refer to Wyoming's application deployment plan document [3].

Forward Collision Warning

This application is a V2V communication-based safety feature that issues a warning to the driver of the connected host vehicle in case of an impending front-end collision with a CV ahead in traffic in the same lane and direction of travel on both straight and curved geometry roadways. Forward collision warning (FCW) will help drivers avoid or mitigate front-to-rear vehicle collisions in the forward path of travel. The system does not attempt to control the host vehicle to avoid an impending collision. This application will follow the description from SAE Standard J2945, March 1, 2016.

Infrastructure-to-Vehicle Situational Awareness

This application enables relevant downstream road condition information including weather alerts, speed restrictions, vehicle restrictions, road conditions, incidents, parking, and road closures to be broadcast from a RSU and received by the connected host vehicle. Such information is useful to connected host vehicles that are not fully equipped with weather sensors or to connected host vehicles in paths toward or entering areas with hazardous conditions. The Wyoming pilot will extend this application to use full coverage of the I-80 corridor with satellite communications to send road condition information directly to selected CVs. This step is important for mitigating the short-range and sparse placement of RSUs along the corridor. This application will follow the description from SAE Standard J3067, August 2014, section 2.9.3.6.

Distress Notification

This application enables CVs to communicate a distress status when the vehicle's sensors detect an event that might require assistance from others or the vehicle's operator manually initiates a distress status. The vehicle generates and broadcasts a distress message (e.g., Mayday) to the nearest RSU. When an RSU is not within communication range, the message is received by CVs that are in the vicinity and forwarded to an RSU that then forwards it to the Wyoming CV System. The distress message will include the location, time of message, distress message explanation (e.g., air bag deployed, vehicle disabled, operator initiated), and vehicle make and model. Additionally, the distress notification (DN) received by nearby CVs is broadcast to notify oncoming vehicles that a distressed vehicle is ahead. Although this application is loosely based on the Mayday application description from SAE Standard J3067, section 3.5.9.2.1, it is built on a higher priority traveler information message (TIM) communication using SAE Standard J2735, March 2016, section 5.16, part 3, Integrated Transport Information System (ITIS) advisory elements.

Work Zone Warning

This application provides information about the conditions that exist in a work zone toward which the vehicle is approaching. This capability provides approaching vehicles with information about work zone activities that could present unsafe conditions for the vehicle, such as obstructions in the vehicle's travel lane, lane closures, lane shifts, speed reductions, or vehicles entering/exiting the work zone. This application will follow the TIM work zone warning described in SAE Standard J2735, part 3 in section 6.142.

Spot Weather Impact Warning

Similar to situational awareness, this application enables relevant road condition information, such as fog or icy roads, to be broadcast from an RSU and received by the connected host vehicle. This application, however, is distinct from situational awareness in that it provides more localized information (i.e., at the segment level instead of area-wide or region-wide). This application will follow the TIM advisory content from part 3 defined in SAE Standard J2735, section 6.142 for ITIS data elements 6.54 for weather conditions and 6.55 for winds (as defined in SAE Standard J2540_2). This application includes information on parking availability, when needed, as part of the advisory.

Improved TMC Operations

WYDOT is expecting to use the information generated by the Wyoming CVPD to support their ongoing traffic—80 management and traveler information services. WYDOT will use the information collected by the CVs to augment sensor data to set VSLs along I-80 and update their 511 and other traveler information systems. In addition, information from the Wyoming CV System will update the WYDOT Commercial Vehicle Operator Portal (CVOP) system to provide freight-specific information to subscribed fleet partners. Currently, more than 800 firms subscribe to CVOP.

WYDOT CVPD Performance Targets

The Wyoming CVPD Team has incorporated 21 performance targets into eight performance categories to characterize expected benefits associated with the Wyoming deployment. Table 2-3 through Table 2-11 show these performance targets. Table 2-3 through Table 2-11 also provide a mapping of the seven applications to the different performance measurement categories.

Table 2-3. Performance Measures and Targets [4]: Improved Road Weather Condition Reports Received into the TMC

No.	Performance Measure	Target
1	Number of road weather condition reports per road section/day pre- and post-CV pilot (quantity)	30% increase
2	Number of road sections with at least one reported road condition per hour pre- and post-CV pilot (coverage)	25% increase
3	Average refresh time of road condition reports in each section pre- and post-CV pilot (latency)	30% decrease

Table 2-4. Performance Measures and Targets [4]: Improved Ability of the TMC to Generate Alerts and Advisories

No.	Performance Measure	Target
4	Pikalert generated motorist alert warnings that were accepted by TMC operators	90% accepted

Table 2-5. Performance Measures and Targets [4]: Effectively Disseminated and Received Infrastructure-to-Vehicle (I2V) and V2I Alert/Advisory Messages from the TMC

No.	Performance Measure	Target
5	Number of messages sent from the TMC that are received by the RSU	90% of sent alerts/advisories were received by RSU
6	Number of messages sent and received between the RSU and WYDOT fleet vehicles' OBU (when vehicles are in the vicinity of an RSU)	75% sent were received in either direction
7	CVs that likely took action following receipt of an alert ● Parked ● Reduced speed ● Came to a stop safely ● Exited	80% of vehicles likely took action based on alert

Table 2-6. Performance Measures and Targets [4]: Improved Information to Commercial Vehicle Fleet Managers

No.	Performance Measure	Target
8	Number of operational changes made by fleet managers due to information from TMC (compare before and after the CV pilot) ● Routing ● Timing ● Parking availability ● Canceled trips	20% increase in operational changes during CV pilot
9	Commercial vehicle managers are satisfied with information provided by the TMC (compare before and after the CV pilot) ● Road conditions ● Road weather forecasts ● Parking information	90% of responding commercial vehicle fleet managers expressed satisfaction with information during CV pilot
10	Commercial vehicle drivers experienced benefits due to CV technology during major incidents and events on I-80	N/A

Table 2-7. Performance Measures and Targets [4]: Effectively Transmitted and Received V2V Messages

No.	Performance Measure	Target
11	Number of V2V messages properly received in surrounding vehicles from sending vehicle (WYDOT fleet vehicles in vicinity of each other)	75% of alerts sent from an equipped vehicle were received by other vehicles
12	CVs that took action following receipt of a V2V alert ● Parked ● Reduced speed ● Came to a stop safely ● Exited	80% of vehicles took action based on V2V alert

Table 2-8. Performance Measures and Targets [4]: Automated Emergency Notifications of a Crash

No.	Performance Measure	Target
13	Number of emergency notifications that are first received in the TMC from CVs (compared to alternate traditional methods, such as 911 caller)	N/A

Table 2-9. Performance Measures and Targets [4]: Improved Speed Adherence and Reduced Speed Variation

No.	Performance Measure	Target
14	Total vehicles traveling at no more than 5 mph over the posted speed (compare before and after CV pilot)	20% improvement over baseline of total vehicles traveling no more than 5 mph over posted speed during CV pilot. Baseline will determine what percentage is traveling no more than 5 mph over posted speed prior to CV pilot.
15	Total vehicles traveling within ±10 mph of 85th percentile speed (compare before and after CV pilot)	20% improvement over baseline of total vehicles traveling within ±10 mph of the 85th percentile speed during CV pilot. Baseline will determine what percent is traveling within ±10 mph of the 85th percentile speed prior to CV pilot
16	Speeds of applicable CVs are closer to posted speed when compared to non-CVs	CVs are 20% closer to posted speed

Table 2-10. Performance Measures and Targets [4]: Reduced Vehicle Crashes

No.	Performance Measure	Target
17	Number of CVs involved in a crash ● Initial crashes ● Secondary crashes[1] (total and specifically rear-end crashes)	N/A
18	Reduction of the number of vehicles involved in a crash (compare a 5-year average before pilot to CV pilot data) ● Track connected versus non-CVs	25% reduction in the number of vehicles involved in a crash
19	Reduction of total and truck crash rates within a work zone area (compare a 5-year average before pilot to CV pilot data) ● Track connected versus non-CVs	10% reduction in total and truck crash rates within work zones
20	Reduction of total and truck crash rates along the corridor (compare a 5-year average before pilot to CV pilot data) ● Track connected versus non-CVs	10% reduction in total and truck crash rates
21	Reduction of critical (fatal or incapacitating) total and truck crash rates in the corridor (compare a 5-year average before pilot to CV pilot data) ● Track connected versus non-CVs	10% reduction in total and truck critical crash rates

[1] Secondary crashes are defined as the number of crashes beginning with the time of detection of the primary incident where the collision occurs either (a) within the incident scene or (b) within the queue, including the opposite direction, resulting from the original incident (Federal Highway Administration [FHWA], 2000).

Table 2-11. Identified Performance Measures by CV Application

Category	WYDOT Needs	No. Performance Measure	Evaluation Question	CV Application
Safety	Improved road weather condition reports received into the TMC	1. Number of road weather condition reports per road segment/day (quantity) 2. Miles with at least one reported road condition per hour (coverage) 3. Average refresh time of road condition reporting in each segment (latency)	Does the amount and specificity of roadway weather condition data increase from the before period to the pilot period?	Situational Awareness (SA) Work Zone Warning (WZW) Spot Weather Impact Warning (SWIW) TMC Ops
Public Agency Efficiency	Improved ability of the TMC to generate alerts and advisories	4. Pikalert generated alerts and advisories that were accepted by TMC operators	Does the pilot deployment allow the TMC staff to generate more alerts and advisories for road users compared to the before period?	SA WZW SWIW TMC Ops
Public Agency Efficiency	Effectively disseminated and received I2V and V2I alert/ advisory messages from the TMC	5. Number of messages sent from the TMC that are received by the RSU 6. Number of messages sent and received between the RSU and WYDOT fleet vehicles' OBU (when vehicles are in the vicinity of an RSU) 7. CVs that likely took action following receipt of an alert: - Parked - Reduced speed - Came to a stop safely - Exited	Can the TMC provide more relevant alerts and advisories to the connected roadway users than the non-connected users? Did this affect the behavior of the connected roadway user compared to the non-connected user?	SA DN WZW SWIW TMC Ops

Category	WYDOT Needs	No. Performance Measure	Evaluation Question	CV Application
Mobility	Improved information to commercial vehicle fleet managers	8. Number of operational changes made due to information from TMC during CV pilot: - Routing - Timing - Parking availability - Canceled trips 9. Commercial vehicle managers are satisfied with information provided by the TMC during the CV pilot - Road conditions - Road weather forecasts - Parking information 10. Commercial vehicle drivers experienced benefits due to CV technology during major incidents and events on I-80	Do commercial vehicles or fleets experience an increase in perceived value as part of the pilot deployment? Did this value increase result in behavior, policy, or operational changes for the commercial vehicle or fleet?	SA WZW SWIW TMC OpsI
Safety, Mobility	Effectively transmitted and received V2V messages	11. Number of V2V messages properly received in surrounding vehicles from sending vehicle (WYDOT fleet vehicles in vicinity of each other) 12. Percent of CVs that took action following receipt of a V2V alert: - Parked - Reduced speed - Came to a stop safely - Exited	Are CVs able to communicate effectively while on the road? Did this communication result in a change in behavior or a reduction in crashes or other safety-related incidents?	FCW SA DN WZW SWIW TMC Ops
Safety	Automated emergency notifications of a crash	13. Number of emergency notifications that are first received in the TMC from CVs (compared to alternate traditional methods, such as 911 caller)	Are CVs able to more efficiently and effectively transmit emergency notifications to the proper authorities than traditional methods?	SA DN WZW SWIW TMC Ops

Category	WYDOT Needs	No. Performance Measure	Evaluation Question	CV Application
Safety, Mobility	Improved speed adherence and reduced speed variation	14. Total vehicles traveling at no more than 5 mph over the posted speed (compare before and after CV pilot) 15. Total vehicles traveling within ±10 mph of 85th percentile speed (compare before and after CV pilot) 16. Speeds of applicable CVs are closer to posted speed when compared to non-CVs	Does speed limit adherence and speed variability on a given study segment for a given time period decrease from the before period to the pilot period? Is this accompanied by an overall change in average segment speed?	SA DN WZW SWIW TMC Ops
Safety	Reduced vehicle crashes	17. Number of CVs involved in a crash: - Initial crashes - Secondary crashes (total and specifically rear-end crashes) 18. Reduction of total and truck crash rates in the corridor - Track connected versus non-CVs 19. Reduction of total and truck crash rates within a work zone area (compare a 5-year average before pilot to CV pilot data) - Track connected versus non-CVs 20. Reduction of total and truck crash rates along the corridor (compare a 5-year average before pilot to CV pilot data) - Track connected versus non-CVs 21. Reduction of critical (fatal or incapacitating) total and truck crash rates in the corridor (compare a 5-year average before pilot to CV pilot data) - Track connected versus non-CVs	Do CVs experience a reduction in traffic crashes compared to historical and non-CVs along a given study segment during a given time frame?	FCW SA DN WZW SWIW TMC Ops

Wyoming's PM Evaluation Approaches

The Wyoming site has proposed five types of approaches for assessing the performance of its system [5]. This section provides a brief description of each of the proposed analysis approaches. Table 2-12 shows the sources of data available from the Wyoming CVPD.

Before and After

This approach quantitatively compares data under baseline conditions (pre-deployment) with data during the Wyoming CVPD (post-deployment). The before and after evaluation design requires the establishment of a baseline to document conditions before the CV pilot project elements were deployed. This baseline was established during Phase II (2016–2017 winter season) and will define the benchmarks from which future conditions with CV pilot project elements in place can be compared.

The before and after evaluation is most useful for demonstrating effects over a relatively short period because the more time that passes, the greater the likelihood that other factors can obscure the effects of the CV pilot demonstration itself. However, advantages of a longer period include the ability to track the relatively infrequent occurrence of key indicators, such as crashes, and the likelihood that a range of weather events will occur in both the pre- and post-deployment periods. One of the challenges of this approach is ensuring that the data collected before and after the CV pilot project element deployments are as close as possible. Weather conditions are a prime example of how challenging this may be. To address this challenge, the Wyoming CVPD Team proposes to develop a method to characterize weather events to ensure comparisons and analyses of pre- and post-deployment data during similar weather events. The Wyoming CVPD Team will work to define each weather event in terms of weather type, intensity, duration, precipitation amounts, wind speeds, etc. and group weather events into similar categories. This task will be accomplished while establishing the baseline period as well as CV technology post deployment. Analyses will be focused on weather events, and comparisons will be made for similar weather event categorizations and severity.

Many of the PMs identified will utilize the before and after evaluation approach. Examples of data needed to support the before and after analyses include the number of road condition reports, miles of road covered with conditions reports, refresh time of road condition reports, staff time to disseminate broad area traveler information, speed and crash data, and many others. Values for these types of data will be compared before and after CV pilot deployments to measure the percent increase/decrease.

With and Without

This technique quantitatively compares data from conditions where CV pilot project elements are in place and used (experimental) with conditions where CV pilot project elements are not present (control). These comparisons would be made during the same time, location, and conditions. An advantage of the with and without design is the ability to effectively control for variability in weather conditions and other confounding factors that would equally affect two different situations, one of which would experience the CV pilot deployments and the other of which would not. The differences in outcomes will be observed between these two situations, and those differences will be attributed to the effect of the CV pilot elements.

Only a few PMs identified will utilize this method. Examples of data needed to support the with and without analyses include speed of connected versus non-CVs and crashes of connected versus non-CVs.

System Performance Evaluation

This evaluation will quantitatively assess how well the system worked to provide information, alerts, and advisories (V2I and V2V). The two previous evaluation approaches (before and after and with and without) do not apply to the evaluation of these measures. The system performance evaluation approach will collect the necessary data to assess how well the system performed against the expectations (targets). Examples of data needed to support this approach include the number of automated alerts/advisories sent and the number that was received for both the V2I and the V2V applications.

Behavior Assessment

This evaluation measure specifically addresses behaviors, or actions that result from alerts being received by drivers of CVs. Possible behaviors could include reducing speed, coming to a stop safely, parking the truck in the event of a closure, or detouring around an incident or closure if available. Additionally, this evaluation design will apply to operational changes made by fleet managers in response to information received from the TMC.

Qualitative Assessment

This assessment is a descriptive approach to evaluate a particular strategy implementation, a qualitative assessment evaluation seeks to identify what did and did not work well and derive lessons learned from the experience.

For the before and after, with and without, and system performance evaluation designs, qualitative surveys or staff interviews obtained from key informants are useful in supplementing the quantitative data normally collected during the evaluation period and aiding in interpreting evaluation results.

An advantage of this approach is that it is focused on a particular (or several) CV pilot deployment and can track the cause-effect relationships as the use of these deployments yield desired outcomes. The data are primarily derived from readily available sources and surveys and/or interviews with key project stakeholders such as TMC operators, WYDOT maintenance personnel, fleet managers, etc. The qualitative information collected will be used to supplement other pilot outcome data to perhaps better understand why certain things occurred.

Wyoming's PM Evaluation Data Types

The section describes the five types of data that Wyoming PM Team has identified five types of data will be collected and managed as part of this pilot. These data are those slated for collection by the site to support its performance measurement activities. Additional data collection may be required to satisfy USDOT evaluation objectives. Data identified for collection by the site are:

- System Data—Data collected from the CV pilot system. These include BSMs generated and received by various CV objects in the system, time-stamped CV alerts and data, mobile road weather observations generated from equipped vehicles, time-stamped alerts and advisories generated by TMCs received as part of the CV environment by vehicles, time-stamped RSU logs, time-stamped DSRC logs, OBU logs indicating alerts received, etc.
- Non-system Data—Data collected from external systems and databases necessary to support performance measurement. These may include data from traditional ITS systems such as the Road

Weather Information System (RWIS), speed sensors, DMS logs, etc. Examples include traffic data such as speeds (from roadside speed radar detectors), crash database records, construction and maintenance logs, etc. These data are not likely to contain personally identifiable information (PII) and will be available for submission to the Research Data Exchange (RDE) with appropriate metadata.

- Modeling and Simulation Data—In addition to the primary safety PMs of crash reduction, the performance measurement evaluation will also utilize traffic simulation modeling using VISSIM software for the analysis of safety surrogate measures. The simulation model analysis will incorporate CV-equipped driver behavior observed during the demonstration period into the modeling parameters to evaluate changes in the system if a larger percentage of vehicles in the corridor were CV-equipped. Model calibration data, assumptions, and network files created for the modeling exercise will be housed in the University of Wyoming and made available to the IE. Outputs from the modeling and simulation runs will be shared as well.
- Survey Data—Data will be collected from participants in the pilot regarding perception of application effectiveness and assessment of system performance during the baseline surveys where feasible and in post deployment. Survey respondents will likely include participating truck drivers, nonparticipating truck drivers using WYDOT CVOP, commercial vehicle fleet managers, and WYDOT personnel. Additional details will be provided in the stakeholder acceptance evaluation plan. Survey data will be collected by the Wyoming CVPD Team and will be sanitized to remove any PII before sharing with RDE.
- Interview Data—Qualitative data may be collected at various points to support the previously identified PMs. These data also include lessons learned and institutional issues gathered through interviews with involved personnel. Interview data will be stored by the Wyoming CVPD Team and summaries of findings shared with USDOT and the IE. Interview data will not be posted to the RDE.

WYDOT has agreed to support USDOT evaluation needs by providing data required for the IE effort on a bi-weekly basis through established data-sharing protocols. Table 2-12 through Table 2-15 provide the details of the specific data elements to be provided by WYDOT CVPD toward the IE effort of the performance measurement and evaluation support plan [5]. The WYDOT CV Pilot site will store data within the TMC databases in an encrypted format for data that are potential or actual PII. The servers that house these data will be restricted to WYDOT background-checked staff and the CV lead developer and lead performance evaluator. The collected data will be released to USDOT RDE after they have been sanitized for PII. The security management and privacy operating concept provide more guidance on the pilot's approach to managing PII.

Table 2-12 through Table 2-15 summarize the data requirements and sources that the WYDOT CVPD Team plan to use with their evaluation.

Table 2-12. Sources System Data from the Wyoming CVPD: System Data—Vehicle

Data Type	Data Element Description	Source	Collection Approach	Frequency	Performance Measure	Baseline Data?
BSM Part 1	• Date. • Time. • Location. • Speed. • Acceleration. • Heading. • Vehicle size. • Breaking data. Refer to the technical roundtable data elements definition spreadsheet currently under development for a complete list.	OBUs	Download to RSUs, when available	**Sent BSMs:** 10 sec (at 10 Hz) before and after an "interaction," and a snapshot every 30 sec at all times. **Received BSMs:** At all times when CV is within range. **At RSUs:** As available.	All PMs	No
BSM Part 2	• Steering wheel angle. • Brake status. • Air bag deployment. • Traction control. • Antilock brake status. • Transmission status. • Additional vehicle details. Refer to the technical roundtable data elements definition spreadsheet currently under development for a complete list.	OBUs	Download to RSUs, when available	**Sent BSMs:** 10 sec (at 10 Hz) before and after an "interaction," and a snapshot every 30 sec at all times. **Received BSMs:** At all times when CV is within range. **At RSUs:** As available.	All PMs	No

Data Type	Data Element Description	Source	Collection Approach	Frequency	Performance Measure	Baseline Data?
Mobile road weather observations	• Precipitation type. • Solar radiation. • Wiper frequency. • Ground temp. • Ambient temp. • Barometric pressure. • Humidity. See system requirements for a complete list of data elements.	Vehicle data logger	Download to RSUs, when available	**At RSUs:** As available.	All PMs	No
Vehicle interaction events—V2V and V2I	• Time-stamped event logs by type.	OBUs	Download to RSUs, when available	**At RSUs:** As available.	All PMs	No

Table 2-13. Sources System Data from the Wyoming CVPD: System Data—CV System

Data Type	Data Element Description	Source	Collection Approach	Frequency	Performance Measure	Baseline Data?
Pikalert road conditions	Pikalert generated segment-based (1 mi): • Atmospheric: ○ Temperature. ○ Probability of precipitation. ○ Wind speed. ○ Wind direction. • Road weather: ○ Pavement temperature. ○ Subsurface temperature. ○ Forecast. • Customizable forecast time and update. See system requirements for a complete list of data elements.	Pikalert system logs	Direct connection from Pikalert to TMC and data warehouse	Every 5 minutes.	All PMs	No
Pikalert motorist advisories and warnings	• Motorist alert warnings including: ○ Precipitation hazards. ○ Road condition hazards. ○ Visibility hazards. See system requirements for a complete list of data elements.	Pikalert system logs	Direct connection from Pikalert to TMC and data warehouse	Every 5 minutes, or when available.	PM 4	No
TMC generated TIMs, alerts and warnings	• TIMs, alerts and warnings from TMC and satellite providers. Refer to the technical roundtable data elements definition spreadsheet currently under development for a complete list.	TMC system logs	Direct connection to data warehouse	Continuous.	PM 5	No

Data Type	Data Element Description	Source	Collection Approach	Frequency	Performance Measure	Baseline Data?
WYDOT Transportation Reporting and Action Console data	• Highway patrol incident reports. • Operator action logs. • Citizen reports. See system requirements and Traffic Management Data Dictionary (TMDD) data feed specifications for specific data elements.	TMC system logs	Direct connection to data warehouse	Continuous.	All PMs	Yes
WYDOT construction console events	I-80 construction events including: • Start time. • End time. • Location. • Type of construction.	TMC system logs	Direct connection to data warehouse	Continuous.	All PMs	Yes
WYDOT incident console events	See system requirements and TMDD data feed specifications for specific data elements on incidents.	TMC system logs	Direct connection to data warehouse	Continuous.	All PMs	Yes

Table 2-14. Sources Non-System Data from the Wyoming CVPD

Data Type	Data Element Description	Source	Collection Approach	Frequency	Performance Measure	Baseline Data?
Individual vehicle speed data	• Date. • Time. • Speed. • Lane. • Vehicle length. • Vehicle classification.	I-80 Wavetronics radar-based speed sensors	Real time; WYDOT trunk communica tions	Continuous.	PM 14–16	Yes
WYDOT RWIS data	I-80 road weather information stations data including: • Air temperature. • Pavement temperature. • Wind speed, wind gusts. • Precipitation. • Visibility. • Road surface conditions.	RWIS system logs	Direct connection to data warehouse	Every 5 minutes.	All PMs	Yes
WYDOT VSL system events	Time-stamped VSL activations, deactivations, speeds set on all I-80 VSL signs. See system requirements and TMDD data feed specifications for specific data elements.	TMC system logs	Direct connection to data warehouse	Continuous.	All PMs	Yes
WYDOT DMS records	Time-stamped DMS activations, deactivations, and messages on I-80 signs. See system requirements and TMDD data feed specifications for specific data elements.	TMC system logs	Direct connection to data warehouse	Continuous.	All PMs	Yes

Data Type	Data Element Description	Source	Collection Approach	Frequency	Performance Measure	Baseline Data?
WYDOT road closures	• I-80 road closures. • Beginning point. • Ending point. • Start time.	TMC system logs	Direct connection to data warehouse	Continuous.	All PMs	Yes
Crash data records	Vehicle crash records including: 1. Number of crashes (primary and secondary). 2. Crash locations. 3. Crash dates and times. 4. Number of vehicles involved. 5. Vehicle types involved. 6. Crash rate for trucks and other vehicles. 7. Crash contributing factors. 8. CV vehicles involved in a crash (post deployment). 9. Work zone related crashes. 10. Critical injuries.	WYDOT highway safety	Specific request	5-year history for baseline. Otherwise, monthly download.	PM 17–21	Yes

Table 2-15. Planned Wyoming PM Evaluation Surveys and Interviews

Data Type	Data Element Description	Source	Collection Approach	Frequency	Performance Measure	Baseline Data?
CVOP fleet manager survey responses	Survey results focused on satisfaction and actions taken by fleet managers based on TMC information.	Electronic survey	Web-based data entry	Initially for baseline, and then periodically as appropriate.	PM 8–9	Yes
CVOP driver survey responses	Survey results of commercial vehicle drivers regarding use of CV technologies during demonstration.	Electronic survey	Web-based data entry	Periodically as appropriate.	PM 10	No
WYDOT staff surveys and interviews	Survey and interview results of WYDOT staff regarding operations before and after CV technology deployment.	Combination of electronic survey and on-site interviews	Web-based data entry and notes	Initially for baseline, and then periodically as appropriate.	All PMs	Yes

Chapter 3. USDOT Evaluation Goals, Objectives, Hypotheses, and Performance Measures

This section identifies the key USDOT goals for the CV pilots and the related objectives, hypotheses, and PMs for the Wyoming CVPD. Note that these are preliminary objectives, hypotheses, and PMs that will need to be refined by the IE in coordination with USDOT as the CV Pilots progress through Phase 2. The intent of the USDOT evaluation effort is to leverage the site performance measurement activity outlined in Chapter 2 and to augment site performance measurement activity as required to address the set of broader federal evaluation goals.

Definitions

The following definitions are used in the document for the various stakeholder groups:

- Pilot Deployer: These include pilot managers and decision makers, partnering agencies, and technical staff involved in application design, development, testing, etc.
- Transportation Managers: These include the TMC operators, TMC meteorologists, fleet managers, highway safety patrol, and maintenance personnel.
- End Users: These include the truck drivers (CV-equipped WYDOT fleet and commercial). Note that non-equipped vehicles are also end users, but data will not be collected or measured from these stakeholders.

IE Goals and Objectives for Evaluating the Wyoming CVPD

The goal of the USDOT's CVPD Program is to demonstrate and quantify the extent to which deploying, testing, operationalizing cutting-edge mobile and roadside technologies, and enabling CV applications can:

- Save live and enhance safety.
- Improve personal mobility.
- Reduce negative environmental impacts.
- Improve public agency efficiency and decision making by transportation managers.
- Improve end-user satisfaction with travel.

As discussed previously, the role of the independent evaluation is to assess the extent to which CV technologies improved safety, mobility, the environment, and public efficiency in the I-80 corridor. As part of the independent evaluation effort, the TTI CVPD Evaluation Team is responsible for assessing extent to which the each individual pilot deployment improved personal mobility, reduce environmental impacts, and transformed public agency operations. The TTI CVPD Evaluation Team will use many of the same hypothesis, PMs, and data used by the Wyoming CVPD Team will use to conduct their evaluation. The intent of the independent evaluation is not replace or supersede the evaluation performed by the site, but to, hopefully, confirm and reaffirm the results found the Wyoming CVPD Team using the same data collected at the sites. If differences in findings occurs, the TTI CVPD Evaluation Team will work with the USDOT and the Wyoming CVPD Team to find the source, document, and resolve those differences.

It should be noted that TTI CVPD Evaluation Team will be evaluating the MEP impacts resulting from the Wyoming CVPD. The Volpe Institute is responsible for assessing the extent to which deploying CV technologies in commercial vehicles using I-80 corridor reduced crash frequencies and severity, and improved safety. The TTI CVPD Evaluation Team plans to use the results of these finding (as well as an assessment of the extent to which safety improvement also resulted in mobility improvements in the corridor) to perform a benefit-cost assessment.

The key MEP objectives of the independent evaluation for the Wyoming CVPD evaluation are as follows:

1. Assess the extent to which deploying CV technologies improved mobility, travel reliability, and throughput in the I-80 corridor during adverse weather conditions.
2. Estimate the extent to which reductions in crash frequency and severities contributed to improvements in mobility and travel reliability along the I-80 corridor as a result of equipping commercial fleet vehicles and WYDOT maintenance vehicles with CV technologies.
3. Estimate the extent to which deploying CV technologies improved travel and freight reliability for commercial fleet vehicles equipped with CV technologies.
4. Quantify the extent to which CV technologies helped improve emergency management on the I-80 corridor through early identification of conditions and improved messaging and communication.
5. Assess the extent to which improved traveler information on road weather conditions and construction activities in the corridor improved freight drivers' ability to better plan and adjust their trips (e.g., locate truck parking locations along the corridor).
6. Assess the extent to which deploying CV technologies in the I-80 corridor help public agencies official to better manage operations and deploy traffic management strategies.
7. Estimate the extent to which improved mobility for connected trucks and for all traffic will reduce negative environmental impacts along I-80 during adverse weather.
8. Estimate that extent to which the life-cycle mobility, environmental and public agency efficiencies benefits as market penetration and background traffic changes over the seven years after deployment.
9. Conduct a benefit-cost assessment associated with equipping commercial fleet vehicles with CV technologies in the I-80 corridor.

Table 3-1 shows which of the deployed CV applications deployed in the I-80 corridor associated with these evaluation objectives for Wyoming.

Table 3-1. Mapping of Planned Applications to USDOT Objectives for Wyoming CVPD

USDOT Objective	FCW	SA	DN	WZW	SWIW	Traffic Mgmt./TI
1		X		X	X	X
2	X	X	X	X	X	X
3		X				X
4		X				X
5	X	X		X	X	X
6		X				X
7	X	X	X	X	X	X
8	X	X	X	X	X	X
9	X	X	X	X	X	x

Evaluation Hypotheses

Table 3-2 identifies the key mobility, environmental and public agency efficiency hypotheses that TTI CVPD Evaluation Team will use in its independent evaluation to determine the extent to which the Wyoming CVPD achieved USDOT's overall goals and objectives. The TTI CVPD Evaluation Team will use these evaluation hypotheses to guide the development of the rest of the components of the independent evaluation plan. Note: safety is a critical component of the Wyoming CVPD. The Volpe Institute is responsible for assess the impact of the CVPD on safety in the deployment corridor.

Table 3-2. Key MEP Evaluation Hypotheses for Wyoming CVPD

ID	Hypothesis
1	The pilot deployment will improve mobility for both equipped and non-equipped vehicles in the deployment corridor during inclement weather events.
2	By reducing the number of trucks that are stranded, must backtrack, or otherwise waste time and fuel resulting from road closures or a lack of appropriate parking availability, the pilot deployment will result in improved travel reliability for vehicles equipped with CV technologies in the corridor.
3	The pilot deployment will reduce educe negative impacts on the environment through reduction in crashes and increases in speed adherence.
4	By increasing situational awareness, the pilot deployment will result in improved public agency efficiency and decision making by transportation managers.
5	As the market penetration of connected trucks and fleet vehicles increases, benefits will increase in terms of reduced emissions and incident detection time.
6	As the market penetration of connected trucks and fleet vehicles increases, non-equipped vehicles traversing the I-80 corridor will see reductions in emissions.
7	The safety, mobility, environmental, and public efficiency (SMEP) benefits exceed the costs associated with deploying the CV technologies in the deployment corridors.
8	Incremental increases in CV deployment will result in higher benefit-cost ratio up to a certain deployment cost threshold, after which benefit-cost ratio will reduce.
9	End users will be satisfied with performance of CV applications and with the impact of the CV deployment on their travel.
10	End users will be satisfied with the performance of the CV devices.
11	The Wyoming CVPD agencies have the financial and institutional frameworks in place to provide for the long-term sustainability of the CV pilot deployment.

** In some cases, no action may be an appropriate response.

Performance Measures

Table 3-3 shows the PMs, data sources, and analysis type that the TTI CVPD Evaluation Team plans to assess the evaluation hypotheses.

Table 3-3. Performance Measure and Data Sources for Independent Evaluation of Wyoming CVPD

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
1	The pilot deployment will improve mobility for both equipped and non-equipped vehicles in the deployment corridor during inclement weather events.	• Change in Average Travel Time • Change in Average Delay • Change in Average Speed • Change in Vehicle Throughput • Change in the Temporal Extent of Congestion • Change in the Spatial Extent of Congestion	• WYDOT Radar-based Speed Sensors • BSM Part 1 • NPMRDS • WYDOT RWIS Weather Station	• Before/After using Observed data
2	By reducing the number of trucks that are stranded, must backtrack, or otherwise waste time and fuel resulting from road closures or a lack of appropriate parking availability, the pilot deployment will result in improved travel reliability for vehicles equipped with CV technologies in the corridor.	• Change in 95th percentile Travel Time • Change in Buffer Time • Change in the proportion of equipped trucks traveling at or above speed limit • Change in the number of rapid deceleration of trucks during inclement weather events • Change in the proportion of vehicles traveling 5 mph at or above the work zone speed limit	• WYDOT Radar-based Speed Sensors • BSM Part 1 • NPMRDS • WYDOT RWIS Weather Station	• Before/After using Observed data
3	The pilot deployment will reduce negative impacts on the environment through reduction in crashes and increases in speed adherence.	• Change in the vehicle emissions • Change in fuel consumption	• Simulation of incident/crash situations	• Modeling analysis to assess the impacts of the With vs Without cases

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
4	By increasing situational awareness, the pilot deployment will result in improved public agency efficiency and decision-making by transportation managers.	• Change in perception of agency awareness of conditions in the deployment corridors • Changes in the perceived accuracy of alerts/warnings/advisories/ traveler information • Changes in the perceived effectiveness of alerts/ warnings/advisories/ traveler information • Changes in timeliness of agency responses to changing travel conditions • Number and type of operational changes (such as signal timing adjustments) and business practice changes made by transportation managers • Perceived impact/effectiveness of operational and business practice changes. • Changes in notification and/or response times to major incidents and crashes. • Changes in perceived effectiveness of traffic management system responses to changing traffic conditions.	• WYDOT Crash Data • WYDOT Road Closure Reports • WYDOT DMS Records • WYDOT VSL System logs • WYDOT Incident Console Logs • WYDOT Transportation Reporting and Action Console data • Pikalert Motorist advisories and warnings • TMC generated TIMs, alerts, and warnings • Mobile Road Weather observations • Interviews and surveys	• Qualitative perception data from surveys • Quantitative data from system logs
5	As the market penetration of CVs increases, benefits will increase in terms of reduced queues, delays, emissions, and increased vehicle throughput during inclement weather conditions.	• Average Trip Time per vehicle (VHT/V) • Average User Delay/Wait Time • Average Speeds • Average vehicle-miles traveled per vehicle	• Simulation	• Modeling analysis to assess the impacts of the With vs Without cases

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
6	As the market penetration of CVs increases, non-equipped vehicles traversing the pilot deployment area will see reductions in queues, delays, and emissions.	• Average Trip Time per vehicle (VHT/V) • Average User Delay/Wait Time • Average Speeds • Average vehicle-miles traveled per vehicle	• Simulation	• Modeling analysis to assess the impacts of the With vs Without cases
7	The SMEP benefits exceed the costs associated with deploying the CV technologies in the deployment corridors.	• Total Deployment Costs ○ Development ○ Procurement ○ Installation ○ Operations ○ Maintenance ○ Salvage • Dollar Value of Benefits ○ Safety ○ Mobility ○ Environmental ○ Public Agency Efficiency	• Safety Analysis • Mobility Analysis • Environmental Analysis • Public Agency Efficiency Analysis • Agency Cost Records	• Benefit/Cost
8	Incremental increases in CV deployment will result in higher benefit-cost ratio up to a certain deployment cost threshold.	• Benefit-cost ratio at various market penetrations	• Cost data • Dollar value of benefits	• Simulation

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
9	End users will be satisfied with the performance of the CV applications and with the impact of the CV deployment on their travel	• Perception of whether advisories/ alerts/warnings/traveler information were: o Timely. o Sufficiently detailed. o Easy to understand. o Accurate. o Useful. o Appropriateness. • Perceived impact (if any) that alerts/warnings/advisories/traveler information had on safety and/or mobility. • Attitudes toward the consistency of the alerts (Did they fell they consistently received an alert under similar situations?) • Attitudes toward CV systems (related to trust in information, privacy and security, etc.)	• Surveys/Interviews	• Qualitative perception data from surveys
10	End users will be satisfied with the performance of the CV devices.	• Overall satisfaction with performance of CV devices • Number and nature of problems with CV devices	• Survey/Interviews	• Qualitative perception data from surveys

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
11	The Wyoming CVPD agencies have the financial and institutional frameworks in place to provide for the long-term sustainability of the CV pilot deployment.	• Changes needed in business processes • Changes needed in agency systems and technologies capabilities • Changes needed in agency culture • Changes needed in the organizational structure and workforce requirements • Changes needed in institutional arrangements and collaborations • Changes needed in performance measurement practices • Perceived impact/effectiveness/ acceptance of those changes • Perceived extent to which SMEP goals were met • Lessons learned by agencies	• Stakeholder Surveys/ Interviews	• Qualitative perceptions from interview data

Chapter 4. Confounding Factors and Risks

This section identifies confounding factors that are external to the evaluation process and have the potential to compromise the accuracy of estimated PMs and resulting conclusions if not controlled. A confounding factor is a variable that completely or partially accounts for the apparent association between an outcome and a treatment. This can lead to erroneous conclusions about the relationship between the independent and dependent variables. It is critical to identify confounding factors and isolate their impacts so that performance improvements are neither overstated nor understated. The effects of confounding factors can be subdued or eliminated by using an appropriate experimental design that accounts for these external factors. Since confounding factors are external to the experiment, they are usually not monitored during the experimental period. As a result, changes in these factors during the experimental period may bias eventual findings. On the contrary, risks are internal factors in an experiment that can lead to erroneous conclusions.

Potential confounding factors and risks that may affect the Wyoming CVPD evaluation are discussed below. These are the minimum confounding factors and risks; additional ones may arise at a later stage. Thus, confounding factors and risks should be identified and assessed at the outset of the evaluation effort and tracked throughout the project.

Key Confounding Factors

This section identifies confounding factors that can impact the Wyoming CVPD evaluation process. For a detailed discussion of the confounding factors, please refer to the WYDOT CV Pilot Performance Measurement and Evaluation Support Plan [5]. This section also describes potential strategies to mitigate the impacts of identified confounding factors.

Changes in Weather Conditions between the Pre- and Post-Deployment Periods

Adverse weather conditions are the principal contributing factor to the transportation problems at the pilot site. Unusual weather patterns or changes in weather conditions along I-80 from the pre- to the post-deployment period have the potential to invalidate conclusions about the effectiveness of the CV pilot deployment in addressing the needs of the pilot site. Comparisons must be made between similar (adverse/non-adverse) weather conditions to help ascertain the true impacts of CV technology.

Freight and Passenger Vehicle Demand

The corridor is heavily used by commercial freight trucks, making system performance highly dependent on freight demand. This factor impacts both the total number of freight trucks and the percentage of trucks in the overall traffic flow in the corridor. Freight demand along the corridor is mostly impacted by the national economy since earlier research has shown that more than 90 percent of the truck traffic along I-80 neither originates nor is destined for locations within Wyoming [5]. Fluctuations in freight traffic could be caused by changes in goods movement demand, the economy, fuel prices, or construction seasons, all of which are major variables in the logistic decisions made by fleet managers. Similarly, changes in fuel prices, the economy, policies, and local area population can affect the passenger vehicle demand in the pilot area. Variable demand levels in freight and passenger vehicles during the analysis period may affect the underlying travel patterns, traffic conditions, and traveler behavior along the I-80 corridor.

Unusually High/Low Crashes or Incidents

Incident or crash occurrence can vary substantially for no obvious reasons from one period to the other. These incidents/crashes affect the level of travel delay experienced on roadways. For example, as a result of regression to the mean, the number of crashes may reduce significantly on a roadway during an analysis period. If not investigated and documented correctly, these reductions may be wrongly attributed to some safety improvement project that was deployed during the same analysis period. Issues of this nature (i.e., decrease seen as a natural result of the regression phenomenon and not caused by the treatment) can cause false conclusions to be made with regards to the effectiveness of the CV pilot deployment.

Work Zones

Long-term work zones on the study corridor may affect travel patterns and instigate volume increases or decreases in the study corridor.

Economic Conditions

As was apparent during and following the last recession, travel patterns (including passenger vehicle demand, freight, and construction activity) are closely tied to local, regional, and even national economic conditions. While these conditions can play a role in transportation activity, the effects of economic swings can be slow to materialize and dissipate.

Fuel Prices

Change in fuel prices can impact demand. For example, lower prices may result in additional freight and automobile trips. While fuel prices may adjust more quickly than general economic conditions, the effects of changing fuel prices may be more noticeable over a longer time frame than the 18-month Phase 3 performance reporting period.

Potential Mitigation Approaches

The effects of confounding factors can be minimized by using appropriate experimental designs or statistical techniques so that comparisons in data are done for similar conditions. The evaluation team will need to differentiate between benefits occurring during the transition period sand those occurring during the post-transition period to control for confounding factors such as uncertainty in decision making.

Experimental Designs with Control/Treatment Groups

Experimental designs that make use of control and treatment groups are the most effective in mitigating the impacts of variability in weather, traffic, and crash/incident conditions. These approaches compare trip outcomes of vehicles with the technology (treatment group) to those of vehicles without the technology (control group) traveling on the same road under similar road weather, traffic, and crash/incident conditions. By having both treatment and control group vehicles travel in similar conditions, the impact of weather, traffic, and crash/incident variability on performance measurement is minimized.

- Statistical techniques (e.g., counterfactual modeling, cluster analysis, propensity scoring):
  - *Statistical counterfactual:* In experimental designs that make use of control/treatment groups, the control group serves as the counterfactual. Alternately, counterfactuals can be developed using a statistical model, such as a regression analysis, to estimate what would have happened in the absence of an intervention.
  - *Pairwise matching enabled by cluster analysis:* An evaluation design that makes use of the classic before and after analysis is not effective in controlling for confounding factors. However, statistical techniques (e.g., cluster analysis, propensity score matching) may be used to account for the impact of confounding factors. For example, cluster analysis may be performed to group data in the pre (before) and post (after) deployment periods into clusters such that data in each cluster have similar characteristics (i.e., similar traffic demand, freight demand, weather, incidents). Cluster analysis controls for the effects of confounding factors by ensuring that comparison is only made between pairs of before and after data within each cluster.
- Traffic simulation tools: Traffic simulation tools can be used to mitigate for weather, traffic, and crash/incident condition variability. Driver behaviors in these conditions with and without alerts can be collected and used to calibrate the simulation model. With a calibrated simulation model, different CV strategies and operational scenarios can be tested under the same weather, traffic, and crash/incident conditions. Counterfactuals are established by disabling or de-activating the modeled CV applications and estimating PMs while keeping everything else (i.e., network demand, vehicle split) the same.

Key Risks

This section discusses key risks that may impact the evaluation effort. Although the Wyoming CVPD Team may not be in a position to address some of these risks, these issues should be discussed as soon as they are identified, and where possible, the team should avoid, control, or mitigate these risks.

Uncertainty in Decision Making during Transition Period

The adoption of CV technology will provide decision makers such as TMC operators, maintenance personnel, and highway patrol personnel with considerable information spatially and temporally. It is unknown how this information will affect the decision-making process in terms of provision of road weather advisories for trucks and fleet providers, determination of speeds for VSLs, incident response, maintenance, etc. However, it can take time to understand the system and make decisions. There is a period of learning. If the incoming CV data and information are not used effectively, benefits of CV technology will be reduced. It is important to distinguish between the transition period and the post-transition period in order to prevent an underestimation of benefits.

Participants Exploiting Limits of Application

Some participants may develop a false sense of complacency from a perceived protection afforded by CV technology and applications, and may demonstrate risky driving behaviors. For example, a truck driver may drive at a relatively higher speed in foggy conditions because he/she knows that a FCW will be issued if there is a vehicle in front. These risky behaviors may increase crashes. Appropriate participant training may be needed.

Lack of Continuous Speed Data along I-80

Radar speed sensors are spaced approximately 6–7 mi apart in the VSL sections of the I-80 corridor. These speed sensors are located along with the VSL signs and RWIS sensors to take advantage of the power and communication infrastructure available at these sites. Vehicle speeds in between VSL signs are unknown. To accurately capture speed variations within the corridor and enhance the efficacy of the VSL application, alternative speed data collection techniques should be investigated to supplement the data, such as the National Performance Management Research Data Set (NPMRDS), especially since the market penetration of connected trucks will be limited during the pilot deployment period.

Additional equipment and devices may be needed to supplement the data available from the site. Some options for data collection equipment and devices include:

- Procuring portable speed sensing trailers and installing them at various locations within the VSL corridor to obtain additional sensing data, such as vehicle speed, weather data, etc.
- Procuring and installing Bluetooth® readers to estimate travel times and speeds.
- Purchasing global positioning system or after-market safety devices and outfitting vehicles with these devices to collect vehicle speed data.

Lack of Availability of Incident Detection Time

Incident detection time (i.e., the time when a distress message sent by a truck is received by the center) is not currently available from the deployer. The Wyoming CVPD Team should explore acquisition of this information if at all possible. In the absence of this information, an alternative is to interview connected truck drivers, fleet managers, TMC operators, and highway patrol personnel to determine if there is a perceived reduction in the incident response time. In this case, of course, the accuracy of this measurement will be reduced.

Institutional Issues

While good cooperation and buy-in from partners can bolster the success of this type of project, institutional challenges can hamper the success. Institutional challenges can occur both within the primary agency and with the partner agencies. Often, institutional issues stem from a lack of buy-in or opposition to the project by participants for a variety of reasons. Institutional issues can also present themselves in the form of agency processes or policies that inhibit the project implementation. There is no single solution to institutional issues; they can be complex. As with any technology project, the Wyoming CVPD Team should take steps to address institutional challenges if and when they become evident. Future project tasks will address institutional issues in more detail.

Managing Confounding Factors

The TTI CVPD Evaluation Team will take a two-pronged approach to managing confounding factors associated with the Wyoming CVPD. The first prong will be simple to monitor and track some of the confounding factors, such as fuel costs and economic conditions. It is well known that items such as substantial changes in fuel costs and economic conditions can impact travel patterns, particularly those associated with leisure travel as well as truck demands. Because the post-deployment evaluation period is short, in econometric time scales, fuel prices and economic conditions are not likely to have a significant impact of travel in the corridor, unless a major economic catastrophe occurs during the evaluation period. The TTI CVPD Evaluation Teams will monitor fuel prices and economic conditions as part the evaluation to determine if significant changes occurred between the pre- and post-deployment conditions. If significant changes occur, then the TTI CVPD Evaluation Team will consult with the Wyoming CVPD Team and the

FHWA Evaluation Team to determine the extent to which these changes impacted the evaluation results and the best strategy for interpreting the deployment results.

In addition to monitoring certain confounding factor, the TTI CVPD Evaluation Team will use other confounding factors, such as weather, incidents conditions, work zones, etc. to identify situations and scenarios to assess the effectiveness of the CVPD deployment. The TTI CVPD Evaluation Team will use these cluster analysis procedures to identify conditions and circumstances that had similar impacts on performance in the corridor. The TTI CVPD Evaluation Team will use standard clustering tools and techniques to determine typical operating conditions that exist in the corridor. The TTI CVPD Evaluation Team will then compare the post-deployment and pre-deployment performance for each of the similar operating conditions. The TTI CVPD Evaluation Team will provide more details on the clustering analysis procedures in the TTI CVPD Evaluation Data Management Plan.

Chapter 5. Evaluation Design

This section discusses the evaluation designs chosen to account for confounding factors and other threats to the validity of evaluation.

Candidate Experimental Designs

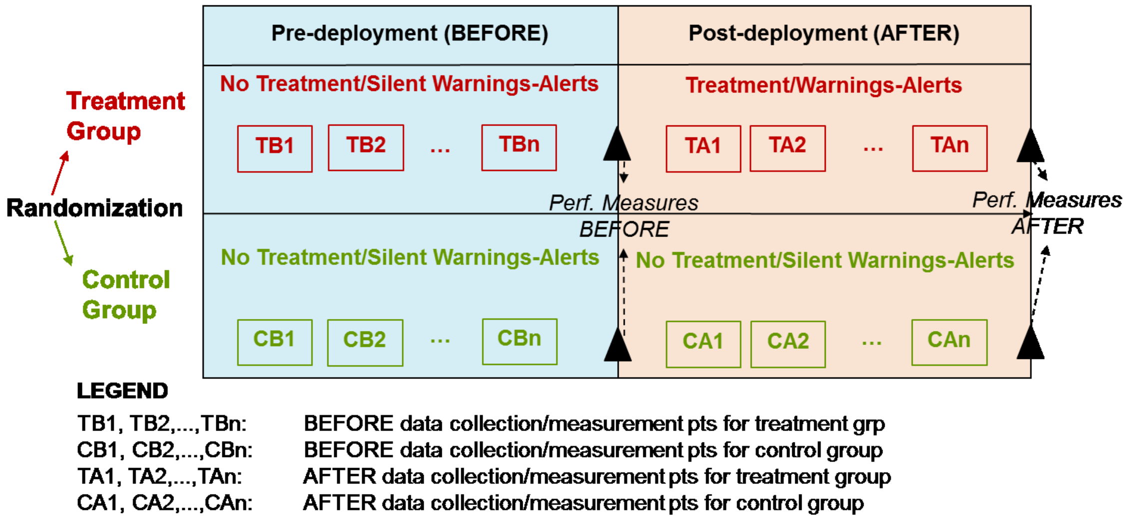
This section briefly discusses three key designs that FHWA has identified that may be applicable for evaluating the proposed CVPDs.

Randomized Experiments

In randomized experiments, study subjects are randomly assigned to the control group (i.e., the group that does not receive any intervention or treatment) and the treatment group (i.e., the group that receives the intervention). Data for each group are collected before (pre-test or pre-implementation) and after the treatment (post-test or post-implementation). At the end of the experiment, differences between the treatment and control groups can be attributed directly to the effect of the treatment if the sample is large enough. Randomization ensures that the control and treatment groups are equivalent with respect to all factors other than whether they received the treatment. Here, the control group serves as the counterfactual of what would have happened in the absence of the treatment, which is a key requirement in determining whether a treatment caused a particular outcome. Figure 5-1 shows a graphical illustration of the design.

An example application of such a design is to assess if an in-vehicle VSL application is beneficial or not. Test drivers are randomly assigned to the control group or the treatment group. In the pre-test period, neither the control group nor the treatment group drivers receive any messages. In the post-test period, the control group drivers do not receive the VSL message, while the treatment group drivers receive the VSL message. Data are collected for both groups, and PMs (e.g., emissions) are calculated for the pre-test period and the post-test period. A comparison of the differences in the PMs between the control and treatment groups reveals whether the changes observed are due to the VSL application or confounding factors.

This type of evaluation design provides the most assurance that outcomes are the result of the treatment (or the pilot deployment). However, these types of evaluation efforts can be expensive.



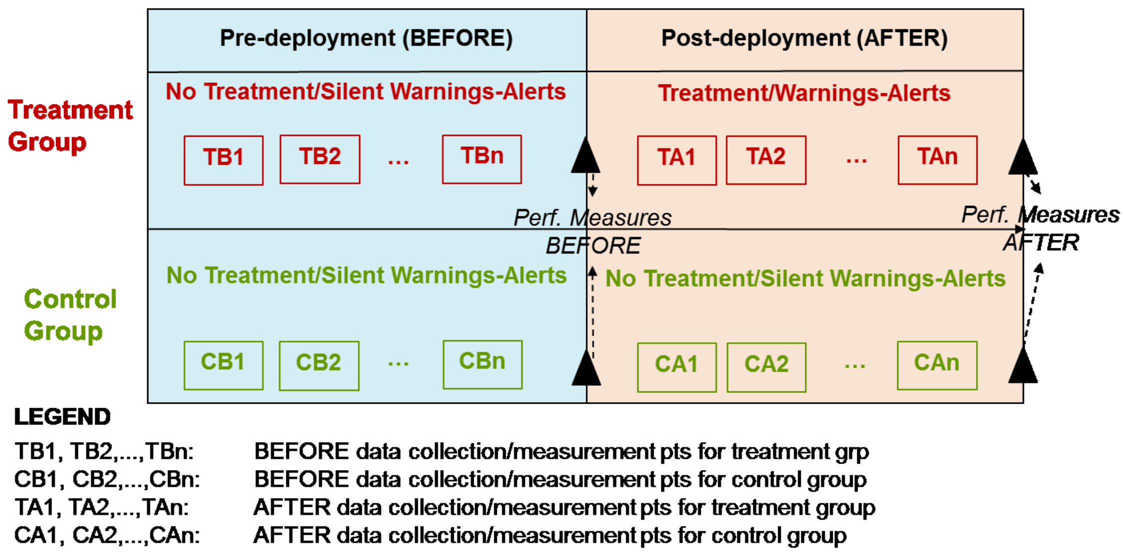
Source: Noblis

Figure 5-1. Randomized Experimental Design

Quasi-experiments

Quasi-experimental design is an approximation of the randomized experiment. Quasi-experimental designs use control and treatment groups, but assignment to the groups is nonrandom (unlike randomized experiments). The control and treatment groups cannot be assumed to be similar. Results may not be conclusive since there may be a possible selection bias. Thus, the differences in the two groups must be assessed during the pre-test and accounted for in the analysis. Figure 5-2 shows a graphical illustration of the design.

Continuing with the earlier example where in-vehicle VSL application is to be evaluated, test drivers are assigned *without randomization* to the control group and the treatment group. As seen in the previous example, in the pre-test period, neither group receives any messages. In the post-test period, the control group drivers do not receive the message, while the treatment group drivers receive the message. Data are collected for both groups, and PMs (e.g., emissions) are calculated for the pre-test period and post-test period. An assessment of the characteristics (e.g., age, familiarity with the facility) of the test drivers in the control and treatment groups is conducted during the pre-test period to determine the differences between the two groups. This is accounted for in any changes in the PMs between the control and treatment groups during the post-test period. This design can be termed as the pre-test/post-test design with no random assignment.

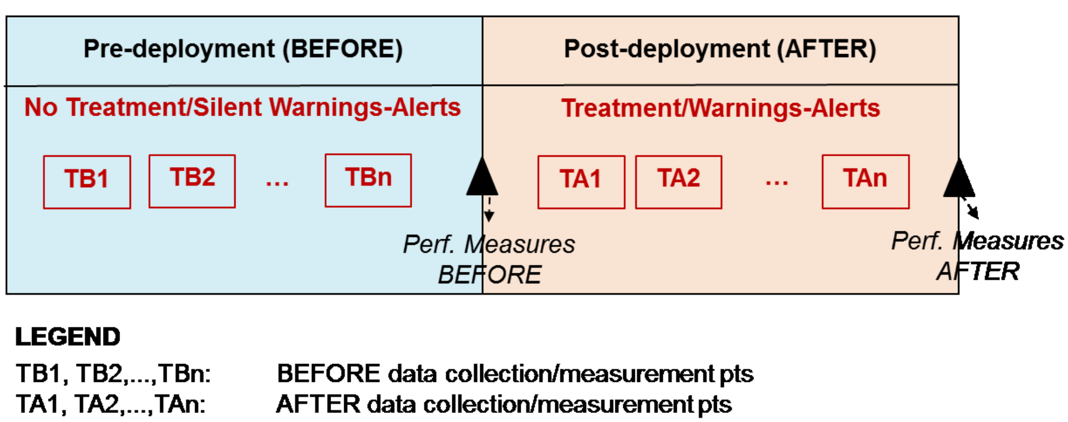


Source: Noblis

Figure 5-2. Quasi-experimental Design

Non-experimental Design

In this design, the impact of the treatment is assessed by examining changes in the post-test period given the trend in the pre-test period. The non-experimental design does not include a control group, making it the weakest study design (however, this would be the least expensive option). Without a control group, it is difficult to assess what would have happened in the absence of the improvements. It does not account for confounding factors and does not control for other threats to internal validity, possibly leading to false conclusions. Before and after studies and longitudinal studies are examples of such a design. Figure 5-3 provides a graphical illustration of the design.



Source: Noblis

Figure 5-3. Non-experimental Design

Planned Evaluation Designs

Based on the WYDOT's plan for executing their deployment, the TTI CVPD Evaluation Team will use a simple before and after, non-experimental plan for assessing the mobility, environmental, and public agency benefits of the Wyoming CVPD Deployment.

Mobility Impacts

Because of the way that Wyoming CVPD has structured their deployment, the TTI CVPD Evaluation Team will use a before and after approach (non-experimental) to the mobility impacts associated with the deployment. The TTI CVPD Evaluation Team will use this evaluation format for the following reasons:

1. Because the primary objective of the Wyoming CVPD is to improve safety, mobility is really an ancillary benefit compared to expected safety benefits. It is highly likely that mobility benefit will have to estimate using simulation.
2. The Wyoming CVPD does not plan to equip vehicle to operating either in a shadow mode (i.e., where a vehicle collects all the data and performs all the computations a deployed vehicle except that is does not provide alerts like a CV) or a control group as part of their deployment. Therefore, direct comparison of vehicle performance with and without the technology active under similar condition will not be available in the Wyoming Deployment.
3. The events that the CVPD is trying to address (winter weather, construction, etc.) generally produce significant reductions in capacity (lane closures, slow free-flow speeds, etc.). Any improvement in mobility by the applications are likely to be overpowered by the magnitude of the event. Therefore, direct observation of improvements due to CV applications are likely to be masked by the magnitude of the event itself.

Given these limitations, the TTI CVPD Evaluation team will use a before and after comparison to assess the mobility benefits of the deployment. The TTI CVPD Evaluation Team will use a cluster analysis to identify the different types of operational conditions experienced in the corridor. The TTI CVPD Evaluation Team will use factors such as precipitation type, precipitation rate, pavement conditions, etc. to identify potential operating conditions in the corridor. The TTI CVPD Evaluation Team will use the data from the after (post-deployment) conditions to identify potential operating conditions. After identifying the potential operating condition in the after period, the TTI CVPD Evaluation Team will the use the same grouping criteria to identify similar operating conditions in the before period. The TTI Evaluation Team plans to compare before and after field observations and simulation data in the mobility analysis.

Because operating conditions can vary significantly over the entire length of the I-80 corridor, the TTI CVPD Evaluation Team plans to divide the corridor into shorter analysis section. Potential analysis sections include the following:

- East State Border to Cheyanne.
- Cheyanne to Laramie.
- Laramie to Rawlins.
- Rawlins to Rock Springs.
- Rock Springs to West State Border Environmental Impacts.

An important part of the economic evaluation of the Wyoming CVPD involves estimating the environmental benefits resulting from introducing CV technologies along the deployment corridor. The TTI CVPD Evaluation Team plans to use the results of the simulation analysis to estimate the impacts of the deployed CV technologies on the environment. The environmental analysis will focus on estimating the reductions in both vehicle emissions and fuel consumption in the deployment corridors. The TTI CVPD Evaluation Team will use simulation to capture the vehicle trajectories on a second-by-second basis for different types of common events along the corridor. These vehicle trajectories will be fed into the Motor Vehicle Emission Simulation (MOVES) model to estimate both fuel savings and emission reductions in the deployment corridors under different situations. Using the results from MOVES, the TTI CVPD Evaluation Team will estimate vehicle emissions and fuel savings benefits for both equipped and unequipped vehicles.

Public Agency Efficiency Impact Assessment

CV technologies can potentially provide public agencies with a new and rich source of data that can be used to improve decision making by public agencies. Public agencies can potentially use this new source of data to improve operational decision making, make adjustments to traffic control strategies, respond faster and better to incident conditions, provide travelers with better information about road surface conditions, etc. One part of the TTI CVPD evaluation is to assess the degree to which deploying CV technologies in the deployment corridor helped public agencies improve their efficiency and effectiveness of detecting, responding, and managing changing traffic conditions—whether they are incidents, unscheduled road closures, inclement weather conditions, or normal day-to-day travel congestion.

Benefit-Cost Analysis

The TTI CVPD Evaluation Team will also conduct a benefit-cost analysis associated with the I-80 deployment. The purpose of the benefit-cost analysis is to determine whether the safety, mobility, environmental, and public agency benefits exceeded the total costs associated with deploying the CV technologies in the deployment corridors. If the project were to increase the cost of travel, result in other increased user costs, or any other negative benefits, then those results would also be entered as a benefit, but as a negative benefit.

A particular challenge with the Wyoming I-80 corridor is the large geographic area and the mostly rural nature of the corridor. The performance data will not be as granular as they might be in an urban corridor or district. However, as a pilot project, this is both a challenge and an opportunity. The analysis will use any available data to examine the benefit-cost ratio. Not all the details for the most precise benefit-cost data will be available, but this project is also an opportunity to identify data needs for future ITS deployments and will likely uncover data sources that have not been used or considered in past technology projects. Sampling, generalized data, or modeling can be used where specific data cannot be obtained.

For many transportation projects, the value of travel time savings is the largest benefit category. In this case, though, the team will look at a broader picture. In addition to potential travel time savings, other important potential benefit-cost factors include safety in the form of reduced crashes or severity, reduced emissions, reduced fuel usage, reduced vehicle operating costs, and reduced cost to commercial carriers from reduced freight delay. Since I-80 is a long, heavy freight corridor, it is anticipated that several benefit factors will be important in determining the overall benefit-cost ratio of a CV implementation.

The benefit-cost analysis time frame will include the following:

- The analysis will encompass the planning, implementation, and 10 years post deployment.
- The analysis will assume that the measured impacts of the projects (such as travel time savings) from the early years will continue at the same level in the later years of the project.

- All monetary amounts will be discounted to a common year, generally the start of project operations.
- The analysis will use a 7 percent discount rate for most items in accordance with Office of Management and Budget guidance [6].

The costs used for the benefit-cost analysis will include the following:

- The costs to plan, implement, operate, and maintain the CV deployment projects.
- The marginal costs that the agencies and users incurred due to the project.
- If applicable, salvage value, which will be subtracted from the cost of the equipment. Items such as fees for the travelers to use part of the CV deployment project *will not* be included in the benefit-cost analysis.

The benefits for the deployment will include the following. Other applicable benefit data or refinements will also be included as they are identified:

- Mobility:
    - Actual travel time with the CV deployment projects will be compared to travel times in a hypothetical base case without the CV deployment projects.
    - The travel times will include all travelers in automobiles, trucks, and buses potentially deriving specific benefits from these CV deployment projects.
    - Travel times can either be measured from field data or modeled depending on data availability and model accuracy.
    - Monetary values of time will be derived from the TIGER Benefit-Cost Analysis (BCA) Resource Guide [7], or when appropriate, local values of time can be used.
    - The cost for freight delays will be included in the analysis. Although the availability of this information is limited, the team will investigate sources of information. The FHWA Office of Operations has generalized figures for the cost of freight delay [8]; however, it is hoped that better and more specific information can be obtained. One potential method will be part of a survey of the commercial carriers specific to the I-80 corridor asking for the most detailed delay cost information they are willing to provide.
- Crashes:
    - Volpe will develop crash reduction predictions for the corridor.
    - Preferably, the estimated changes will be based on the Abbreviated Injury Scale (AIS) (from AIS1 being a minor injury to AIS6 involving a fatality) plus property damage-only crashes [9].
    - Using Volpe's estimate, the TTI CVPD Evaluation Team will determine the monetary value of the changes in crashes based on Federal guidance.
- Emissions:
    - The change in emissions between the actual case, with the CV demonstration projects and a hypothetical base case, as if those projects had not occurred will be estimated for a 10-year time frame.
    - These changes will then be monetized using the same Federal guidance as noted above.
    - Pollutants that will be examined in the analysis include carbon dioxide, volatile organic compounds, nitrogen oxide, particulate matter, sulfur oxide, and carbon monoxide.

- Fuel Usage:
    - Current and predicted costs for fuel will be based on information from the U.S. Energy Information Administration website [10].
    - The portion of the cost of fuel that is tax will be removed prior to calculations since that is a transfer and not a change in societal benefits.
- Vehicle Operating Costs:
    - Costs will be based on the American Automobile Association (AAA) [11] values that are published annually.
    - Any reduction/increase in vehicle miles traveled will result in reduced/increased maintenance, tires, and depreciation based on average per-mile vehicle operating costs as calculated by AAA.
    - The costs *will not* include ownership costs since it is assumed that those costs remain.

In addition to the benefit-cost data associated with the current deployment, the TTI CVPD Evaluation Team will also use modeling to examine the extent to which different market penetration rates are likely to affect benefits in the deployment corridors. The following are highlights of this study:

- The team will estimate the benefits and costs for both the actual CV penetration rate and higher CV penetration rates.
- The growth scenarios will use only the existing suite of applications being deployed, and no new applications will be added to the vehicles.
- At a minimum, the study will use the following:
    - Cost to increase the penetration rate (additional purchases of CV equipment, labor, maintenance, etc.).
    - Estimates of safety, mobility, fuel, and emissions impacts of higher penetration rates.
    - Simulations based on data collected from the CV deployment project.
- In addition to examining changes in performance with different penetration rates, changes in background traffic demands will also be projected.

User Satisfaction Assessment

WYDOT and the TTI CVPD Evaluation Team, with assistance from Volpe, will also evaluate user satisfaction associated with the deployments. In this part of the assessment, WYDOT will survey users (i.e., actual vehicle operators) to determine how well they liked the technology and if it satisfied their needs. Survey questions will also be developed to measure the usability of the systems and applications. Users of the applications will be surveyed at various points during deployment to determine how user satisfaction changes throughout the deployment.

Because of the need to protect privacy and PII, WYDOT's Institutional Review Board (IRB) policies and procedures will govern the collection of user satisfaction information. The TTI CVPD Evaluation Team will provide WYDOT CVPD Team with survey questions to add to their post deployment user surveys to assess user acceptable and satisfaction with the deployment. The WYDOT CVPD Team will be responsible for collecting the survey responses and anonymizing them for use by the TTI CVPD Evaluation Team. The TTI CVPD Evaluation Team analyze the anonymized responses to user satisfaction surveys.

Stakeholder Acceptance

The stakeholder acceptance analysis focuses on assessing the extent to which the stakeholders believe that their goals were achieved. This analysis will primarily consist of information collected during the stakeholder acceptance interview. As part of the interview process, the TTI CVPD Evaluation Team will ask a series of questions that focus on how public agency practices changed because of introducing CV technologies in the deployment corridor. The TTI CVPD Evaluation Team will design the questions to solicit information related to the six dimensions in the American Association of State Highway and Transportation Officials' (AASHTO's) Transportation System Management and Operations (TSMO) Capability Maturity Model (CMM) framework [12]. As part of this process, the questions will help uncover any institutional issues associated with the CV deployment.

To assess stakeholder acceptance, the TTI CVPD Evaluation Team will conduct structured interviews of the major stakeholders to assess their perceptions of how well deployment achieved their desired goals and objectives. Through these interviews, the TTI CVPD Evaluation Team will collect information about what went right with the deployments and what agencies would change related to their 55 deployments. The TTI CVPD Evaluation Team will also query the stakeholders to determine the steps agencies have taken to sustain the deployments. The TTI CVPD Evaluation Team will document the lesson learned by the Wyoming CVPD Team as part of these stakeholder interviews.

Chapter 6. Data Sources

This section identifies the primary sources of data that the TTI CVPD Evaluation Team will use to conduct the independent evaluation of the Wyoming CVPD. The TTI CVPD Evaluation Team is currently in the process of developing a data collection/data management plan. That plan contains specific details related to data collection plans and procedures, data privacy, data quality assurance and quality control, data management, and data dissemination. Below is a summary of the information provided in the data management plan as well as the PMs and evaluation support plan.

Currently, the TTI CVPD Evaluation Team does not foresee the need to install any additional data collection capabilities to collect data for the independent evaluation. It appears that all data can be supplied by the current or planned systems and technologies in the deployment area. However, as risks develop during the deployment and are reviewed, additional sources may be considered.

Sources of Mobility Data

The TTI CVPD Evaluation Team plans to use data from both system and non-system sources to produce mobility-related PMs (i.e., travel times, speed, travel time reliability measures). The TTI CVPD Evaluation Team will use speed measurements from WYDOT's radar measurement system to estimate link and segment travel times during different operating conditions. The TTI CVPD Evaluation Team will use the procedures specified in National Cooperative Highway Research Program *Guide to Effective Freeway Performance Measurement* [13] to generate these estimates of travel time. These sensors will also be the source of traffic volume data that the TTI CVPD Evaluation Team will use in the mobility assessment.

In addition to data from the radar system, the TTI CVPD Evaluation Team is also considering using data from the NPMRDS [14] as another source of mobility data. The NPMRDS is a data portal procured by FHWA to assist state and local governments with PMs. The NPMRDS has 5-minute speed and travel time data sets for over 400,000 road segments, including I-80 in Wyoming. The data are stored in three separate databases: one for passenger cars only, one for trucks only, and one for a combination of trucks and passenger cars. These dataset contain the following data elements:

- Speed — speed is recorded in mph as an integer. The harmonic average speed for all reporting vehicles on the segment.
- Average speed — the historical average speed. Historical average speeds are calculated by the CATT Lab by taking the harmonic average of speeds on each segment for each hour of day and for each day of the week. For data from February 1, 2017, onward, this historical average speed is calculated over the period of February 1, 2017–June 30, 2017. For data prior to February 1, 2017, the average is calculated using the 12-month period preceding November 2014.
- Reference speed — an approximation of free-flow speed for the segment. This value is calculated by the CATT Lab using the 95th percentile of the speeds between 10 PM and 5 AM. The reference speed is calculated over a 6-month period starting April 1, 2017–September 30, 2017.
- Travel Time — Travel time recorded in minutes or seconds. It is the ratio between the segment length and the harmonic average speed for all reporting vehicles on the segment.

- Data Density — refers to one of three values.
  - A: Fewer than five values
  - B: Five to nine values
  - C: More than nine values

Use the raw speed measure data, the NPMRDS calculates the following metrics as defined from the *Travel Time Reliability* publication provided by FHWA and produced by TTI with Cambridge Systematics, Inc.

- Comparative Speed — measured speed as a percentage of the historic average speed for this time of day and day of week.
- Congestion — measured speed as a percentage of the free flow speed.
- Historic Average Congestion — Historic average speed as a percentage of the free flow speed for this time of day and day of week.
- Buffer Time — the extra time (or time cushion) that travelers must add to their average travel time when planning trips to ensure on-time arrival (95 percentile Travel Time − Average Travel Time).
- Buffer Index — the Buffer Time's percentage value of the Average Travel Time ((95 percentile Travel Time − Average Travel Time) / Average Travel Time). Its value increases as reliability gets worse. For example, a buffer index of .4 (40 percent) means that, for a 20-minute average travel time, a traveler should budget an additional 8 minutes (20 minutes × 40 percent = 8 minutes) to ensure on-time arrival most of the time.
- Planning Time — the total time a traveler should plan for to ensure on-time arrival (95 percent Travel Time).
- Planning Time Index — the total travel time that should be planned when an adequate buffer time is included (95 percentile Travel Time / Free-flow Travel Time). The planning time index differs from the buffer index because it includes typical delay as well as unexpected delay. Thus, the planning time index compares near-worst case travel time to a travel time in light or free-flow traffic. For example, a planning time index of 1.60 means that, for a 15-minute trip in light traffic, the total time that should be planned for the trip is 24 minutes (15 minutes × 1.60 = 24 minutes).
- Travel Time Index — travel time represented as a percentage of the ideal travel time (Travel Time / Free-flow Travel Time).

It is not likely that the TTI CVPD Evaluation Team will be able to use BSM records directly to compare produce mobility related PMs as BSM data will be available in the post-deployment period only. The TTI CVPD Evaluation Team will use BSM data to help calibrate the performance of CVs in the simulation models.

Sources of Data for Cluster Analyses

The TTI CVPD Evaluation Team will use cluster analysis to group data into similar operating conditions. The TTI CVPD Evaluation Team will use data from the following source to perform the cluster analysis:

- WYDOT Crash Records.
- WYDOT Road Closure Reports.

- WYDOT VSL Event logs.
- WYDOT DMS Event logs.
- WYDOT Incident Console Records.
- WYDOT Transportation Reporting and Action Console data.
- Pikalert Motorist Advisories and Warnings.
- TMC Operational TIMs, alerts, and warnings.
- Mobile Road Weather Observations.

The TTI CVPD Evaluation Team plans to analyze the pre-deployment data to examine which data elements from these sources are best to characterize the prevailing operating conditions on I-80.

Sources of Public Agency Efficiency Data

The TTI CVPD Evaluation Team plans to assess the impacts the deployment on public agency efficiency by examining primarily changes in response time and action taken by WYDOT during particular events. Therefore, the TTI CVPD Team will use the WYDOT TMC event logs as the primary source of data for these comparisons.

Chapter 7. Mobility Data Analysis

This section describes how the observed data will be used to measure performance and to evaluate the Wyoming CVPD. This section also describes the methods used for estimating PMs.

Analysis Approach

The priority of the Wyoming CVPD is to maximize safety of road users by preventing weather-related crashes and incidents. Traditional mobility-related PMs such as travel time, reliability, and travel delay are secondary objectives of this pilot. While the TTI Evaluation Team will attempt to quantify reductions in weather-related delays and travel, the Team expects most of the mobility benefits associated with the deployment to come from reductions in collision-related congestion. Therefore, the TTI Evaluation Team will focus heavily on quantifying the effects of weather-related crashes in the corridor.

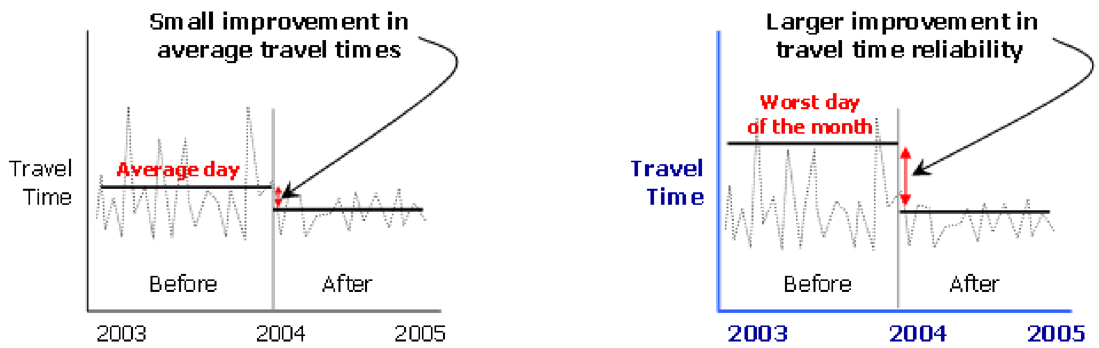
Travel Times/Speed/Delay

As the primary focus of the Wyoming CVPD is on improving safety and situational awareness, the TTI CVPD expects travel time and speed to be ancillary measures of performance for the Wyoming CVPD. As discussed in Chapter 6, the TTI CVPD Evaluation plans to use a cluster analysis group the operational data into like conditions. The TTI CVPD Evaluation Team will use data from the post-deployment period to identify common operating conditions occurring in the deployment corridor. The TTI CVPD Team will use several different clustering algorithms group the data and determine a representative day from the conditions. The TTI CVPD Evaluation Team will then use group the pre-deployment data similar and to identify a representative scenario from the pre-deployment condition. The TTI Evaluation Team will use standard comparison of means and analysis of variance techniques to determine whether the mean performance of the before and after conditions of the representative scenario differ statistically.

Freight delay is a PM for this pilot because of the nature of the pilot deployment area. Along parts of I-80 in southern Wyoming, freight traffic comprises 30 to 55 percent of the traffic stream, with seasonal truck percentages as high as 70 percent. With such high freight concentrations, freight delay represents one of the largest areas of potential benefits. For this analysis, the TTI CVPD Evaluation Team plans to compare average (mean) total delay of all trucks (equipped and unequipped) for the same time periods before and after deployment of the CV technologies. Actual vehicle travel times will be collected using either the probe vehicle data logs or vehicle re-identification systems, such as Bluetooth or similar vehicle tracking systems. Typically, these data measurements are aggregated into 15-minute periods throughout the entire day. These data are collected automatically by the systems and can be aggregated to the appropriate analysis period desired by the TTI CVPD Evaluation Team. The TTI CVPD Evaluation Team will apply cluster analysis procedures to the data to determine the effects that confounding factors (such as incidents, weather, special events, etc.) have on the travel time data. A separate analysis will be performed for normal conditions (no backups) and congested conditions (when the applications are most likely to be issuing alerts). Other options to explore include the availability of freight data embedded within the NPMRDS.

Travel Time Reliability

In addition to travel time, the TTI CVPD Evaluation Team will analyze travel time reliability measures in the deployment area before and after activation of the CV technologies. Travel time reliability is “a measure of consistency or dependability in travel times, as measured from day-to-day and across/over different times of the day” [13]. As illustrated in figure 7-1, travel time reliability is often computed in before and after studies to capture reductions associated with the worst few days compared to the average day.



Source: FHWA [13]

Figure 7-1. Travel Time Reliability

The TTI CVPD Evaluation Team plans to use two travel time reliability measures in assessing the overall impacts of deploying the CV technologies in the evaluation corridor: the 95th percentile travel time and the buffer time. The 95th percentile travel time is the travel time, reported in minutes and seconds, that 95 percent of vehicles experienced during the analysis period. Buffer time represents the time differential between the average and the 95th percentile travel times for the same analysis period (peak period, peak hour, etc.). Buffer time represents the extra time needed by travelers to ensure a high rate of on-time arrival.

Agency Efficiency

The TTI CVPD Evaluation Team expects the deployments of CV technologies to change the level of efficiency of the transportation network. Agency efficiency is measured in terms of how well agencies can respond to changing conditions or unexpected events occurring on their networks. Agency efficiency can be measured in terms of the following:

- Changes in notification and/or response times to major incidents and crashes.
- Improved situational awareness of events occurring on the transportation network.
- Improved timeliness and quality of TIMs.
- Improved traffic management system responses to changing traffic conditions.

To assess agency efficiency, the TTI CVPD Evaluation Team will examine operations logs of agencies for events, both before and after the deployment of the CV technologies, to assess how agency responses to these events changed. The TTI CVPD Evaluation Team will model the impacts of the changes in PMs, such as changes in incident clearance times, to quantify their impacts on mobility.

Chapter 8. Simulation-Based Evaluation

The TTI CVPD Evaluation Team expects modeling and simulation to play a significant role in the evaluation of the Wyoming CVPD. With the limited number of vehicles being equipped with CV technology, direct measurement of the extent to which the deployment of the CV technologies changes safety and mobility in the deployment area will most likely have to be estimated using modeling and simulation. This section provides a high-level overview of the AMS approach that the TTI CVPD Evaluation Team will use as part of the evaluation of the Wyoming CVPD. This section discusses the AMS activities needed to estimate PMs while controlling for confounding factors and provides an overview of the methods to be used for estimating PMs, as well as the hypotheses that will be tested using AMS.

The TTI CVPD Evaluation Team will use simulation and modeling to perform the following types of analysis:

- Estimating the potential mobility benefits associated with improvements in safety as a result of deploying the CV technologies.
- Examining how changes in market penetration levels may impact potential mobility benefits in the future.
- Investigating mobility measures such as delay and queuing over a variety of weather and incident conditions.
- Examining speed adherence and speed variation.

The TTI CVPD Evaluation Team will provide specific details related to the AMS in the Wyoming AMS evaluation plan.

Modeling Approach

In addition to the primary safety PMs of crash reduction, the performance measurement evaluation will also utilize traffic simulation modeling using VISSIM software for the analysis of safety surrogate measures. The simulation model analysis will incorporate CV-equipped driver behavior observed during the demonstration period into the modeling parameters to evaluate changes in the system if a larger percentage of vehicles in the corridor were CV-equipped. The Wyoming CVPD Team will also model environmental impacts, including emissions, using the MOVES model. The TTI CVPD Evaluation Team anticipates that the University of Wyoming will be responsible for housing the model calibration data, assumptions, and network files created for the modeling exercise and make it available to the TTI Team upon request. The TTI CVPD Evaluation Team will share the outputs from the modeling and simulation runs with the Wyoming CVPD Team.

Modeling Environmental Impacts

The purpose of the sustainability estimation is to assess the impact of CV technologies along three environmental dimensions: emissions, fuel consumption, and eco-system services. CV technology will provide drivers with advanced information about traffic congestion and roadway conditions. Informed travelers may decide to avoid certain routes, smooth their speed profiles, or switch to alternative modes or departure times—all of which have the potential to reduce emissions, petroleum, and wildlife-vehicle collisions. The subsections below provide a high-level overview of the assumptions, constraints, needs, objectives, PMs, and methodology for each of the three environmental dimensions.

Emissions

Past research examines emissions impacts of various CV technologies. The most common methodology in these estimations uses output from a traffic simulation model as input to an emissions model, and then measures the change in emissions along a given segment of road before and after the technology is installed. For example, Stathopoulos and Noland estimated fuel consumption and emissions for an improved traffic flow scheme using the traffic simulation model and the emissions model Comprehensive Modal Emissions Model (CMEM) [14]. Similarly, Servin et al. [15] integrated the traffic simulation model Paramics with CMEM to evaluate emissions for intelligent speed adaptation strategies under varying freeway congestion conditions. Chamberlin et al. [16] integrated MOVES and Paramics to evaluate intersection control strategies.

MOVES is a project-level simulator that uses a vehicle's operating characteristics—including idling, acceleration, deceleration, and cruise—to measure emissions and petroleum consumption. Zhao and Sadek [17] provided a comparison of three methods of estimating emissions along a link using second-by-second vehicle speeds from traffic as an input to MOVES: a mean, mode, and probe vehicle approach. In the mean and mode approach, the mean or mode of the speed of all vehicles along a link are estimated for each second of the simulation. This second-by-second speed is used as the MOVES input. The probe approach involves randomly sampling a subset of vehicles along the link every second and using their speeds as inputs to MOVES. The authors showed that along an arterial and freeway testbed, the probe approach provides much greater accuracy than the mean or mode approaches.

The TTI CVPD Evaluation Team plans to use Zhao and Sadek's [17] probe approach to link the traffic simulation models VISSIM4 and Aimsun with the MOVES model. The team will use the second-by-second vehicle trajectory output from the simulation models as the input to MOVES. The main assumption is that the traffic simulation can capture the changes in travel behavior with and without the CV technology accurately.

The PM used in the emissions analysis will be the change in total emissions and emissions along the link between the with and without CV technology cases. The TTI CVPD Evaluation Team will measure greenhouse gas emissions and certain criteria pollutant emissions, such as nitrogen oxide, particulate matter, and carbon monoxide.

The main constraints involved with measuring the impact on emissions using the methodology above are related to the secondary effects, such as changes in travel behavior, that are not captured by the traffic simulation model. For example, if drivers with CV technology change their routes or departure times such that they are no longer captured in the traffic simulation model, then those emissions will also not be captured.

Fuel Consumption

Because fuel consumption and emissions are directly proportional and are both outputs from the MOVES model, the TTI CVPD Evaluation Team plans to use the same methodology as above for both emissions and fuel consumption. The performance metric will be quantity and percentage of petroleum increase or decrease between the with and without CV technology cases.

Chapter 9. Survey-Based Evaluation

The TTI CVPD Evaluation Team will collect some limited survey data from participants in the pilot for perception of application effectiveness and assessment of system performance during the baseline and in post deployment. Survey respondents will likely include participating truck drivers, nonparticipating truck drivers, commercial vehicle fleet managers, and WYDOT State DOT personnel. The Wyoming CVPD Team will be responsible for collecting survey data and sanitizing it to remove any PII before sharing with RDE.

The TTI CVPD Evaluation Team plans to use electronic-based surveys and on-site interviews as part of the performance measurement activities. The stakeholder groups could include commercial vehicle fleet managers, commercial vehicle drivers, WYDOT TMC operators, WYDOT maintenance, and highway patrol officers. The WYDOT CVOP is one tool that will be used to survey commercial vehicle operators. These activities may take place before (baseline) and after CV technologies are deployed and being demonstrated. The focus of the surveys and interviews will be to supplement system data to understand better operational actions taken and the reasons for the actions, use of CV technologies, impacts of CV technologies, satisfaction with the information provided, and conditions that led to certain behaviors. Collection of PII-type data will be limited as much as possible and removed during analysis to represent grouped data only.

The survey-based approach is relevant for measuring impacts on public agency efficiency and end-user satisfaction, as well as for making qualitative assessments of safety and mobility impacts. This approach is also relevant for gathering lessons learned that are transferable to prospective CV deployments. Lessons learned should at a minimum target the following areas:

- Application design, development, and testing.
- Data management.
- Privacy and PII protection.
- Security management.
- Interoperability and standards.
- Device testing, licensing, and installation.
- System operations and maintenance.
- Performance management.
- Stakeholder outreach.

The TTI CVPD Evaluation Team will also use this approach to assess whether pilot deployers and transportation managers were able to develop solutions to technical challenges faced in implementing the CV pilot deployment. Specific elements that should be covered include:

- List of perceived technical challenges.
- Ability to develop solutions to technical challenges.
- Reasons why a challenge could not be overcome.

- Description of solutions developed to address challenges.
- Perceived success of solutions.

User Satisfaction Surveys

The Wyoming CVPD Team, with the support and direction of USDOT and Volpe, will be developing an anonymous driver survey instrument that will be used to obtain feedback on how well the Aftermarket Safety Devices and applications operated. The Wyoming CVPD Team has not finalized the exact modality of the survey instrument, but it is anticipated that it would be a combination of web forms (over the Internet) and on-site interviews.

The TTI CVPD Evaluation Teams does not know the exact content of the survey at this time, but it should include questions that allow the following information to be collected from the users:

- Perception of whether advisories/alerts/warnings/traveler information were:
  - Timely.
  - Sufficiently detailed.
  - Easy to understand.
  - Accurate.
  - Useful.
- Perception of the impact (if any) that alerts/warnings/advisories/traveler information had on safety and/or mobility.
- Perception of the overall satisfaction with performance of CV devices.
- Number and nature of problems with CV devices.

The TTI CVPD Evaluation Team will work with Volpe and the Wyoming CVPD Team to develop and implement appropriate questions and protocols for collecting user satisfaction data.

Stakeholder Acceptance/Satisfaction Plan

The TTI CVPD Evaluation Team is also responsible for measuring stakeholder acceptance and satisfaction with the deployment. The purpose of this element of the evaluation is to determine how well the pilot deployment program fulfilled stakeholder goals and objectives. In developing this stakeholder acceptance/satisfaction plan, the TTI CVPD Evaluation Team will select a manageable list of high-level goals drawn from written documents of WYDOT deployment leaders. Generally, stakeholder goals are related to mobility, environment, and public agency efficiency. In addition, the intent of the stakeholder acceptance/satisfaction surveys is to capture the lessons learned by the stakeholders in the planning and design phase as well as the operations phase of the deployment. The stakeholder surveys will also seek out institutional issues that may have developed with the deployment.

To capture stakeholder acceptance information, the TTI CVPD Evaluation Team will conduct interviews with pertinent deployment stakeholders. Potential stakeholders are outlined in the section below. The team will develop a script of open-ended questions to follow during the interview process. The team will pattern the interview questions after AASHTO's TSMO CMM guide [12]. The TTI CVPD Evaluation Team will structure the interview questions to obtain stakeholder input on the six agency capability maturity dimensions defined by AASHTO to support traffic management operations. The TTI CVPD Evaluation Team will develop interview questions that solicit stakeholder input and lessons learned related to the following:

- *Business Processes*—these questions will relate to the formal scoping, planning, programming, and budgeting associated with developing and implementing the CVPD.
- *Systems and Technologies*—these questions will be relate to the use of the system engineering process, level of maturity of the system architecture standards, and procedures to ensure interoperability and standardization of CV technologies and applications.
- *Performance Measurement*—these questions will focus on the capability and maturity of performance measurement definitions, as well as data acquisition and use of PMs to support and sustain the deployment.
- *Culture*—these questions will relate to the level of technical understanding, leadership, outreach, and legal authority needed to deploy and sustain a CV technology deployment.
- *Organization and Workforce*—these questions will relate to the organizational structure, staff development, and staff recruitment and retention processes needed to support and sustain a CV deployment.
- *Collaboration*—these questions will relate to the type and nature of the relationships that a deploying agency needs to have with public safety agencies, local governmental entities, and others to develop and sustain a CV deployment.

The TTI CVPD Evaluation Team recommends sampling the stakeholder acceptance at least twice during the evaluation period: shortly before or after the systems and applications become active, and then right before the end of the evaluation period. Sampling twice during the evaluation would allow the TTI CVPD Evaluation Team to determine whether processes, procedures, and agency capabilities had to change as the deployment transitioned from planning and design to operations.

Because of the potential sensitive nature of the data collected through these interviews, the TTI CVPD Evaluation Team will be under the control of Texas A&M University's (TAMU) IRB. The TTI CVPD Evaluation Team will clear all survey questions and protocols through TAMU's IRB first, and will implement protocol to ensure confidentiality and privacy of responses before any interviews are performed.

Wyoming Pilot Stakeholders

The Wyoming CVPD has multiple stakeholders in addition to WYDOT, the lead agency. The TTI CVPD Evaluation Team assumes that consultants or technology firms engaged in the pilot deployments would not be considered stakeholders, but that might be a point of discussion. The TTI CVPD Evaluation Team will not include Users as part of the stakeholders group.

For purposes of this stakeholder acceptance/satisfaction plan, the stakeholders of interest are those public- or private-sector entities that are directly affected by the pilot deployment (i.e., key agency partners) or those that may interact with the pilot (i.e., key stakeholder agencies). Types and examples of these agencies are:

- Primary Stakeholder:
  - WYDOT.
- Operating Agencies:
  - Wyoming State Highway Patrol (part of WYDOT—one of only a few States in the Nation).
  - WYDOT Maintenance Managers.
  - WYDOT Traffic Management Center Operators.
- Fleet Operators:
  - WYDOT Snowplow Operators.
  - Freight Operators.
- Ancillary Stakeholders:
  - Wyoming Trucking Association.
  - Oil and Gas Industry Representatives.
- Policy Makers:
  - Governor's Office.
- Deployment Team Members:
  - ICF.
  - TriHydro.
  - National Center for Atmospheric Research.
  - University of Wyoming.
  - Center for Advanced Transportation Technology at University of Maryland.
  - McFarland Management.

Schedule

The TTI CVPD Evaluation Team will determine the interview schedule based on the anticipated progress of the pilot site. The informal conversions to confirm the accuracy and relevance of goals, objectives, and metrics will take place prior to deployment. The TTI CVPD Evaluation Team will conduct actual stakeholder assessment interviews after the deployment has been operational for a minimum amount of time (to be determined together with FHWA) or recently concluded.

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