Connected Vehicle Pilot Deployment Program Phase 1, Performance Measurement and Evaluation Support Plan –ICF/Wyoming

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Final Report — June 6, 2016

FHWA-JPO-16-290

U.S. Department of Transportation

Produced by DTFH6115C00038
U.S. Department of Transportation

Notice

Technical Report Documentation Page

1. Report No. FHWA-JPO-16-290	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Connected Vehicle Pilot Deployment Program Phase 1, Performance Measurement and Evaluation Support Plan – ICF/Wyoming		**5. Report Date** 6/6/2016 **6. Performing Organization Code**
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9. Performing Organization Name and Address ICF International, 1725 Eye St NW, Washington DC, 20006 Wyoming DOT, 5300 Bishop Boulevard, Cheyenne, WY 82009 Trihydro Corporation, 1252 Commerce Drive, Laramie, WY 82070 McFarland Management, 1015 W. Hays Street, Boise, ID 83702 University of Wyoming, 1000 E University Avenue, Laramie, WY 82071		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTFH6115C00038
12. Sponsoring Agency Name and Address U.S Department of Transportation 1200 New Jersey Ave, SE Washington, DC 20590		**13. Type of Report and Period Covered** Performance Measurement and Evaluation Plan, 2-5-2016 to 06-06-2016 **14. Sponsoring Agency Code**

15. Supplementary Notes

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16. Abstract

The Wyoming Department of Transportation's (WYDOT) Connected Vehicle (CV) Pilot Deployment Program is intended to develop a suite of applications that utilize vehicle to infrastructure (V2I) and vehicle to vehicle (V2V) communication technology to reduce the impact of adverse weather on truck travel in the I-80 corridor. These applications support a flexible range of services from advisories, roadside alerts, parking notifications and dynamic travel guidance. Information from these applications are made available directly to the equipped fleets or through data connections to fleet management centers (who will then communicate it to their trucks using their own systems). The pilot will be conducted in three Phases. Phase I includes the planning for the CV pilot including the concept of operations development. Phase II is the design, development, and testing phase. Phase III includes a real-world demonstration of the applications developed as part of this pilot.

This document presents the performance measurement and evaluation support plan utilized in this pilot. As such, it identifies and describes the measures and corresponding targets, data needed, and evaluation designs that will be used to complete a successful performance measure and evaluation of the WYDOT CV Pilot Demonstration. Additionally, this document will address confounding factors and mitigation approaches, system performance reporting, and data collection and management.

17. Key Words Connected Vehicle Technology, I-80 Corridor, Road Weather, Truck Safety	**18. Distribution Statement** This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages**	**22. Price**
None	None	78	NA

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

Acknowledgements

The development team would like to thank the U.S DOT for the timely and high-quality support offered by U.S DOT review teams, Volpe and the support contractor Noblis. Their input on performance measures and data needs helped improve the performance measurement plan for the CV Pilot in Wyoming.

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1 Scope

1.1 Project Scope

Wyoming Department of Transportation (WYDOT) is one of the first wave of Connected Vehicle (CV) Pilot sites selected to showcase the value of and spur the adoption of Connected Vehicle Technology in the United States. Connected Vehicle Technology is a broad term to describe the applications and the systems that take advantage of Dedicated Short-Range Communications (DSRC) between vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) to improve safety, mobility and productivity of the users of the nation's transportation system.

As one of the three selected pilots, WYDOT is focusing on improving safety and mobility by creating new ways to communicate road and travel information to commercial truck drivers and fleet managers along the 402 miles of Interstate 80 (I-80 henceforth) in the State. For the pilot project, WYDOT will work in a planning phase through September 2016. The deployment process will happen in the second phase (ending in September 2017) followed by an 18-month demonstration period in the third phase (starting in October 2017).

Systems and applications developed in the pilot will enable drivers of connected vehicles to have awareness of hazards and situations they cannot even see. Specifically, WYDOT hopes to improve operations on the corridor especially during periods of adverse weather and when work zones are present. Through the anticipated outcomes of the pilot, fleet managers will be able to make better decisions regarding their freight operations on I-80, truckers will be made aware of downstream conditions and provided guidance on parking options as they travel the corridor, and automobile travelers will receive improved road condition and incident information through various existing and new information outlets.

1.2 Performance Measurement and Evaluation Plan Introduction

The WYDOT CV Pilot will demonstrate new technologies and techniques to collect, process, and disseminate road and weather conditions and safety alerts/advisories including the use of DSRC to communicate such alerts. WYDOT and FHWA are interested in a collaborative activity to assess the Pilot's system performance and other impacts. There are two distinct, but coordinated, efforts planned. The first will be conducted by the Wyoming Project Team, and the second by a contracted FHWA Independent Evaluator (IE) yet to be selected.

The focus of the Project Team's evaluation will be to understand what worked, what didn't, and how to improve the system and determine future enhancements. Additionally, the Project Team's evaluation will measure the impacts to the trucking industry, Wyoming residents, and other users of the I-80 corridor and look for ways to expand upon the identified benefits.

The FHWA IE will focus on national programmatic aspects of this CV Pilot project, combined with other similar projects being conducted. The IE team will strive to understand how the project outcomes can contribute to the future of the Connected Vehicle Program nationally. Toward this end, the Wyoming Project Team will work collaboratively to ensure a comprehensive and successful evaluation is completed and documented in such a way to benefit Wyoming, other interested states, and the national CV Program. The Wyoming Team will make available the needed data, where available, identified by the IE.

1.3 Document Overview

This document is an overview of the performance measures and evaluation plan utilized in this pilot. As such, it identifies and describes the measures and corresponding targets, data needs, and evaluation designs that will be used to complete a successful performance measurement and evaluation of the WYDOT CV Pilot Demonstration. Additionally, this document will address confounding factors and mitigation approaches, system performance reporting, and data collection and management.

1.4 Document Organization

The remainder of this document consists of the following sections and content:

- Section 2 provides the notes and glossary of acronyms used in this document and the pilot.
- Section 3 provides information on the references used to develop this document.
- Section 4 identifies the critical performance measures and targets including a description of their relationship to the system applications and users/stakeholders identified in the Concept of Operations.
- Section 5 identifies the project confounding factors and mitigation approaches that will affect the approaches used to conduct the evaluations.
- Section 6 defines the system performance and impact evaluation designs for each of the measures described in Section 3.
- Section 7 describes the mechanisms and frequency of performance reporting.
- Section 8 defines the expected support the Wyoming Project Team plans to provide to the IE contractor including the data sharing framework.
- Section 9 describes the data collection and management plan that will be utilized for the system and non-system data collected as part of the pilot.
- Section 10 explains the roles and responsibilities of the project partners.
- Section 11 provides the schedule for performance measure and evaluation support activities.
- Section 12 describes the expected next steps to ensure successful evaluation activities.

This is considered a living document and will be revisited and likely revised near the end of Phase II activities (design/deployment) with the goal of ensuring the measures and approaches described within are up-to-date going into Phase III (demonstration) and represent the most recent project deployment plans.

1.5 System Overview

This project will develop systems that make relevant information directly available to, and shared among, equipped fleets. Information is also shared through linkages with fleet management centers (who will then communicate it to their trucks using their own communication systems).

Supporting the applications and the CV environment of roadside, vehicle and back-office infrastructure are core services that allow safe, secure, reliable operations of the system. The main project objectives of the pilot to be accomplished and demonstrated are as follows:

- Deploy and operate a set of vehicles that are equipped with on-board units (OBU) with DSRC connectivity. These vehicles will be a combination of snow plows, maintenance fleet vehicles, emergency vehicles and private trucks that will broadcast a basic safety message, collect vehicle data and provide it remotely to the WYDOT Transportation Management Center. Some of the vehicles will be equipped with additional weather sensors to monitor road conditions along the corridor. These vehicles will also receive in-vehicle alerts from various applications developed as part of the pilot.
- Deploy roadside units (RSUs) with DSRC connectivity that are able to transmit advisories and alerts to equipped vehicles along I-80.
- Leverage the data provided from the equipped vehicles to develop and demonstrate a suite of V2V and V2I applications. As part of the pilot, several applications will be developed to support wide-area travel advisories, variable speed limit postings, forecast road condition information, spot-specific warnings, detours, emergency alerts, and parking notifications.

A detailed explanation of the Wyoming CV Pilot project can be found in *Connected Vehicle Pilot Deployment Program Phase I, Concept of Operations (ConOps) (*Gopalakrishna, et al., 2015a) and the *Connected Vehicle Pilot Deployment Program Phase I, System Requirements (SyRs)* (Gopalakrishna, 2015c)

1.5.1 System Objects

The following objects are of interest to the system:

- Vehicles – Four categories of vehicles will play a role in the pilot.
    - Snow Plow – This group represents WYDOT snow plows that will be equipped with an on-board unit (OBU) with Dedicated Short Range Communication (DSRC) connectivity. The OBU will support communications and generate safety messages, and could collect and report vehicle data, weather and road condition data, store data and provide an interface to communicate safety alerts and advisories.
    - Highway Patrol – This group represents WYDOT highway patrol vehicles that will be equipped with an OBU with DSRC connectivity. The OBU will support communications and generate safety messages, and could collect and report vehicle data, weather and road condition data, store data and provide an interface to communicate safety alerts and advisories.
    - Other Fleet –This group represents other vehicles owned by WYDOT (besides snow plows and highway patrol), cities and partners that will be equipped with an OBU with DSRC connectivity. The OBU will support communications and

generate safety messages, store data and provide an interface to communicate safety alerts and advisories. No weather data collection will be conducted as part of this pilot.
    - Connected Trucks – This group represents vehicles owned by commercial vehicle operators that are participating in the pilot. These trucks will be equipped with an OBU with similar functions and capabilities as described for the WYDOT fleet. A subset of vehicles will also have weather sensors to collect road and atmospheric information.
- Infrastructure – One infrastructure element is part of the pilot.
    - WYDOT Roadside Unit (RSU) – This object describes the roadside unit that will be deployed as part of the system. RSUs include DSRC connectivity, application support, data storage, and other support services to enable CV applications. WYDOT RSUs can be either fixed or portable equipment depending on the use-case.
- Back Office Systems – Four major systems are part of the pilot and will be hosted at the WYDOT Transportation Management Center (TMC).
    - Operational Data Environment (ODE) – This system collects all information collected with connected devices, checks its quality and then shares it with other systems in charge of analyzing and distributing the information. The ODE will be hosted at Wyoming DOT TMC.
    - PikAlert™ System (PA) – This system supports the integration and fusion of CV and non-CV weather data to develop warnings and advisories regarding adverse weather condition along I-80. CV data is received from the ODE while non-CV data comes from the NWS and the WYDOT Data Broker. The generated information is then shared with the Data Broker for further distribution.
    - WYDOT Data Broker (DB) – This WYDOT system receives information from the ODE, PA and some external systems (WTI, TRACS and RCRS), analyze it and share it with the corresponding system or service including back to the ODE and other sources.
    - WYDOT Data Warehouse (DW) – This WYDOT system stores various TMC-related data and will be used to store CV-related data as well. The data warehouse includes time-stamped logs of CV and non-CV data that will be used for performance measurement.
- External Systems
    - Third-Party Information Service Providers (TPI) – This object represents third-party developers of data and information products for both WYDOT and the end-consumer. These may include weather products that are used by WYDOT TMC and driver-focused applications that use data from the TMC.
    - WYDOT Transportation Reporting and Action Console (TRAC) – This system provides a tabular list of events that are currently ongoing and require operator review/action. These events may be entered manually, can be reported based on other systems like RCRS, radio communications with field personnel, citizen reports etc. The posted information is picked up by an operator who takes the necessary steps to address the issue and provides information of when the issue is resolved. For the connected vehicle pilot, additional events will be provided by the ODE or the PikAlert into the TRAC system

- WYDOT Commercial Vehicle Operation Portal (CVOP) – This system provides forecasted road condition information on common commercial vehicle routes through an online portal for freight stakeholders. This portal will be updated as part of the pilot to provide current information as well.
- Wyoming Traveler Information System (WTI) – This system provides traveler information services to the general public and fleet management centers via various means (website, 511, 511 App, Text/Email Alerts). The WTI gets information from the WYDOT Data broker.
- Road Condition Reporting System (RCRS) – This system allows field personnel (snow plow operators) to report weather and pavement conditions of the roadway from the field using an Android tablet-based application. The RCRS provides the reported information to the WYDOT data broker and WTI.
- Incident Console (IC) – This system provides geotagged and timestamped incident information on incidents along I-80.
- Construction Administration (CA) – This system provides geotagged and timestamped incident information on scheduled and unscheduled work-zone activities along I-80.
- 511 Application – WYDOT developed application that provides information on road closure, traffic, weather, and public and private parking services available in the corridor.
- Security Credential Management System (SCMS) – This external system generate security certificates in order to securely manage messages from connected devices.
- National Weather Service– This object represents the models/systems NWS offices who are responsible for forecasts along the I-80 corridor.
- Situation Data Warehouse (SDW) – This external system stores near real-time data and shares it with the remote telecommunication systems for further distribution.

The following Figure 1-1 shows a representation of the physical architecture of Wyoming's CV Pilot project.

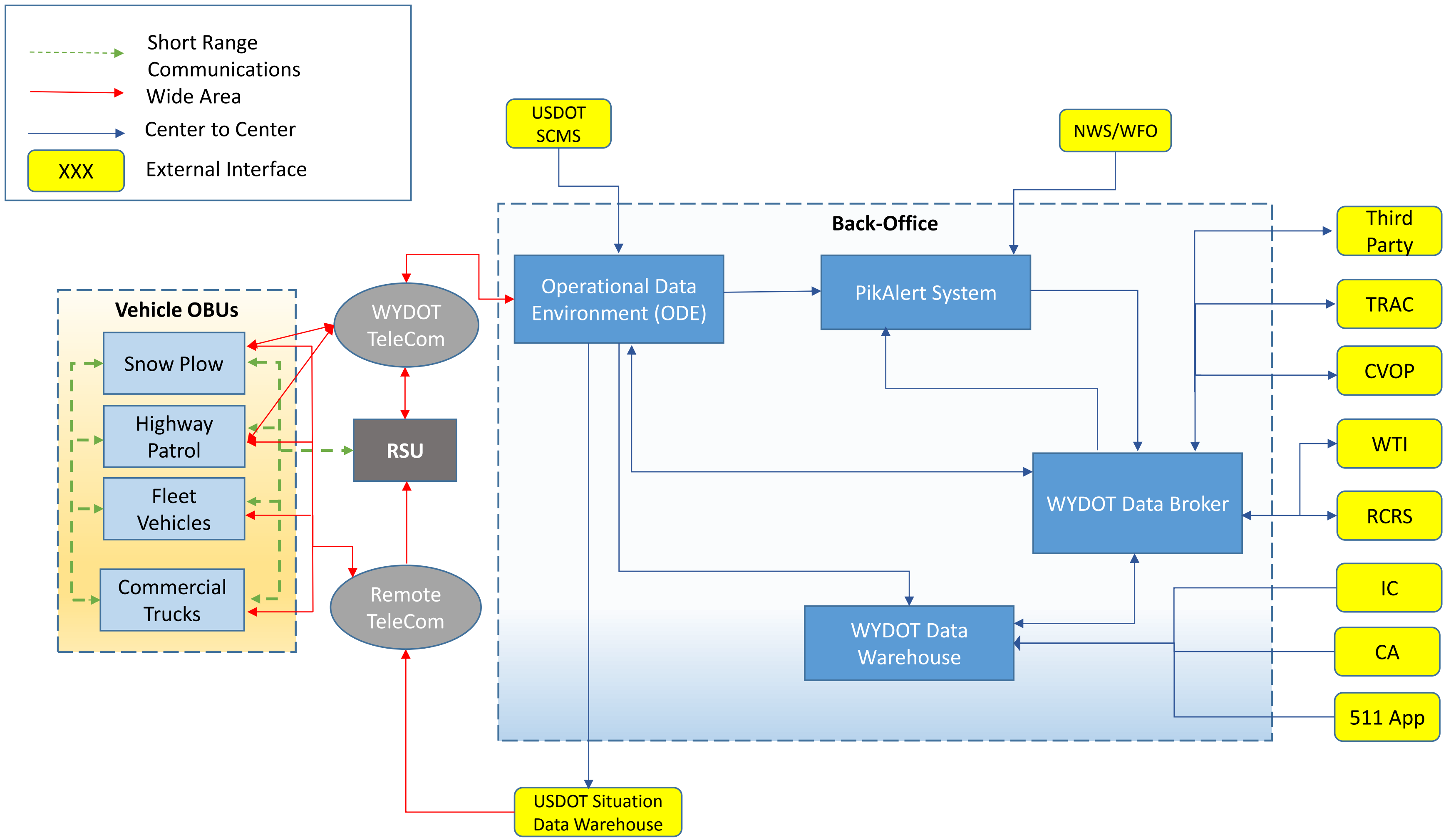

Figure 1-1. Physical Architecture of Wyoming's CV-Pilot Project. (Source: ICF)

1.5.2 Proposed System Functionality

The project's system capabilities are organized by two categories – the pilot system which describes the back-office related capabilities and the mobile distribution system which describes the capabilities relating to field to vehicle and vehicle to vehicle interactions. The system, comprised of the pilot system and the mobile distribution element, provides the following capabilities.

- Pilot System – Collect Road and Weather Data – The system shall collect road and weather data from a variety of sources including connected trucks, connected WYDOT fleets, fixed infrastructure sensors like RWIS, the National Weather Service, maintenance personnel and adjacent State DOTs. The data collected include both directly observed road and weather conditions and other data (such as vehicle telematics) that will help estimate the conditions of road segments along I-80.
- Pilot System – Collect Work Zone Information – The system shall collect work zone information including location, duration and nature of activity reported by maintenance personnel and centers
- Pilot System – Collect Dynamic Travel Information – The system shall collect dynamic travel information such as travel speeds, parking availability, and incident notifications
- Pilot System – Share Integrated and Fused Advisories – The system shall fuse travel information, road condition data and weather data to generate segment-level advisories along I-80. The system shall share advisories with connected vehicles, fleet management centers, traditional ITS channels like DMS/HAR/511 and to partners like truck parking facilities and adjacent State DOTs
- Pilot System – Provide Dynamic Travel Information – The system shall provide dynamic travel information to support travel decisions pre-trip and en-route. Dynamic travel information may relate to variable speed limits, road closures, and truck parking availability.
- Mobile Distribution – Share Safety and Road Condition Messages – The mobile distribution aspect of the system shall share safety and road condition messages between connected vehicles and between vehicles and the roadside infrastructure. Safety and road condition information shared by connected vehicles to other connected vehicles include situational awareness of downstream conditions, speeds, information on slowing traffic or queues. This information will also be relayed to roadside equipment when connected vehicles pass them in the corridor.
- Mobile Distribution – Collect Messages from Other Connected Vehicles - Connected vehicles shall collect messages from other connected vehicles about situational awareness of conditions and provide the information to the driver in a meaningful format.
- Mobile Distribution – Collect Messages from Infrastructure - Connected vehicles and the pilot system shall collect messages from infrastructure about advisories and alerts including speeds, parking availability, upcoming travel conditions and provide the information to the driver in a meaningful format.
- Mobile Distribution – Generate Emergency Message - Connected vehicles shall have the capability to generate an emergency message while traveling on the I-80 corridor when conditions warrant such a message from or about other emergency conditions on the corridor observed by the vehicle.

The system capabilities and functions described in the previous paragraphs are implemented through the following seven applications:

- Road Weather Advisories for Trucks - This application provides the capability of collecting road weather data from WYDOT Fleets and Connected Trucks and using that data to develop short-term warnings or advisories that can be provided to individual commercial vehicles or to commercial vehicle dispatchers.
- Automatic Alerts for Emergency Responders - This application provides the capability for connected trucks to transmit an emergency message when the vehicle has been involved in a crash or other distress situation.
- CV-enabled Weather-Responsive Variable Speed Limits - This application uses road weather information from connected trucks and WYDOT Fleet vehicles as well as current and historical data from multiple sources to determine the appropriate current safe speed and other traffic management strategies.
- Spot Weather Impact Warning - This application will alert drivers to unsafe conditions or road closure at specific points on the downstream roadway as a result of weather-related impacts (e.g., high winds, flood conditions, ice, and fog).
- Work Zone Warnings - This application provides information about the conditions that exist in a work zone to vehicles that are approaching the work zone.
- Situational Awareness - The application determines if the road conditions measured by other vehicles represent a potential safety hazard for the vehicle containing the application.
- Freight-Specific Dynamic Travel Planning- This application provides both pre-trip and en-route travel planning, routing, and commercial vehicle related traveler information for fleet management centers.

1.5.3 User Needs

A detailed description of the needs is provided in the *Connected Vehicle Pilot Deployment Program Phase I, Concept of Operations (ConOps)* Document (Gopalakrishna et al., 2015a).

2 Notes and Glossary

The following table defines selected project specific terms used throughout this document.

Table 2-1. Glossary of Terms.

Term	Definition
Commercial Vehicle Operator Portal	A WYDOT operated system that provides forecasted road condition information on common commercial vehicle routes.
Confounding Factors	Extraneous variables in technology assessment that could cause evaluation results to be statistically invalid (i.e., weather conditions variability or technology adoption).
Connected Vehicle Penetration Rate	The number of connected vehicles in the I-80 corridor in comparison with total vehicles at a certain time in a specific location.
Evaluation Baseline	The documentation of conditions before CV technology deployment. Used as a foundation to make assessments against conditions after CV technology deployment.
Freight-Specific Dynamic Travel Planning	An application that provides both pre-trip and en-route travel planning, routing, and commercial vehicle related traveler information, which includes information such as truck parking locations and current status.
Independent Evaluator	A contactor yet to be selected that is independent from the Wyoming CV Pilot Demonstration Team and will evaluate the system and other impacts of the deployed Pilot project.
Location and Time	A support function that coordinates accurate location and time across the entire CV environment
Performance Measurement	Activity to identify appropriate measures, data, and analysis approaches to assess the performance of the Wyoming CV Pilot Demonstration project in terms of system performance and impact outcomes.
Performance Targets	Improvement goals assigned to each performance measure (i.e., 10% reduction in crashes due to CV Pilot Demonstration).
PIKALERT	A system developed by NCAR for FHWA that translates vehicle and weather data collected from connected vehicles, fuses them with other data (from NWS for example) to create road segment-level condition reports.

Qualitative Assessment	Subjective quality assessments from stakeholders of how the CV technology worked. (i.e., stakeholder interviews asking how they perceived the use of new technology)
Quantitative Assessment	Numerical assessment of quantities from system data to measure the performance of CV Pilot systems (i.e., number of road condition reports before and after CV Pilot deployment).
Road Condition Reports	Reports provided by field personnel or ITS devices that describe the weather and pavement conditions of the roadway.
Situational Awareness & Safety Awareness	An application that determines if the road conditions [reported from either other vehicles (V2V) or infrastructure (V2I)] represent a potential safety hazard for the vehicle containing the application.
Speed Variability	A term to represent the vehicle speed variations along a section of I-80. The variability refers a distribution of numbers of vehicles at various speed values.
Telecom Program	WYDOT's Telecommunications Program is responsible for the statewide WyoLink radio system, most in-vehicle electronics integration, and various wireless networks including backhaul from roadside electronics devices and Wi-Fi hotspots.
Transportation Management Center	WYDOT-operated center that collects information and informs the public about changing travel conditions for the entire State of Wyoming
Warnings about Upcoming Work Zone	An application that provides information about the conditions that exist in a work zone to vehicles that are approaching the work zone.
WyoLink Radio Network	Statewide digital trunked VHF P-25 compliant public safety land mobile radio communications system, used for voice traffic and secondarily for low-speed mobile data communications.

Table 2-2. Acronym List.

Acronym/Abbreviation	Definition
ABS	Anti-lock Braking System
BSM	Basic Safety Message
CDP	Comprehensive Deployment Plan
ConOps	Concept of Operations
CV	Connected Vehicle
CVOP	Commercial vehicle operator portal

DMS	Dynamic Message Signs
DSRC	Dedicated Short Range Communications
FHWA	Federal Highway Administration
HAR	Highway Advisory Radio
I-80	Interstate 80
IE	Independent Evaluator
IEEE	Institute of Electrical and Electronics Engineers
ISP	Information Service Provider
ITS	Intelligent Transportation System
MEP	Mobility, Environment, and Public Agency
MMUCC	Model Minimum Uniform Crash Criteria
MTBF	Mean time between failures
NWS	National Weather Service
OBU	On-board equipment. This represents the package of DSRC radios, computing, sensors and human-machine interface that will be installed on a vehicle. This is similar to the Retrofit Safety Devices (RSD) used in the Safety Pilot Program.
RSU	Roadside Units. This represents the package of DSRC radios, computing, communications that will be installed on the roadside on I-80
RWIS	Road Weather Information System
PM & ES	Performance Measurement and Evaluation Support
TMC	Transportation Management Center
V2I	Vehicle to infrastructure
V2V	Vehicle to vehicle
VSL	Variable Speed Limit
WDOT	Wyoming Department of Transportation
WTI	Wyoming Traveler Information system

3 References

The following table lists the documents, sources and tools used to develop the concepts in this document.

Table 3-1. References.

#	Documents, Sources Referenced
1	Deepak Gopalakrishna, et al. (2015a). *Connected Vehicle Pilot Deployment Program Phase I, Concept of Operations (ConOps), ICF/Wyoming*. U.S Department of Transportation.
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7	Young, Rhonda, Vijay Sabawat, Promothes Saha, and Yanfei Sui. (2013) *Rural Variable Speed Limits: Phase II*. Wyoming Department of Transportation, FHWA-WY-13/03F. Cheyenne, WY.
8	Garber, N J and Gadirau, R. *Speed Variance and its Influence on Accidents*. AAA Foundation for Traffic Safety. Washington, D.C., HS-040 559.

4 Critical Performance Measures and Targets

4.1 Project Benefits Overview

The expected benefits of the project revolve around objectives of improving safety, mobility and productivity of the users of I-80 in Wyoming. These benefits are directly dependent on the seven applications that will be developed as part of this CV Pilot (see Section 1.5.2. Proposed System Functionality). Table 4-1 links the general benefits to the application and beneficiaries, namely the agencies and users of the system.

Table 4-1. Agency and User Benefits.

Application	Agency			User			
	WYDOT	Fleet Management	Other	Conn. Truck	Conn Snow Plow/Highway Patrol/Fleets	Other Trucks	Other travelers
1. Road Weather Advisories for Trucks	Increased coverage of road condition reports and improved dissemination capability of more accurate information.	More accurate real-time and forecasted short-, medium- and long-term horizon segment-level alerts.	Timely and more accurate forecasted short-, medium- and long-term horizon segment-level alerts.	Improved safety through (near) real-time and more reliable segment-level advisories for the downstream roadway.	Real-time or near real-time and more reliable road condition and weather information for their respective area(s) of operation.	More accurate segment-level road and weather condition alerts through the system's external services and traditional ITS.	More accurate segment-level road and weather condition alerts through third party ISPs and traditional ITS.
2. Automatic Alerts for Emergency Responders	Increased coverage and reduced latency of accident notifications for optimized response time.	Real-time incident alerts for optimized response and route planning.	Near real-time incident alerts.	Improved safety through (near) real-time incident involvement notification or relay of information.	Improved safety through (near) real-time incident involvement notification or relay of information for their respective area(s) of operation.	More accurate segment-level incident alerts through external services and traditional ITS.	More accurate segment-level incident alerts through third party ISPs and traditional ITS.
3. CV-enabled Weather-Responsive Variable Speed Limits	Increased coverage of VSL-oriented strategies.	Real-time notification of implemented VSL-strategies for optimized scheduling and route planning.	Near real-time notification of implemented VSL-strategies.	Improved safety through lower speed variation and (near) real-time and more accurate segment-level advisories for the downstream roadway.	Faster and more accurate segment-level speed alerts for their respective area(s) of operation.	More accurate segment-level speed alerts through external services and traditional ITS.	More accurate segment-level speed alerts through third party ISPs and traditional ITS.
4. Spot Weather Impact Warning	Reduced latency and increased coverage of road condition dissemination and reports along the I-80 corridor.	Real-time warnings of unsafe conditions or road closure at specific points for optimized scheduling and route planning.	Near real-time warnings of unsafe conditions or road closure at specific points.	Improved safety through (near) real-time notification of unsafe conditions or road closure at specific points on the downstream roadway.	Improved and (near) real-time notification of unsafe conditions or road closure at specific points on their respective area(s) of operation.	More accurate spot road and weather condition warnings through external services and traditional ITS.	More accurate spot road and weather condition warnings through third party ISPs and traditional ITS.
5. Work Zone Warnings	Reduced latency of collecting/disseminating information of	Real-time work zone location alerts for	Near real-time work zone location alerts.	Improved safety through (near) real-time notification of	Improved and (near) real-time notification of work zones at	More accurate work zone warnings through external	More accurate work zone warnings through third party

	work zone locations.	optimized scheduling and route planning.		unsafe of work zones at specific points on the downstream roadway.	specific points on their respective area(s) of operation.	services and traditional ITS.	ISPs and traditional ITS.
6. Situational Awareness	Increased coverage of road condition reports and improved dissemination capability of more accurate information.	Real-time wide area alerts for optimized scheduling and route planning.	Near real-time wide area alerts.	Improved safety through (near) real-time wide area alerts near of within the downstream roadway or planned route.	Improved and (near) real-time wide area alerts near of within their respective area(s) of operation.	More frequent and accurate wide area alerts through external services and traditional ITS.	More accurate wide area alerts through third party ISPs and traditional ITS.
7. Freight-Specific Dynamic Travel Planning	Improved truck and driver productivity and safety.	Improved truck and driver productivity and safety.	Improved truck and driver productivity and safety.	More accurate (near) real-time parking, route, and restriction information through external services and traditional ITS.		More frequent and accurate parking, route, and restriction information through external services and traditional ITS.	

4.2 Performance Measures and Targets

The Wyoming CV Pilot Demonstration Team has identified 22 performance measures incorporated within 9 performance categories. These 9 performance categories represent the primary activities and outcomes of the Wyoming CV pilot system illustrated in Figure 4-1. These categories focus on improvements to efficiency, safety and mobility—while no reductions in negative environmental impacts are expected. These categories will be used to organize the description and evaluation design of each performance measure in the next section.

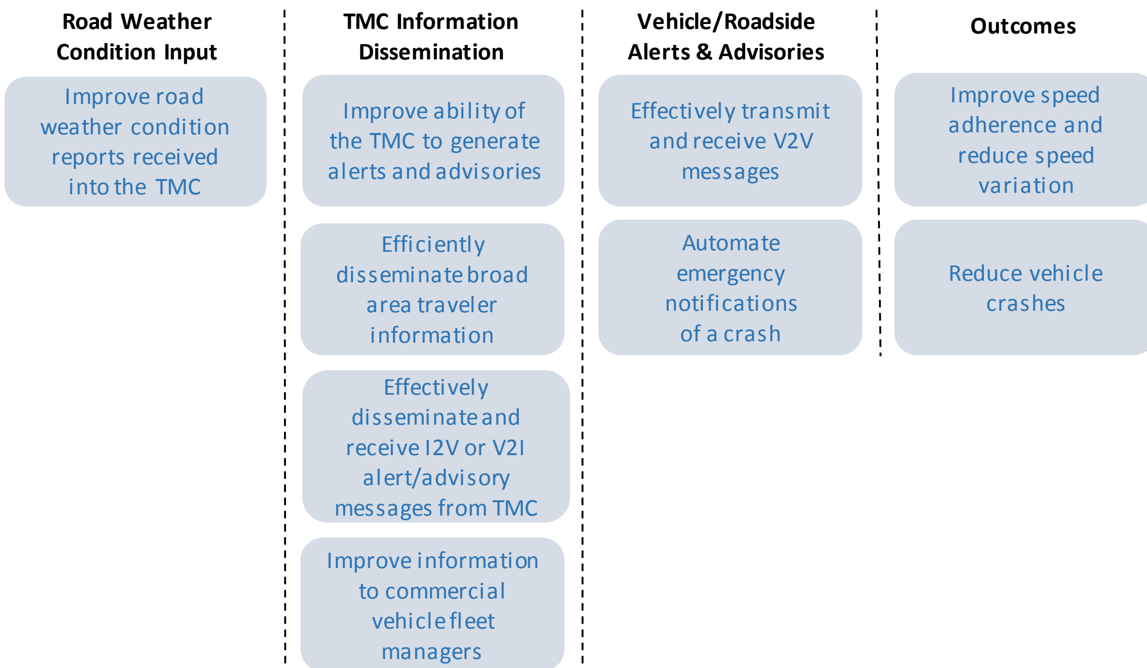

Figure 4-1. Performance Categories (Source: ICF)

Quantitative and qualitative measures are proposed to evaluate the Wyoming CV project with a focus on understanding the extent and impact of the benefits described above. For each performance measure, targets have been identified. These targets are considered preliminary and will be further refined as part of Phase II activities and baseline data collection. Table 4-2 summarizes the proposed performance measures and targets which will guide the evaluation of the Wyoming CV Pilot project.

Table 4-2. Wyoming CV Pilot Performance Measures and Targets.

No.	Performance Measure	Target
	Improved Road Weather Condition Reports Received into the TMC	
1	Number of road weather condition reports per road segment/day pre and post CV Pilot (quantity)	50% increase
2	Miles 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 segment pre and post CV Pilot (latency)	30% decrease
	Improved ability of the TMC to Generate Alerts and Advisories	
4	Pikalert™ generated alerts and advisories that were accepted by TMC operators	90% accepted
	Efficiently Disseminate Broad Area Traveler Information	
5	TMC staff time to disseminate broad area traveler information. Activities include: ● Log/process road condition reports ● Activate/update VSL, DMS, and HAR systems	25% reduction per event
6	Qualitative improvements in 0-6 hour road weather forecasting accuracy due to enhanced road condition data	N/A
	Effectively Disseminate and Receive I2V and V2I Alert/Advisory Messages from the TMC	
7	Alerts/advisories[1] sent from the TMC and received by the RSU	90% of sent alerts/advisories were received by RSU
8	Alerts/advisories sent and received between the RSU and OBU	75% sent were received in either direction
9	Connected vehicles that took action following receipt of an alert ● Parked ● Reduced speed ● Came to a stop safely ● Detoured	80% of vehicles took action based on alert
	Improved Information to Commercial Vehicle Fleet Managers	
10	Number of operational changes made by fleet managers due to information from TMC during CV Pilot ● Routing ● Timing ● Parking availability ● Cancelled trips	20% increase in operational changes during CV Pilot
11	Commercial vehicle managers are satisfied with information provided by the TMC during the CV Pilot ● Road conditions ● Road weather forecasts ● Parking information	90% of responding commercial vehicle fleet managers expressed satisfaction with information during CV Pilot
	Effectively Transmitted and Received V2V Messages	
12	V2V alerts properly received in surrounding vehicles from sending vehicle	75% of alerts sent from an equipped vehicle were received by other vehicles
13	Connected vehicles that took action following receipt of a V2V alert	80% of vehicles took action based on V2V alert

[1] Advisories in this system convey information to the truck driver at a location and time of their travel where an immediate action is not required. On the other hand, alerts require an immediate action from the driver (e.g., reduce speed, stop, pull over or take exit).

	• Parked • Reduced speed • Came to a stop safely • Detoured	
	Automated Emergency Notifications of a Crash	
14	Number of emergency notifications that are first received in the TMC from connected vehicles (compared to alternate traditional methods, such as 911 caller)	N/A
	Improved Speed Adherence and Reduced Speed Variation	
15	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.
16	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
17	Speed of applicable connected vehicles are closer to posted speed when compared to non-connected vehicles	Connected vehicles are 20% closer to posted speed
	Reduced Vehicle Crashes	
18	Reduction of total and rates of truck crash along the corridor (compare a 5-year average before Pilot to CV Pilot data) • Track connected versus non-connected vehicles	10% reduction in total and truck crash rates
19	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-connected vehicles	25% reduction in the number of vehicles involved in a crash
20	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-connected vehicles	10% reduction in total and truck within work zones
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-connected vehicles	10% reduction in total and truck critical crash rates
22	Number of connected vehicles involved in a crash • Initial crashes • Secondary crashes[2] (total and specifically rear-end crashes	N/A

[2] 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 (FHWA, 2000).

4.3 Relationship of Performance Measures to System Applications

The Wyoming CV Pilot Demonstration Concept of Operations identified seven system applications (described in Section 1 above). The performance measures were created with these system applications in mind and each system application is covered by one or more of the performance measures. Table 4-3 illustrates the mapping of performance categories and measures to system applications.

Table 4-3. Mapping of Performance Measures to System Applications.

Performance Measures		System Applications						
Category	Measures	Road Weather Advisories for Trucks	Automatic Alerts for Emerg. Resp.	CV-Enabled Wx-Resp. VSL	Spot Weather Impact Warning	Work Zone Warnings	Situational Awareness	Freight Specific Dynamic Travel Planning
Improved road weather conditions reports received into TMC.	1, 2, 3	X			X	X		
Improved ability of the TMC to generate alerts and advisories.	4	X			X	X	X	X
Efficiently disseminate broad area traveler information.	5, 6	X			X	X	X	X
Effectively disseminate and receive I2V and V2I alert/advisory messages from TMC.	7, 8, 9	X		X	X	X		
Improved information to commercial vehicle fleet managers.	10, 11	X		X	X	X	X	X
Effectively transmitted and received V2V messages.	12, 13	X		X	X	X	X	
Automated emergency notifications of a crash.	14		X					
Improved speed adherence and reduced speed variation.	15, 16, 17	X		X	X	X		
Reduced vehicle crashes.	18, 19, 20, 21, 22	X		X	X	X	X	

4.4 Importance of Establishing a Baseline

Many of the performance measures identified in Table 4-2 require a before/after analysis to be conducted during the evaluation in order to quantify the results. This evaluation method can only be performed if a valid baseline is established prior to any CV technology deployment. This baseline establishment is an essential preparation step that must be accomplished prior to the beginning of Phase III (demonstration). The Wyoming CV Pilot Team plans to establish this baseline during the Phase II activities and document the results in a revised version of this Performance Measurement and Evaluation Support Plan. Specific components that are anticipated to be included in the baseline development include:

- Traffic characteristics including trucks and private vehicles speeds under various conditions and speed variance results
- Weather events: type, severity, roadway impacts, etc.
- Number of road weather reports received at the TMC using traditional methods.
- I-80 coverage (percent of total) with road weather reports during severe weather events. Identify any gaps in coverage.
- Current time for TMC operators to disseminate broad area traveler information.
- Number of operational changes (routing, timing, cancelled trips) by commercial vehicle managers from road weather condition information provided by the TMC.
- Baseline surveys of TMC operators, connected vehicle drivers, and commercial vehicle fleet managers.
- Average refresh time of road condition reports in each designated segment.
- Vehicle speeds, speed variations, and posted speeds for various road weather conditions.
- 5-year history of crash and injury data.
- Location, extent, cause, and duration of I-80 closures over past 5-years.

5 Confounding Factors and Mitigation Approaches

The WYDOT CV Pilot Demonstration is unique in its project extents (over 400 miles of mostly rural Interstate) and its focus on improving safety during severe weather events. This section identifies confounding factors that may impact the ability to successfully implement the evaluation designs described herein and how these factors might be mitigated. The confounding factors identified by the Wyoming Project Team include:

1. CV technology penetration rate
2. Freight and passenger vehicle demand
3. CV technology adoption
4. Weather condition variability
5. New information use
6. Safety data availability
7. Limited duration of evaluation activities
8. Availability of Speed Sensing in the Corridor
9. Reliability of roadside and in-vehicle systems

5.1 CV Technology Penetration Rate

The pilot demonstration testing will be challenged by the relatively few number of vehicles that will be capable of receiving direct information from the infrastructure or other vehicles – especially in comparison to the number of total vehicles on I-80. The technology can be shown to work; however, measuring the benefits with such a small sample size will be limiting.

Mitigation Approaches

The first step to mitigate these issues is to always know what the technology penetration rate is. The evaluation design will include the ability to count all vehicles in the corridor and identify the number of connected vehicles. This data will include number, location, direction, and messages sent and received to and from connected vehicles. When events happen in the corridor, these data will be known and used to understand the evaluation results. Additionally, this information will be used to extrapolate higher technology adoption rates and those impacts through simulation modeling and driver simulator results.

After baseline performance data has been established, statistical sampling analyses can be performed to determine the required number of vehicles that ideally would be equipped for statistical relevance for experimental design. Given the number of vehicles proposed to be equipped (400-500), it is not expected that this number will be met given the budget constraints, which is why supplemental modeling is proposed to provide additional insights.

5.2 Freight and Passenger Vehicle Demand

The corridor is heavily used by commercial freight trucks, making system performance highly dependent on freight demand. This 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% of the truck traffic along I-80 neither originates nor is destined for locations within Wyoming[3]. Fluctuations in freight traffic could be caused by goods movement demand changes, economic conditions, fuel prices, or heavier than normal construction seasons, all of which are major variables in the logistic decisions made by fleet managers. For instance, high fuel prices can also result in fleet managers reducing the maximum speed allowed for its drivers construction along a corridor may push drivers to choose alternate routes or avoid travel altogether if the impacts of construction are viewed as too large.

<u>Mitigation Approaches</u>

I-80 is a major goods movement corridor and alternate routes are generally not practical for the commercial vehicle operators to consider. Freight demand, as measured by number of heavy vehicles using the corridor, will be measured throughout the baseline and deployment phases. Passenger car demand will also be measured and accounted for in the performance measurement analysis and modeling. The number of connected trucks using the I-80 corridor at any given time during technology deployment will be a very small percentage of the total trucks present at that same time. So, the fluctuations of total number of trucks in the corridor is not expected to change the performance measurement approach or demonstration outcomes. If significant changes in the demand is found during these periods, economic and freight demand variables will need to be included in any performance modeling of the corridor.

Construction activities along the corridor will be monitored and logged as part of the Pilot activities. Changes in demand will be measured through vehicle demand and accounted for in the modeling. Impacts of construction activities are likely to be minor given the lack of alternative routing in the region.

5.3 CV Technology Adoption

New technology involving a change in the way people do things is always challenging. For the proposed system, there are myriad agency personnel that are affected: TMC staff, snowplow drivers, commercial vehicle truck drivers, commercial vehicle company dispatch center personnel, etc. How these stakeholders adopt the new technology and information that will now be available is unknown – the lack of technology adoption and information use may affect the evaluation outcomes.

<u>Mitigation Approaches</u>

System training and technology adoption techniques will be used to ensure project stakeholders are familiar with project goals, system operation, and their role in ensuring a successful CV Pilot.

[3] Young, Rhonda, Joel Liesman, David Lucke, and Shane Schieck. (2004) *Wyoming Freight Movement and Wind Vulnerability*. Wyoming Department of Transportation and the Mountain-Plains Consortium. FHWA-WY-04/06F, Cheyenne, Wyoming.

Additionally, qualitative data collection through interviewing project participants and stakeholders will be included in the evaluation designs to assess the level of technology adoption and to what extent the lack of adoption affected the outcomes of the pilot demonstration testing

5.4 Weather Condition Variability

The variability of weather events and entire winter weather seasons presents challenges to analyzing pre- and post- system implementation data. Ideally, the evaluation would compare data during similar weather events – this is not always possible.

Mitigation Approaches

The evaluation designs will include both before/after and with/without analysis methods in an attempt to understand the impacts of the CV technology. In the case of before/after analysis, baseline conditions (before technology deployment) will be documented – this will include the type, intensity, and extent of the weather and road conditions. Once the CV technology is deployed, evaluation designs will include similar weather and road condition data. A process to categorize the quantitative data for various weather events will be performed so the before/after data comparisons can be made that will highlight and focus on the impact of the technology. Previous research has correlated traffic operational characteristics, such as speed selection and car following, and crash histories to key weather variables such as visibility, surface condition, relative humidity and pavement surface temperature[4]. This previous research has used these variables to create weather event categories. These weather event categories will be verified during Phase II of the CV Pilot and then utilized to control for weather condition variability during the performance evaluation.

With/without analysis methods during the same winter weather event have been used successfully in recent Wyoming weather responsive traffic management system evaluations. This approach will compare vehicles with the technology and those without the technology traveling on the same road during the same road weather conditions. This is achievable in the evaluation designs for our project because there will be vehicles traveling in the corridor at the same time under the same conditions that have CV technology and those that do not have the technology.

Microscopic traffic simulation modeling and the University of Wyoming Driver Simulator lab will also be used to mitigate for weather condition variability. Driver behavior observed at both the macroscopic and microscopic levels and used to calibrate weather sensitive traffic simulation model parameters. The driver reactions to conditions with and without alerts will be tested in the driver simulator lab. Both of these technologies allow for controlling of weather variables in the development of modeling and simulation scenarios.

[4] i) Buddemeyer, Jenna, Rhonda Young, Vijay Sabawat, and Emily Layton. (2010) *Variable Speed Limit System for Elk Mountain Corridor*. Wyoming Department of Transportation, FHWA-WY-10/04F, Cheyenne, Wyoming
ii) Young, Rhonda, Vijay Sabawat, Promothes Saha, and Yanfei Sui. (2013) *Rural Variable Speed Limits: Phase II*. Wyoming Department of Transportation, FHWA-WY-13/03F. Cheyenne, WY.

5.5 New Information Use

System capabilities are limited by how much information can realistically be given to drivers. There is a multitude of possible information that could be provided including speed limits, warnings, incidents ahead, detours, parking opportunities, etc. This could cause an information overload situation or drivers misunderstanding the messages. In a project stakeholder meeting it was suggested that the information must be simple to understand and easily delivered. This issue will be a significant design challenge. Additionally, even though this information will be made available to commercial vehicle companies and drivers, it is not known the extent to which the new information will be used by these groups.

Mitigation Approaches

The project Phase II activities will design a system that includes messages that are as simple to understand as possible and will do human factors testing prior to final design decisions being made. The University of Wyoming's driver simulator may be used to assist with possible driver responses to various types of messages to support the system design.

The variability of winter storm and roadway conditions make it difficult to utilize an equipped control group that would experience the same conditions as equipped vehicles receiving messages given the number of vehicles likely to be instrumented in the pilot. The use of a non-equipped control group will be utilized for observation of traffic flow parameters such as speed and gap distributions. It was felt that the only way to adequately control for weather at the vehicle level was through the use of driver simulator studies.

The evaluation designs will include qualitative data collection from those receiving the messages (new information) to understand their impressions of the messages (ease of receipt, understanding, acceptance) and how they responded to the messages (did nothing, took action immediately, etc.).

5.6 Safety Data Availability

Reported crashes in Wyoming area recorded in a statewide database maintained by WYDOT regardless of the agency that has jurisdiction of the roadway where the crash occurred. For the I-80 project corridor most of the crash records will be generated by the Wyoming Highway Patrol. Crash reports are required for any crashes involving an injury or for property damage in excess of $1,000. If an officer is not sent to the crash scene, the drivers are required to notify the law enforcement agency nearest to the scene. Crash reporting forms used by the Wyoming Highway Patrol follow the Model Minimum Uniform Crash Criteria (MMUCC) guidelines.

Crash data can be obtained from WYDOT's Highway Safety Program and contain information about the crash itself and the people and vehicles involved in the crash. No personal identification information is stored in this database. Original crash reports can also be requested from WYDOT which include the reporting officer's narrative of the crash but since these records contain personal information their use and distribution is more restricted.

As with all crash data, underreporting of crashes is a concern. Underreporting typically is correlated with severity so that the less severe the crash type, the higher percentage of crashes that go unreported. An underlying assumption with most crash analyses is that the underreporting percentages remain stable throughout the analysis period.

Typically, crash statics analysis requires multiple years of data for statistically valid results because of the variability of crash frequencies from year to year. Our project will not have multiple years of crash data for evaluation purposes.

Also, the analysis of the crash data available will need to be focused on the appropriate measures. The Wyoming CV Pilot Demonstration evaluation has performance measures and targets for reduction in both crash rates (all vehicles and truck specific crashes) and the total number of vehicles involved in crashes. The corridor experiences large, multivehicle crashes and the team believes the technology can have significant impacts in limiting the number of vehicles involved in a crash and limiting the severity of the crash related injuries.

Mitigation Approaches

The evaluation designs will include the standard crash data analysis, but will go further to analyze surrogate measures (speed, speed variation, etc.) to help understand and measure safety improvements. Additionally, corridor simulation modeling will be used to analyze the impact if a greater percentage of vehicles were equipped with connected vehicle technology. Behavior impacts of connected vehicle technology observed in the pilot will be modeled within traffic simulation models, allowing for the analysis of safety impacts of wider connected vehicle adoption rates. The traffic simulation model output can be analyzed using safety surrogate measures based on vehicle-to-vehicle interactions. Considerable research is ongoing in the area of calibrating microsimulation models, both by members of the pilot team and elsewhere, and it is believed that model advances are well timed for use in this pilot. In particular, the team has contacted members of the research team at Volpe developing a microsimulation work zone tool and feel that much of their work is applicable to this effort.

Also, the evaluation designs will identify the data needed to support measuring the nuances of the crash characteristics (number of vehicles, severity, etc.).

5.7 Limited Duration of Evaluation Activities

The WYDOT CV pilot is focusing on providing information and impacting driving safety during inclement weather which occurs mostly during the winter months. The project schedule, as discussed in Section 10, indicates that the CV Pilot Demonstration will begin in November 2017 and continue through November 2019. This will allow for only two winter seasons for data collection, analysis, and reporting. Baseline data collection and documentation will occur during Phase II (2016-2017 winter season).

Another concern is whether the appropriate weather conditions exist to conduct the evaluation during the evaluation period as designed. These issues may limit the amount and content of evaluation data during the designated evaluation period.

Mitigation Approaches

The project Phase III activities (demonstration/evaluation) are scheduled to begin in November 2017. Our team will ensure that the system is ready to begin demonstration activities at that time. The evaluation data collection activities will also be ready to begin. Our Team's approach will be to collect data for two winter seasons to support the most data collection possible to measure the performance of the system. The second winter season (2018-2019) will collect data through May and complete the project by November 2019, as required in Phase III Demonstration.

Additionally, the evaluation designs will be scalable so that, if desired, Wyoming DOT can continue data collection and evaluation activities beyond the Phase III project schedule limits.

5.8 Availability of Speed Sensing in the Corridor

Currently, radar speed sensors are spaced approximately 6-7 miles apart in the VSL corridors. 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. The Wyoming CV Pilot team acknowledges that knowing the vehicle speeds in between the VSL signs would be helpful to ensuring a consistent and correct speed to enhance safety.

Mitigation Approaches

The Wyoming CV Pilot team will investigate the possibility of portable speed sensing trailers that could be installed in various locations within the VSL corridor to enhance the ability to obtain additional sensing data. These mobile sensor stations include vehicle speed and, possibly, weather related sensing equipment.

Additionally, the CV Pilot Demonstration will know the speed and location of every connected vehicle operating on I-80. This data will also inform the speed conditions in the VSL sections.

5.9 Reliability of roadside and in-vehicle systems

The reliability of roadside and in-vehicle systems is not known. This includes DSRC equipment to transmit and receive information to and from vehicles from the roadside to vehicle, vehicle to roadside, and vehicle to vehicle. The winter environment can be extreme in Wyoming including severe cold, high winds, and significant snowfall. Additionally, the equipment that will be installed in trucks will be subjected to a harsh noise and vibration environment that may impact their operational life and capabilities. If the reliability of this equipment is less than expected, the data collection activities to support system performance measurement could be compromised.

Mitigation Approaches

During the system design/build phase (Phase II), the project team will select the equipment whose specs can accommodate these harsh environments and document the mean time between failures (MTBF) associated with each device. During the performance measurement evaluation, analysis will be conducted to determine the actual MTBF and up-time of the equipment. Also, equipment maintenance required during the demonstration will be documented. Although, this may not help data collection if the equipment doesn’t perform as designed, it will provide insight into the times and location of problem areas that will be factored into the evaluation data analysis.

6 System Impact Evaluation

This section describes each performance measure in detail including a description, data needs, and evaluation design for each. The performance measures are presented within their respective performance grouping as defined in Section 4.

Before the performance measures are discussed, two supportive topics are addressed: Evaluation Design Approaches and Contextual Performance Measurement Elements. These topics will help set the stage for understanding the details that follow.

6.1 Evaluation Design Approaches

The evaluation designs described below will determine how and when data will be collected, what analyses will be conducted, and methods to define how closely targets are being achieved. The design also provides an evaluation structure that can help control for the potential effects of confounding factors. It is important to seek to control such effects in order to be able to say that the Wyoming CV Pilot project itself was responsible, or at least primarily responsible, for the identified outcomes. The evaluation of each performance measure will attempt to show that the outputs and outcomes can properly be attributed to the effectiveness of the strategy and not to other factors that may also be related to the occurrence of those outcomes.

The Wyoming CV Pilot team carefully considered whether or not to include a control group of connected vehicles that did not receive alerts and advisories, and decided that this approach was not viable. There were two primary reasons for this decision, as follows:

1. Vehicles not in close enough proximity – with a very limited number of connected vehicles on the highway at any given time, the chances a connected vehicle and a control vehicle would be in the same location on I-80 to experience the same conditions would be very remote. It is just not a practical approach.
2. Could violate personal security – given the very limited number of connected vehicles on the highway at any given time, if some were identified as equipped and some a control group, there is a significant concern that the system could be able to identify specific vehicles which would violate security rules that are defined in the SMOC.

The Wyoming CV Pilot team believes that our control group includes the vehicles traveling on I-80 (trucks and private vehicles) that are not 'connected' and will behave without the advantage of disseminated alerts and advisories planned as part of the Pilot. Comparisons will be made between connected and non-connected vehicles traveling on I-80 during the same conditions.

Evaluation designs will incorporate both quantitative and qualitative approaches to make assessments of specific performance measures. The following five evaluation design types are anticipated for use during the evaluation activities (Phase III). These are described once here and referred to in the appropriate performance measurement evaluation design discussion so as not to create a lot of duplication of text.

6.1.1 Before-After

This approach quantitatively compares data under baseline conditions (before deployment) with data during the Wyoming CV Pilot demonstration (post-deployment). The before-after evaluation design requires the establishment of a baseline to document conditions before the CV Pilot project elements were deployed. This baseline will be 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. Some of the information to be collected during the baseline conditions are identified above in section 4.4.

The before-after evaluation is most useful for demonstrating effects over a relatively short time 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 longer time periods 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 CV Pilot 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 CV Pilot 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 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 performance measures identified will utilize the before-after evaluation approach. Examples of data needed to support the before-after analyses include 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, as well as many others. Values for these type of data will be compared before and after CV Pilot deployments to measure the percent increase/decrease.

In addition to controlling for weather variability, changes in other system parameters such as passenger and freight vehicle demand, CV penetration rates, construction and maintenance activities, and other confounding factors will be included in the before-after analysis. Cluster analysis, sensitivity analysis, and simulation modeling analysis will be used to ensure the before-after data comparisons will be focused during like conditions. In terms of simulation modeling analysis, variables will based on system data availability for both the before and after periods utilizing statistical methods for identifying contributing factors. Categorization of conditions and inclusion of variables in the model will be used to control for system variability between the before and after conditions to the maximum extent possible.

6.1.2 With-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-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 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.

Fewer performance measures identified will utilize this method. Examples of data needed to support the with-without analyses include speed of connected vs non-connected vehicles, crashes of connected vs non-connected vehicles, and driver behavior in terms of actions taken following receipt of an alert (whether from the TMC or another connected vehicle).

6.1.3 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-after and with-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 number of automated alerts/advisories sent and number that were actually received, including V2I and V2V applications.

6.1.4 Behavior Assessment

This evaluation measure specifically addresses behaviors, or actions, that result from alerts being received by drivers of connected vehicles. Possible behaviors could include speed reductions, 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.

6.1.5 Qualitative Assessment

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

For the before-after, with-without, and system performance evaluation designs, qualitative surveys or staff interviews obtained from key informants[5] 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 tightly 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.

[5] Knowledgeable individuals who understand the range of events and factors that are likely to affect observed outcomes.

6.2 Contextual Performance Measurement data

The following performance measurement data will be collected and used where needed to support the evaluation of performance measures described below. These data are not explicitly mentioned in the details that follow, but are summarized here:

- Connected Vehicle location and direction of travel at all times – the location and direction of travel of all connected vehicles traveling in the corridor will be monitored and stored. This data will enable us to understand if alerts/advisories were transmitted and appropriate actions taken.
- Connected vehicle penetration rate – The penetration rate of connected vehicles in comparison to all vehicles traveling in the corridor is expected to be fairly low and will vary over time and for different conditions. The penetration rate will be estimated during key times and locations in the corridor to support performance measurement activities. This will be used to assess the expected outcomes for various situations and support the use of simulation tools to conduct further analyses.
- Weather event characteristics – Understanding weather events and related road conditions at all times is essential to properly evaluate the performance of the system and travelers' behavior (connected and non-connected). Weather and road conditions will be maintained at all times along the corridor to support evaluation activities.
- Data transmissions – The number, type, content, timing, and location of all alert and advisory messages through V2I, I2V, and V2V media will be documented. TMC, RSE, DSRC, and vehicle system logs will be used to collect and store this information to support evaluation activities.
- Connected Vehicle Incidents – It will be important to know if a connected vehicle is involved in any type of incident. In addition to knowing if and when a connected vehicle is involved in an incident, it will also be important to determine if a connected vehicle came to a stop safely following an alert or advisory message.
- Equipment reliability – It will be important to document the roadside and in-vehicle equipment design and actual failure rates and determine equipment up-time. This will affect the available of data collection and corresponding evaluation and ability to assess the performance measures.

6.3 Performance Measurement Details

The performance measurement details will be presented using the organization in Table 4-2. It should be noted that even though the CV Pilot Demonstration will be operated year round, the vast majority of the measures and data collection will be focused during inclement weather conditions – mostly occurring during the winter months.

6.3.1 Improve Road Weather Condition Reports Received into the TMC

The focus of this performance category is to measure the improvement of road weather condition reports received in the TMC through the use of CV technologies. This information forms the basis of better alerts and advisories, which are the focus of later measures. The following three performance measures contained in this performance category focus on the quantity, coverage, and latency of the reports and are described in greater detail below:

1. Number of road weather condition reporting 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).

6.3.1.1 PM #1: Number of road weather condition reports per road segment/day (quantity)

Description: This measure focuses on the quantity of road weather condition reports. It is expected that the number of reports will increase dramatically through the deployment of CV technology such as snowplow tablets transmitting road reports, vehicle mounted mobile road weather sensors, vehicle on-board data bus connection providing actions (deceleration rates, braking, traction control and stability control activation, crash notification, wiper use, etc.) by the connected vehicles traveling along the corridor. The data will be processed by the Pikalert system and made available to TMC operators. The target is for a 50% increase in the number of reports.

Data Needs: The following data will be collected during the CV Pilot Demonstration, and where appropriate to establish the baseline condition:

- Number of road weather condition reports coming to TMC operators through the Pikalert system
- Number of WYDOT snowplow road weather condition reports submitted (baseline and post deployment)
- Pikalert system logs
- RSU logs
- OBU logs

Evaluation Design: The before-after evaluation approach will be used to measure the number of road weather condition reports compared to similar data representing the baseline conditions. The data identified above will be used to make these comparisons and a percent change in road condition reports will be calculated.

6.3.1.2 PM #2: Miles with at least one reported road condition per hour (coverage)

Description: This measure focuses on the coverage of I-80 with road weather condition reports. It is expected that the miles of I-80 with at least one road condition report per hour will increase substantially through the deployment of CV technology such as snowplow tablets transmitting road reports, and vehicle on-board data bus connection providing actions (deceleration rates, braking, traction control and stability control activation, crash notification, wiper use, etc.) by the connected vehicles traveling along the corridor. The target is for a 25% increase in the miles of I-80 with at least one road condition report per hour.

Data Needs: The following data will be collected during the CV Pilot Demonstration, and where appropriate to establish the baseline condition:

- Number of road weather condition reports coming to TMC operators through the Pikalert system
- Number of WYDOT snowplow road weather condition reports submitted (baseline and post deployment)
- Pikalert system logs
- RSU logs
- OBU logs

Evaluation Design: The before-after evaluation approach will be used to measure the miles of I-80 with at least one road condition report per hour compared with similar data representing the baseline conditions. The data identified above will be mapped to the corridor and against the maintenance operational segments and used to calculate a percent increase in miles of I-80 with at least one road condition report per hour.

6.3.1.3 PM #3: Average refresh time of road condition reporting in each segment (latency)

Description: Wyoming DOT's goal is for road condition reports in each segment to be updated (refreshed) when conditions change. Currently, this is accomplished by DOT maintenance personnel as they are plowing and treating the roadways. During the CV Pilot that data will be enhanced with other input from connected vehicles and better equipped snow plows. The road condition reports by segment will be an output of the Pikalert system following ingestion and processing of multiple sources of information. It is expected that the refresh time will increase by 30% during the Pilot Demonstration.

Data Needs: The following data will be collected during the CV Pilot Demonstration, and where appropriate to establish the baseline condition:

- Number of road weather condition reports coming to TMC operators through the Pikalert system
- Number of WYDOT snowplow road weather condition reports submitted (baseline and post deployment)
- Pikalert system logs
- RSU logs
- OBU logs

Evaluation Design: The before-after evaluation approach will be used to measure the road condition reporting refresh time in each segment compared to the baseline conditions. The baseline will be established using current TMC logs which document the road condition reports by segment. During the Pilot, the Pikalert system logs will provide recommended road condition reports by segment. Time stamps in both systems will be used to determine the refresh rate for the baseline and Pilot cases and comparisons made to calculate the percent change in the refresh rate.

6.3.2 Improved ability of the TMC to generate alerts and advisories

The focus of this performance category will be to measure the effectiveness of the Pikalert system to generate alerts and advisories that reflect current conditions. The following performance measure will be described in greater detail below:

4. Percent of Pikalert generated alerts and advisories that were accepted by TMC operators.

6.3.2.1 PM #4: Pikalert generated alerts and advisories that were accepted by TMC operators.

Description: The Pikalert system will generate alerts and advisories after processing input from several sources, as previously noted. These alerts and advisories will be presented to the TMC operators for possible dissemination to the public through broad area systems, to commercial vehicle fleet managers, and to connected vehicles. This performance measure will determine the percentage of Pikalert system generated alerts and advisories that were accepted and disseminated, or rejected by TMC operators. There could be several reasons the Pikalert system recommended alerts and advisories may not be appropriate for dissemination by the TMC operators including accuracy concerns, timing concerns, or because they don't fit with other activities in the corridor known to the TMC operator. This performance measure will determine the percent of Pikalert system recommended alerts and advisories that were accepted by TMC operators – with a target of 90% acceptance.

Data Needs: The following data will be collected during the CV Pilot Demonstration

- Pikalert system logs of recommended alerts and advisories
- TMC logs of those Pikalert system recommendations being accepted by TMC operators and disseminated

Evaluation Design: The system performance evaluation approach will be used to measure the acceptance of Pikalert system generated alerts and advisories by TMC operators. A percent of accepted alerts and advisories will be calculated and reported.

6.3.3 Efficiently Disseminate Broad Area Traveler Information

The TMC will continue to disseminate traveler information via their normal channels - web page, 511 phone, mobile app, DMS, HAR and VSL. This performance category will attempt to measure the staff efficiency gains in performing these functions. The following two performance measures are contained in this performance category and will be described in greater detail below:

5. TMC staff time to disseminate broad area traveler information
6. Qualitative improvements in 0-6 hour road weather forecasting accuracy due to enhanced road condition data

6.3.3.1 PM #5: TMC staff time to disseminate broad area traveler information.

Current activities of TMC staff include:

- Log/process road condition reports
- Activate/update VSL, DMS, and HAR system

Description: Currently the TMC operators perform several duties that are manual such as logging and processing road condition reports from the field and activating and updating VSL, DMS and HAR systems. During the Pilot Demonstration many of these activities will be become automated or semi-automated. For instance, it is expected that the logging and processing of road condition reports will be performed by the Pikalert system, updating the WTI will be fully automated, the activation and updates to the VSL, DMS, and HAR systems will be made easier through semi-automation and recommendations made by the systems. During the Pilot, it is expected that the TMC operator time currently expended on manual activities will be significantly reduced and that time saved can be focused on addressing the other urgent issues especially during severe weather events. A target of 25% reduction in time per event was established.

Data Needs: The following data will be collected during the CV Pilot Demonstration, and where appropriate to establish the baseline condition:

- Time studies of TMC operator time to perform the duties defined above during baseline conditions (Phase II) and during Pilot Demonstration (Phase III).

Evaluation Design: The before-after evaluation approach will be used to measure the reduction in time needed by TMC operators to disseminate broad area traveler information. Baseline and Pilot data will be compared and a percent change calculated.

6.3.3.2 PM #6: Qualitative improvements in 0-6 hour road weather forecasting accuracy due to enhanced road condition data

Description: Meteorologists located in the TMC currently produce road weather forecasts that are used to inform the maintenance dispatchers and the commercial vehicle operator portal (CVOP). The CVOP is a website used by trucking companies that subscribe to the service. The meteorologists use multiple information sources in order to develop these road weather forecasts. One of the primary inputs is road condition data. Currently that road condition data comes from the field maintenance reports. During the Pilot, the road condition reports will be generated by the Pikalert system using multiple sources. This measure will qualitatively assess the improvements in 0-6 hour road weather forecasting accuracy due to the enhanced road condition data. The input will come from interviewing the TMC meteorologists, TMC operators, and a select group of commercial vehicle operators who subscribe to the CVOP service.

Data Needs: The following data will be collected during the CV Pilot Demonstration, and where appropriate to establish the baseline condition:

- Baseline interviews with the TMC meteorologists, TMC operators, and a select group of commercial vehicle operators who subscribe to the CVOP service to understand what they think of and how they use the road weather forecasts.
- Pilot Demonstration interviews with the TMC meteorologists, TMC operators, and a select group of commercial vehicle operators who subscribe to the CVOP service to understand how the road weather forecasts have changed, if they feel the forecasts are more accurate, and any process changes that have resulted from the changes.

Evaluation Design: The qualitative assessment evaluation approach combined with the before-after evaluation approach will be used to measure the changes in forecast accuracy due to enhanced road condition data. Interview guides will be developed for each of the phases (baseline and Pilot). Interviews will be conducted with the TMC meteorologists, TMC operators, and a select group of commercial vehicle operators who subscribe to the CVOP service to learn their impressions of the road weather forecasts and changes in those forecasts during the Pilot Demonstration.

6.3.4 Effectively Disseminate and Receive I2V and V2I Alert/Advisory Messages from the TMC

This performance category will focus on how the system performed to get the alerts/advisories to their designated recipients and what actions those recipients took in response. The following two performance measures are contained in this performance category and will be described in greater detail below:

7. Alerts/advisories sent from the TMC that were received by the RSU.
8. Alerts/advisories sent and received between the RSU and OBU.
9. Connected vehicles that took action following receipt of an alert.

6.3.4.1 PM #7: Alerts/advisories sent from the TMC that were received by the RSU

Description: This measure is focused on understanding how a key aspect of the Wyoming CV system performs: the alerts and advisories sent to the RSUs from the TMC. This performance measure will determine the percent of alerts/advisories that were sent from the TMC were actually received by the RSUs. This is extremely important to a successful CV system. This evaluation will assess the performance of the system that will actually send an alert from the TMC, the communication to the RSUs, and the RSUs to log the receipt of the message. During the Pilot, it is anticipated that 90% of the alerts and advisories sent will be received by the RSUs.

Data Needs: The following data will be collected during the CV Pilot Demonstration:

- TMC logs
- RSU logs

Evaluation Design: The system performance evaluation approach will be used to measure the percent of sent alerts/advisories that are received by RSUs. Analysis of the logs identified above will allow the evaluators to follow the alerts/advisories through the various systems and links to not only determine the percent that reach their intended recipients, but also determine which system operated as designed and which system may have had difficulties in passing along the information properly.

6.3.4.2 PM #8: Alerts/advisories sent and received between the RSU and OBU

Description: This measure focuses on the remaining message chain to ensure it gets to the designated recipients. This performance measure will determine the percent of alerts/advisories that were sent from the RSUs were actually received by their designated recipients (connected vehicles). This evaluation will assess the DSRC to transmit the information to the vehicle, and the OBU system in the vehicle to receive the information. During the Pilot, it is anticipated that 75% of the alerts and advisories sent from the RSUs will be received by their designated recipients.

Data Needs: The following data will be collected during the CV Pilot Demonstration:

- RSU logs
- DSRC logs
- OBU logs

Evaluation Design: The system performance evaluation approach will be used to measure the percent of sent alerts/advisories that are sent by RSUs are received by their designated recipients. Analysis of the logs identified above will allow the evaluators to follow the alerts/advisories through the communication and data systems to not only determine the percent that reach their intended recipients, but also determine which system operated as designed and which system may have had difficulties in passing along the information properly.

6.3.4.3 PM #9: Connected vehicles that took action following receipt of an alert

These actions include:

- Parking
- Reducing speed
- Came to a stop safely
- Detouring

<u>Description:</u> This measure will assess the effectiveness of the alerts to encourage the driver of the connected vehicle to take an action. Of course, this will depend on the type and content of the alert so the action must also be appropriate to the message. For instance, if a road closed ahead alert is sent, then an appropriate action such as a parked vehicle or an initiated detour appropriate to the closure would be expected. The evaluation of this measure will also take into consideration the temporal and spatial aspects of the messages and actions. The action must be appropriate to the timing and location of the message. The target established for this measure is that 80% of connected vehicles will take an appropriate action based on the alert/advisory received.

<u>Data Needs:</u> The following data will be collected during the CV Pilot Demonstration:

- TMC logs
- OBU logs
- Temporal and spatial data of all connected vehicles
- Information regarding connected vehicle's involvement in any incident

<u>Evaluation Design:</u> The behavior assessment design approach will be used to measure the percent of connected vehicle drivers that took an appropriate action following receipt of an alert. Analysis of the logs identified above will allow the evaluators to compare the alert messages with the actions taken by a connected vehicle that received the message. A percent of appropriate action taken, given the alert will be calculated.

In addition to analyzing equipped vehicle logs, the evaluation of this performance measure will utilize the driver simulator lab at the University of Wyoming. Driver simulator studies will be used to ensure that the alerts provided during the Pilot Demonstration have been designed to be safely understood by the driver and to maximize the likelihood of desired behavioral responses such as deceleration and lane changing. Using the driver simulator provides driver behavior data under controlled and repeatable conditions where statistical analyses can be performed regarding driver responses. The results from these analyses will provide additional indicators in evaluating this performance measure.

6.3.5 Improved Information to Commercial Vehicle Fleet Managers

The Wyoming CV Pilot will be communicating with commercial vehicle fleet managers in a more significant way by providing forecasts, alerts, and advisories directly from the TMC. This performance category focuses on how effective the enhanced messaging was for the fleet managers. The following two performance measures are contained in this performance category and will be described in greater detail below:

10. Number of operational changes made by fleet managers due to information from the TMC during the CV Pilot.
11. Commercial vehicle managers are satisfied with information provided by the TMC during the CV Pilot.

6.3.5.1 PM #10: Number of operational changes made due to information from TMC during CV Pilot

These changes include:

- Routing

- Timing
- Parking availability
- Cancelled trips

Description: This measure will assess the operational changes made by fleet managers due to information from the TMC during the CV Pilot compared to a baseline condition. WYDOT is expecting to provide much better information to fleet managers to help them make better decisions regarding routing, trip timing, and canceling trips. This information will include parking availability as provided by commercial vehicle drivers through the 511 Mobile App. This evaluation will determine the value of the information during the CV Pilot to the fleet managers. It is expected that an increase of 20% in the effective operational changes will be achieved. The qualitative input from the fleet managers will be captured in the next measure.

Data Needs: The following data will be collected during the CV Pilot Demonstration, and where appropriate to establish the baseline condition:

- TMC logs indicating information provided to commercial vehicle fleet managers
- Fleet manager logs of operational changes made (type and timing) based on input from the TMC – baseline and during the CV Pilot.

Evaluation Design: The before-after evaluation approach will be used to measure the potential increase in the number of operational changes made by fleet managers due to information from the TMC during the CV Pilot. Baseline and Pilot data will be compared and a percent change in the number of operational changes will be calculated.

6.3.5.2 PM #11: Commercial vehicle managers are satisfied with information provided by the TMC during the CV Pilot

Description: The information that commercial vehicle fleet managers will receive during the CV Pilot will be enhanced in terms of content, timing, and direction of alerts and advisories. In addition to measure #10 above, it will be important to qualitatively assess their level of satisfaction with the new information. The evaluation of this measure will gather important information about not only their satisfaction, but input to WYDOT about how the information can be improved in the future. It is expected that 90% of participating commercial vehicle fleet managers will express their satisfaction with the new information.

Data Needs: The following data will be collected during the CV Pilot Demonstration:

- Pilot Demonstration interviews with the commercial vehicle fleet managers.

Evaluation Design: The qualitative assessment evaluation approach will be used to measure the level of satisfaction commercial vehicle fleet managers have with the new information from the TMC. An interview guide will be developed and interviews conducted with the participating commercial vehicle fleet managers to learn their impressions and level of satisfaction with the new information. The interview will also focus on what improvements they would suggest in the information to assist them in effectively managing their fleet.

6.3.6 Effectively transmitted and received V2V messages

Section 5.3.4 addressed the effectiveness of alert and advisory messages sent to connected vehicles from the TMC. This performance category focuses on the effectiveness of V2V messages between vehicles. The following two performance measures are contained in this performance category and will be described in greater detail below:

12. V2V alerts properly received in surrounding vehicles from sending vehicle
13. Percent of connected vehicles that took action following receipt of a V2V alert

6.3.6.1 PM #12: V2V alerts properly received in surrounding vehicles from sending vehicle

Description: This performance measure is focused on understanding how well the V2V system worked in the real world. It will focus on V2V messages (basic safety messages and specific alerts) being received by other connected vehicles. The evaluation will determine the percent of BSMs and alerts sent by connected vehicles that were properly received by other connected vehicles in the area (either direction of travel). It will of course be very important to know where and when messages were sent and where the other possible vehicles are that might receive the message. Again, this action is not dependent on the RSU to relay the information, but rather the DSRC equipment on board the connected vehicles to send and receive messages from and to other connect vehicles. The information indicating receipt of V2V messages will be kept in OBU logs for analysis. During the Pilot, it is anticipated that 75% of the V2V messages that were sent, were received by other connected vehicles.

Data Needs: The following data will be collected during the CV Pilot Demonstration:

- OBU logs recording sent and received V2V messages from other connected vehicles
- DSRC logs indicating messages sent and received
- RSU logs that recorded V2V messages being transmitted to other connected vehicles

Evaluation Design: The system performance evaluation approach will be used to measure the percent of messages (sent by a connected vehicle) were received by other connected vehicles in the area. In addition to vehicle OBU logs, RSU logs (in the vicinity of the transmitting vehicle) will be used to understand the V2V messages sent by connected vehicles. A percent of messages properly received by connected vehicles that were sent by other connected vehicles will be calculated.

6.3.6.2 PM #13: Percent of connected vehicles that took action following receipt of a V2V alert

These actions include:

- Parking
- Reducing speed
- Came to a stop safely
- Detouring

Description: This measure will assess the effectiveness of the V2V messages and what action the driver of the connected vehicle receiving the message took. Of course, this will depend on the type and content of the V2V message so the action must also be appropriate to the message. This is similar to the PM #9 regarding actions taken from alerts and advisories sent from the TMC. The evaluation of this measure will also take into account the temporal and spatial aspects of the messages and actions. The action must be appropriate to the timing and location of the message. The target established for this measure is that 80% of connected vehicles will take an appropriate action based on the V2V message received.

Data Needs: The following data will be collected during the CV Pilot Demonstration:

- OBU logs regarding sent and received V2V messages
- Temporal and spatial data of all connected vehicles
- Information regarding connected vehicles' involvement in any type of incident

Evaluation Design: The behavior assessment design approach will be used to measure the percent of connected vehicle that took an appropriate action following receipt of a V2V message. Analysis of the logs identified above will allow the evaluators to compare the V2V messages sent with the actions taken by another connected vehicle that received the message. A percent of appropriate actions taken, given the V2V message, will be calculated.

In addition to analyzing equipped vehicle logs, the evaluation of this performance measure will utilize the driver simulator lab at the University of Wyoming. Driver simulator studies will be used to ensure that the alerts provided during the Pilot Demonstration have been designed to be safely understood by the driver and to maximize the likelihood of desired behavioral responses such as deceleration and lane changing. Using the driver simulator provides driver behavior data under controlled and repeatable conditions where statistical analyses can be performed regarding driver responses. The results from these analyses will provide additional indicators in evaluating this performance measure.

6.3.7 Automated emergency notifications of a crash

Prompt notification of a crash could mean the difference between life and death for those involved. The CV technology has the ability, in certain circumstances, to transmit these notifications based on processing of vehicle diagnostics. This performance category focuses on the impact of more prompt crash notification through the CV Pilot systems. The following related performance measure is described in greater detail below:

14. Number of emergency notifications that are first received in the TMC from connected vehicles (comparted to alternate traditional methods, such as 911 caller).

6.3.7.1 PM #14: Number of emergency notifications that are first received in the TMC from connected vehicles (compared to alternate traditional methods, such as 911 caller).

Description: This performance measure focuses on the number of emergency notifications received in the TMC from connected vehicles versus other means of notification. Emergency notifications can come from several sources including driver or passenger of vehicle involved in the emergency through a 911 call, other motorist 911 call, highway patrol, maintenance staff, or automated message from a connected vehicle. There have been several instances when the notification of an emergency was not made in time to save the persons involved in a crash. The Wyoming CV Pilot team believes this connected vehicle feature is another way lives can be saved. There is no target for this measure. The number of connected vehicle emergency notifications will be logged during the Pilot Demonstration, as well as total emergency notifications from other sources.

Data Needs: The following data will be collected during the CV Pilot Demonstration:

- Number of emergency notifications from connected vehicles
- Total number of emergency notifications from all sources

Evaluation Design: The system performance evaluation approach will be used to log the number of emergency notifications from connected vehicles. These numbers will be compared to the total emergency notifications from all sources.

6.3.8 Improved speed adherence and reduced speed variation

This performance category focuses on speed behavior in the corridor as measured by adherence to posted speed limits and variation of speeds among vehicles. Data for the performance measures will be collected from the Variable Speed Limit (VSL) areas within the overall project corridor. The decision to focus on the VSL corridors was based the availability of existing roadside speed radar equipment and the expectation that the Connected Vehicle pilot's RSE would likely be installed in these areas since the VSLs represent locations with historically the greatest safety concerns. The following three performance measures are contained in this performance category and will be described in greater detail below:

15. Vehicles traveling at no more than 5 mph over the posted speed (compare before and after CV Pilot)
16. Vehicles traveling within +/- 10 mph of 85th percentile speed (compare before and after CV Pilot)
17. Speed of connected vehicles are closer to posted speed when compared to non-connected vehicles

The speed performance measures involve the analysis of observed speeds of both connected and non-connected vehicles. The connected vehicle fleet will be comprised of WYDOT fleet, including snowplows and Highway Patrol vehicles, and privately operated vehicles, including light duty and larger freight vehicles. When measuring speed performance, the unique characteristics of this diverse vehicle fleet will need to be considered and it may be necessary to remove or to separately analyze some of the vehicle types. It is anticipated that snowplows and Highway Patrol vehicles are two vehicle types that will likely be excluded from the analyses given their non-typical speed behavior.

6.3.8.1 PM #15: Vehicles traveling at no more than 5 mph over the posted speed

Description: This measure focuses on the adherence to posted speeds of vehicles traveling the project's VSL corridors with speed compliance defined as vehicles traveling at no more than 5 mph above current posted speeds. Speed adherence measurement will focus primarily on the VSL corridors since those are the high risk areas on the corridor. It is expected that CV technology will lead to higher posted speed adherence due to increased awareness of current speed postings. Increased speed adherence also anticipates that the faster reporting and more comprehensive road condition information will reduce lag time for the TMC to change VSL postings. Baseline speed adherence will be determined from observations of vehicles from roadside speed radar equipment. The speed adherence data for the period during the CV demonstration will be determined from roadside speed radar equipment and from CV data logs from equipped vehicles. The target for this performance measure is for a 20% improvement over the baseline of the percent of total vehicles in the VSL corridors traveling at no more than 5 mph over the posted speed.

Data Needs: The following data will be collected during the CV Pilot Demonstration and prior to the Demonstration as needed to support the establishment of baseline conditions:

- Time-stamped speed of individual vehicles from roadside speed radar equipment at locations in the VSL corridors including vehicle length (for classification of vehicles into passenger cars and trucks)
- VSL event logs indicating changes to VSL speed limit signs
- OBU logs from CV equipped vehicles including vehicle speeds

Evaluation Design: Both before-after and with-without evaluation approaches of vehicles in the VSL corridor will be used. Previous research has shown that speed adherence varies greatly depending on the magnitude of the posted speed reduction and by vehicle types (passenger cars versus trucks) so data will be analyzed for different speed reduction categories for cars, trucks, and combined traffic flows[6]. Speed compliance rates for all vehicles before and during the CV demonstration period will be compared to determine the differences between the two groups. In addition, speed adherence rates for vehicles with and without CV technology will be compared for the period during the CV demonstration period. Since the time, speed and location of CV-equipped vehicles will be known, these observations can be removed from the roadside speed radar sets so that the “with-without” data sets can be compared.

Speed compliance, as measured as percentage of vehicles traveling at no more than 5 mph above posted speed, was analyzed during ideal conditions and during storm events at early stages of the VSL deployment and found to be highly variable with compliance rates ranging from 35 to 50% during storm events and 70 to 85% during ideal conditions when the maximum speed limit was posted. New baseline data will be collected during Phase II of the CV Pilot to determine current compliance rates and it is anticipated that these compliance rates will be much higher due to improved operations of the VSL as the TMC has refined operational procedures related to setting speed limits. These new procedures both reduce response times for increasing and decreasing speeds in response to changing conditions and increase the consistency of the speeds that have been set. Once the new baseline data has been established, the target values for this performance measure will be reevaluated.

6.3.8.2 PM #16: Vehicles traveling within +/- 10 mph of 85th percentile speed

Description: This measure focuses on speed variation of vehicles traveling the VSL corridors as measured as the percent of vehicles traveling within 10 mph of the 85th percentile speed. Speed variation is an important indicator of safety as previous studies have shown that reductions in speed variation are correlated with increased safety[7]. Lower speed variation leads to less required lane changes and better car following behavior. It is expected that CV technology will lead to lower speed variation due to increased awareness by drivers of current speed postings. Improvements are also anticipated due to reduced lag time for the TMC to change VSL speed limit postings in response to faster and more comprehensive road condition information, allowing the VSL postings to better represent current conditions. Baseline speed variation as measured by percent of vehicles traveling within 10 mph of 85th percentile speed will be determined from analysis of individual vehicle observations from roadside speed radar equipment. Speed variation data from the CV pilot demonstration phase will be analyzed for all vehicles in the corridor from the roadside speed radar equipment and on CV data logs from equipped vehicles. The target for

[6] Young, Rhonda, Vijay Sabawat, Promothes Saha, and Yanfei Sui. (2013) *Rural Variable Speed Limits: Phase II*. Wyoming Department of Transportation, FHWA-WY-13/03F. Cheyenne, WY.
[7] Garber, N J and Gadirau, R. *Speed Variance and its Influence on Accidents*. AAA Foundation for Traffic Safety. Washington, D.C., HS-040 559.

this performance measure is for 20% improvement over baseline in percent of vehicles in the VSL corridors traveling within +/- 10 mph of the 85th percentile speed.

Data Needs: The following data will be collected during the CV Pilot Demonstration and prior to the Demonstration as needed to support the establishment of baseline conditions:

- Time-stamped speed of individual vehicles from roadside speed radar equipment at locations in the VSL corridors including vehicle length (for classification of vehicles into passenger cars and trucks)
- VSL event logs indicating changes to VSL speed limit signs
- OBU logs from CV equipped vehicles including vehicle speeds

Evaluation Design: Both with-without and before-after evaluation approaches will be used to assess this performance measure. Speed variation as measured by percent of vehicles traveling within 10 mph of the 85th percentile speed for all vehicles traveling the VSL corridors before and during the CV demonstration period will be compared. Speeds along the corridor tend to have bi-modal distributions given the large percentages of trucks in the vehicle stream so data will be analyzed for cars, trucks, and combined traffic flows. The large percentage of trucks traveling in the corridor supported the decision to use a 20 mph range as opposed to the more traditional 10 mph pace value. The use of this performance measure captures both ends of the speed variation spectrum (i.e. both higher and lower than desired speeds), which is not captured in the speed adherence performance measure. In addition to this performance measure, the speed data will also be analyzed through the development of full speed distribution curves to ensure that this selected performance measure is capturing all relevant speed distribution characteristics of the data. The development of these distribution curves during the baseline development process may lead to further refinement of this performance measure specification.

Speed variations for vehicles with and without CV technology will be compared during the CV demonstration period, although the number of equipped vehicles during the demonstration period will likely limit the usefulness of this comparison. Since the time, speed and location of CV-equipped vehicles will be known, these observations can be removed from the roadside speed radar sets so that the “with-without” data sets can be compared. While the number of equipped vehicles is relatively low compared to total traffic volumes, the comparisons of the two datasets will likely be insightful. The effects of these differences can be analyzed in microsimulation models to look at the impacts larger market penetration could have.

Evaluation of speed variance during the early deployment stages of the I-80 VSL corridors indicated reductions in speed variation due to the use of the VSL but also showed high variability in driver responses to the system. Previous research using this measure indicates ranges of 40% to 70% of vehicles have speeds within this range during storm events and 60% to 80% during ideal conditions[8]. New baseline data will be collected during Phase II of the CV Pilot to determine current compliance rates and it is anticipated that these compliance rates will be closer to the 75 to 80% range due to improved operations of the VSL as the TMC has refined operational procedures related to setting speed limits. These new procedures both reduce response times for increasing and decreasing speeds in response to changing conditions and increase the consistency of the speeds that have been set. Once the current baseline data has been

[8] Young, Rhonda, Vijay Sabawat, Promothes Saha, and Yanfei Sui. (2013) *Rural Variable Speed Limits: Phase II*. Wyoming Department of Transportation, FHWA-WY-13/03F. Cheyenne, WY.

established, the target values for this performance measure will be reevaluated prior to the pilot deployment.

6.3.8.3 PM #17: Speed of connected vehicles are closer to posted speed when compared to non-connected vehicles

Description: This measure focuses specifically on the speed selection behavior of connected vehicles as compared to non-connected vehicles traveling the VSL corridors by comparing the speeds of the two vehicle types under the same conditions during VSL activations. This performance measure provides insight beyond the before-after analyses discussed in the two previous performance measures by taking a disaggregated view of speed selection behavior. Speed selections close to posted speed yield low speed variations and result in lower safety risk. It is expected that CV technology will lead to lower speed variation due to increased awareness by drivers of current speed postings. Improvements are also anticipated due to reduced lag time for the TMC to change VSL speed limit postings in response to faster and more comprehensive road condition information, allowing the VSL postings to better represent current conditions. Baseline speed behavior of non-connected vehicles will be measured from analysis of individual vehicle observations from roadside speed radar equipment. Speed selection data from the CV pilot demonstration phase will be analyzed for all vehicles in the corridor from the roadside speed radar equipment and on CV data from equipped vehicles. The target for this performance measure is for connected vehicles to select speeds that are 20% closer to the posted speed than non-connected vehicles in the VSL corridors.

Data Needs: The following data will be collected during the CV Pilot Demonstration:

- Time-stamped speed of individual vehicles from roadside speed radar equipment at locations in the VSL corridors including vehicle length (for classification of vehicles into passenger cars and trucks)
- VSL event logs indicating changes to VSL speed limit signs
- OBU logs from CV equipped vehicles including vehicle speeds

Evaluation Design: Evaluation will be a “with-without” evaluation approach of vehicles in the VSL corridor. Speed behavior as measured by the magnitude of the speed difference between the observed and posted speeds for vehicles traveling the VSL corridors during the CV demonstration period. Since the time, speed and location of CV-equipped vehicles will be known, these observations can be removed from the roadside speed radar sets so that the “with and without” data sets can be compared. While the number of equipped vehicles is relatively low compared to total traffic volumes, the comparisons of the two datasets will likely be insightful. To ensure that conditions are comparable between the two vehicle types, observations from non-connected vehicles will be limited to the time periods within 10 minutes of any connected vehicle observation so that weather, traffic, lighting, and other conditions that could affect speed selection behavior are as similar as possible. In order to ensure a meaningful comparison, distribution of vehicle types (cars and trucks) will be matched for the CV equipped and non-equipped groups.

6.3.9 Reduced vehicle crashes

This performance category focuses on safety as measured by a reduction in vehicle crashes along the project corridor. Safety improvements are the Pilot’s primary objective. They can be measured by number of crashes, number of vehicles involved in crashes, and number of critical crashes[9]. The following five performance measures are contained in this performance category and will be described in greater detail below:

18. Reduction of total and truck crash rates along the corridor
19. Reduction of the number of vehicles involved in a crash
20. Reduction of total and truck crash rates within a work zone area
21. Reduction of total and truck critical crash rates in the corridor
22. Number of connected vehicles involved in a crash

The safety performance measures were selected to capture the primary objective of the Wyoming CV Pilot project to reduce vehicle crashes along the project corridor. Given the confounding factors of weather and a short demonstration period for evaluation, there is concern about the project's ability to quantify the safety impacts in a manner that have statistical relevance. The performance measures described in the following section are designed to both maximize the team's ability to measure safety impacts in the short term but also set up a plan for long term evaluation.

In addition to the primary safety performance measures of crash reduction, the evaluation design described below 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. It is anticipated that CV deployment will result in changes to speed selection, lane changing and car following behavior for CV-equipped drivers that can be modeled in a microsimulation environment. The use of traffic simulation modeling allows for the analysis of conflict-event safety surrogates such as time to collision, post encroachment time, and deceleration rates. Other safety surrogate measures such as distribution of speeds and number of lane changes may also provide insightful. Selection of appropriate safety surrogate measures will be explored during the baseline development process in Phase II of the pilot. Input for the calibration of the microsimulation models will come from existing roadside speed and gap observations, CV equipped vehicles, traffic simulator studies, and other ongoing research efforts by the pilot team and other agencies such as Volpe Center's effort in developing the work zone microsimulation tool, which includes a weather component to their driver behavior models. The use of the Surrogate Safety Assessment Model (SSAM) will also be explored to determine the model's transferability to the Wyoming Pilot corridor.

Typical lag times between crash event and the inclusion of crash reports in the database is 8-days according to WYDOT's Highway Safety Program. Delays exceeding this stem from Highway Patrol workloads. If this lag is determined to be too long during the deployment phase, alternate reporting directly from Highway Patrol logs could be implemented for the vehicle crash related performance measures.

The crash performance measures involve the analysis of crashes involving connected and non-connected vehicles. The connected vehicle fleet will be comprised of WYDOT fleet, including snowplows and Highway Patrol vehicles, and privately operated vehicles, including light duty and larger freight vehicles. When measuring safety performance, the unique characteristics of this

[9] Defined by the Wyoming *Strategic Highway Safety Plan* as the crashes that involve incapacitating injuries or fatalities (WYDOT, 2012).

diverse vehicle fleet will need to be considered and it may be necessary to remove or to separately analyze some of the vehicle types.

6.3.9.1 PM #18: Reduction of total and truck crash rates in the corridor

Description: This measure focuses on the number of reported crashes in the project corridor for both total crashes and crashes involving at least one heavy vehicle. It is expected that the number of crashes will decrease through deployment of CV technology due to increased driver awareness of road conditions, posted speeds, and road incidents. Crash involvement for both connected and non-connected vehicles will be analyzed. Baseline data will be collected on reported crashes (both total and truck crashes) for the five-year period before the CV pilot demonstration period. The target for this performance measure is a 10% reduction in total and truck corridor crash rates.

Data Needs: The following data will be collected during the CV Pilot Demonstration and prior to the Demonstration as needed to support the establishment of baseline conditions:

- Crash data from WYDOT-maintained crash database for the project corridor starting 5-years prior to and continuing through CV demonstration period. Coordination with Wyoming Highway Patrol may be required depending on lag time from crash incident to inclusion in database for crash events that occur during the demonstration period.
- Traffic volume data from existing roadside traffic monitoring equipment.
- Weather data from the corridor's Road Weather Information System (RWIS) sensors covering same time period as crash data
- Data from CV equipped vehicles regarding involvement in crashes on project corridor

Evaluation Design: Evaluation of this performance measure will use a before-after evaluation approach for reported crash rates (both total and truck crashes) in the project corridor. Crash rates will be calculated using traffic volumes from roadside traffic monitoring equipment. The crash rate data will need to be normalized with weather data to remove seasonal weather variations. In order to capture weather variation, different crash data time periods will be analyzed to determine which time periods yield meaningful results while still capturing weather differences. Previous research studying the effectiveness of Wyoming's VSL corridors showed promise for using models based on 7-day crash frequency.[10] Since the primary focus of Pilot is on weather-related safety hazards, the crash data will likely be divided into winter and summer season crashes with winter being the six-months from mid-October through mid-April. Crash rate data for time period before and after will be modeled along with a binary variable representing CV deployment. The coefficient of the CV variable estimated represents the change in crash rate from the before and after periods. Weather variables in the model allows for comparison of crash frequencies between time periods with differing weather conditions.

While the primary evaluation type will be a before-after, a "with-without" evaluation will also be attempted for this performance measure but it is believed that the low number of equipped vehicles make this approach unlikely to be statistically relevant. Crash involvement for equipped vehicles will be obtained from fleet manager records and vehicle data logs.

[10] Saha, Promothes, and Rhonda Young. (2014) Weather-Based Safety Analysis for the Effectiveness of Rural VSL Corridors. *Proceedings from the 93rd Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2014.

As mentioned in the introduction to the safety performance category, the use of traffic simulation modeling to derive surrogate safety measures will be used to supplement the crash analysis models developed to support this performance measure. The observed behavioral response of CV-equipped vehicles with respect to speed selection, car following, and lane changing behavior will be the primary difference between the before and after traffic simulation models.

6.3.9.2 PM #19: Reduction of the number of vehicles involved in a crash

Description: This measure focuses on the number of vehicles involved in reported crashes in the project corridor. It is expected that the number of vehicles involved in crashes will decrease through deployment of CV technology due to increased driver awareness of road conditions, posted speeds, and road incidents. The project corridor frequently experiences multi-vehicle crashes involving due to low visibility conditions and low friction road surfaces preventing drivers from seeing an incident ahead in time to stop. Crash involvement for both connected and non-connected vehicles will be analyzed. Baseline data will be collected on the number of vehicles in reported crashes for the five-year period before the CV pilot demonstration period. It is anticipated that the safety impacts of the CV pilot project will have a greater impact on the number of vehicles involved in a crash than on the crash frequency alone, therefore the target for this performance measure is a 25% reduction in reported number of vehicles involved in crashes.

Data Needs: The following data will be collected during the CV Pilot Demonstration and prior to the Demonstration as needed to support the establishment of baseline conditions:

- Crash data from WYDOT-maintained crash database for the project corridor starting 5-years prior to and continuing through CV demonstration period. Coordination with Wyoming Highway Patrol may be required depending on lag time from crash incident to inclusion in database for crash events that occur during the demonstration period.
- Traffic volume data from existing roadside traffic monitoring equipment.
- Weather data from the corridor’s Road Weather Information System (RWIS) sensors covering same time period as crash data starting 5-years prior to beginning of CV demonstration period.
- Data from CV equipped vehicles regarding involvements in crashes on project corridor.

Evaluation Design: Evaluation of this performance measure will use a before-after evaluation approach for number of vehicles involved in reported crashes in the project corridor. The crash data will need to be normalized with weather data to remove seasonal weather variations. In order to capture weather variation, different crash data time periods will be analyzed to determine which time periods yield meaningful results while still capturing weather differences. Previous research studying the effectiveness of Wyoming’s VSL corridors showed promise for using models based on 7-day crash frequency. Since the primary focus of Pilot is on weather-related safety hazards, the crash data will likely be divided into winter and summer season crashes with winter being the six-months from mid-October through mid-April. Crash data for time period before and after will be modeled along with a binary variable representing CV deployment. The coefficient of the CV variable estimated represents the change in number of vehicles involved in a crash from the before and after periods. Weather variables in the model allows for comparison of number of vehicles involved in a crash between time periods with differing weather conditions. Traffic volumes will also be incorporated into the model to account for influences of differing exposure rates.

As mentioned in the introduction to the safety performance category, the use of traffic simulation modeling to derive surrogate safety measures will be used to supplement the crash analysis models developed to support this performance measure. The observed behavioral response of CV-equipped vehicles with respect to speed selection, car following, and lane changing behavior will be the primary difference between the before and after traffic simulation models. The safety surrogate measures used to evaluate the before and after simulation models will be finalized during Phase 2 of the pilot but it is expected to utilize time to conflict measures as well as number of lane changes and speed variation measures.

6.3.9.3 PM #20: Reduction of total and truck crash rates within a work zone area

Description: This measure focuses on the work zone related crash rate within the project corridor. It is expected that the crash rates in work zone areas will decrease through deployment of CV technology due to increased driver awareness of current work zone activities. Crash rates for both connected and non-connected vehicles will be analyzed. Baseline data will be collected on the number of vehicles in reported crashes within defined work zones or designated at work zone related in the crash database for the five-year period before the CV pilot demonstration period. The target for this performance measure is a 10% reduction in crash rates within work zones.

Data Needs: The following data will be collected during the CV Pilot Demonstration and prior to the Demonstration as needed to support the establishment of baseline conditions:

- Crash data from WYDOT-maintained crash database for the project corridor starting 5-years prior to and continuing through CV demonstration period. Coordination with Wyoming Highway Patrol may be required depending on lag time from crash incident to inclusion in database for crash events that occur during the demonstration period.
- Traffic volume data from existing roadside traffic monitoring equipment.
- Weather data from the corridor’s Road Weather Information System (RWIS) sensors covering same time period as crash data.
- Location and Duration of Work Zones in Project Corridor starting 5-years prior to beginning of CV demonstration period.
- Data from CV equipped vehicles regarding involvements in crashes on project corridor.

Evaluation Design: Evaluation of this performance measure will use a before-after evaluation approach for work zone crash rates the project corridor. Crash rates will be calculated using traffic volumes from roadside traffic monitoring equipment. The crash data will need to be normalized with weather data to remove seasonal weather variations. It is anticipated that weather will be less of a confounding factor for work zone related crash rates than total crash rates given the timing of construction activities during summer months but the presence of strong winds and high elevations of the project corridor require some consideration of weather year round. In order to capture weather variation, different crash data time periods will be analyzed to determine which time periods yield meaningful results while still capturing weather differences. Previous research studying the effectiveness of Wyoming’s VSL corridors showed promise for using models based on 7-day crash frequency. Crash rate data for time periods before and after will be modeled along with a binary variable representing CV deployment. The coefficient of the CV variable estimated represents the change in work zone reported crash from the before and after periods. Weather variables in the model allows for comparison of number of vehicles involved in a work zone crash between time periods with differing weather conditions.

While the primary evaluation type will be a before-after, a "with-without" evaluation will also be attempted for this performance measure but it is believed that the low number of equipped vehicles make this approach unlikely to be statistically relevant. Crash involvement for equipped vehicles will be obtained from fleet manager records and vehicle data logs.

As mentioned in the introduction to the safety performance category, the use of traffic simulation modeling to derive surrogate safety measures will be used to supplement the crash analysis models developed to support this performance measure. The observed behavioral response of CV-equipped vehicles driving within work zones with respect to speed selection, car following, and lane changing behavior will be the primary difference between the before and after traffic simulation models. The safety surrogate measures used to evaluate the before and after simulation models will be finalized during Phase 2 of the pilot but it is expected to utilize time to conflict measures as well as number of lane changes and speed variation measures.

6.3.9.4 PM #21: Reduction of total and truck critical crash rates in the corridor

Description: This measure focuses on the crash rate of critical crashes within the project corridor. WYDOT's *Strategic Highway Safety Plan (SHSP)* identifies critical crashes as those involving fatal or incapacitating injuries and reduction of these crashes is a primary goal of the SHSP. It is expected that the critical crash rate will decrease through deployment of CV technology due to increased driver awareness of road conditions, posted speeds, and road incidents. Critical crash rates for both connected and non-connected vehicles will be analyzed. Baseline data will be collected on reported critical crashes for the five-year period before the CV pilot demonstration period. The target for this performance measure is a 10% reduction in total corridor crash rate.

Data Needs: The following data will be collected during the CV Pilot Demonstration and prior to the Demonstration as needed to support the establishment of baseline conditions:

- Crash data from WYDOT-maintained crash database for the project corridor starting 5-years prior to and continuing through CV demonstration period. Coordination with Wyoming Highway Patrol may be required depending on lag time from crash incident to inclusion in database for crash events that occur during the demonstration period.
- Traffic volume data from existing roadside traffic monitoring equipment.
- Weather data from the corridor's Road Weather Information System (RWIS) sensors covering same time period as crash data.
- Data from CV equipped vehicles regarding involvements in crashes on project corridor.

Evaluation Design: Evaluation of this performance measure will use a before-after evaluation approach for the critical (fatal and incapacitating injury crashes) rate in the project corridor. Crash rates will be calculated using traffic volumes from roadside traffic monitoring equipment. The crash data will need to be normalized with weather data to remove seasonal weather variations. In order to capture weather variation, different crash data time periods will be analyzed to determine which time periods yield meaningful results while still capturing weather differences. Previous research studying the effectiveness of Wyoming's VSL corridors showed promise for using models based on 7-day crash frequency, although the lower occurrence of critical crashes will likely require longer time periods to avoid statistical issues associated with low frequency events. Critical crash rate for time period before and after will be modeled along with a binary variable representing CV deployment. The coefficient of the CV variable estimated represents the change in critical crash rate from the before and after periods. Weather variables in the model allows for comparison of number of vehicles involved in a crash between time periods with differing weather conditions.

While the primary evaluation type will be a before-after, a “with-without” evaluation will also be attempted for this performance measure but it is believed that the low number of equipped vehicles make this approach unlikely to be statistically relevant. Crash involvement for equipped vehicles will be obtained from fleet manager records and vehicle data logs.

As mentioned in the introduction to the safety performance category, the use of traffic simulation modeling to derive surrogate safety measures will be used to supplement the crash analysis models developed to support this performance measure. The observed behavioral response of CV-equipped vehicles driving with respect to speed selection, car following, and lane changing behavior will be the primary difference between the before and after traffic simulation models.

6.3.9.5 PM #22: Number of connected vehicles involved in a crash

Description: This measure focuses on the number of CV-equipped vehicles involved in crashes within the project corridor. It is expected that the number of vehicles involved in CV-equipped crashes will be low with deployment of CV technology due to increased driver awareness of current work zone activities. Involvement of CV-equipped vehicles in a crash will be categorized as either involved in the initial crash or secondary crash. This performance measure focuses only on connected vehicles and no baseline data is available since there is no prior use of connected vehicles on the corridor. The target for this performance measure is no initial or secondary crashes involving CV-equipped vehicles.

Data Needs: The following data will be collected during the CV Pilot Demonstration:

- Data from CV equipped vehicles regarding involvement in crashes on the project corridor

Evaluation Design: Evaluation of this performance measure will use the system performance approach and track the involvement of CV-equipped vehicles in crashes along the project corridor. If CV-equipped vehicles are involved in a crash, it will be determined whether they are involved in an initial or secondary crash. Since an objective of the pilot is to reduce secondary crashes through CV technology, the CV-equipped vehicle logs will be analyzed to determine driver responses due to in-vehicle messaging of upstream crash.

6.4 Summary of Evaluation Approach

Table 6-1 presents a summary of the evaluation approach for each performance measure, as well as information regarding the data needed to conduct the evaluation. Refer to Section 9 for additional details and frequency of data collection and sharing.

Table 6-1. Summary of Evaluation Approach.

PM No.	Evaluation Approach: Before-After	With-Without	System Performance	Behavior Assessment	Qualitative Assessment	Data Need
Improved Road Weather Condition Reports Received into the TMC						
1	X					• Number of road weather condition reports coming to TMC operators through the Pikalert system (post deployment) • Number of WYDOT snowplow road weather condition reports submitted (baseline and post deployment) • Pikalert system logs(post deployment) • RSU logs (post deployment) • OBU logs (post deployment)
2	X					• Number of road weather condition reports coming to TMC operators through the Pikalert system (post deployment) • Number of WYDOT snowplow road weather condition reports submitted (baseline and post deployment) • Pikalert system logs (post deployment) • RSU logs (post deployment) • OBU logs (post deployment)
3	X					• Number of road weather condition reports coming to TMC operators through the Pikalert system (post deployment) • Number of WYDOT snowplow road weather condition reports submitted (baseline and post deployment) • Pikalert system logs (post deployment) • RSU logs (post deployment) • OBU logs (post deployment)
Improved Ability of the TMC to Generate Alerts and Advisories						
4			X			• Pikalert system logs of recommended alerts and advisories (post deployment) • TMC logs of those Pikalert system recommendations being accepted by TMC operators and disseminated (post deployment)
Efficiently Disseminated Broad Area Traveler Information						

PM No.	Evaluation Approach: Before-After	With-Without	System Performance	Behavior Assessment	Qualitative Assessment	Data Need
5	X					• Time studies of TMC operator time to perform the duties defined above during baseline conditions (Phase II) and during Pilot Demonstration (Phase III).
6					X	• Baseline interviews with the TMC meteorologists, TMC operators, and a select group of commercial vehicle operators who subscribe to the CVOP service to understand what they think of and how they use the road weather forecasts. • Pilot Demonstration interviews with the TMC meteorologists, TMC operators, and a select group of commercial vehicle operators who subscribe to the CVOP service to understand how the road weather forecasts have changed, if they feel the forecasts are more accurate, and any process changes that have resulted from the changes.
Effectively Disseminated and Received I2V and V2I Alert/Advisory Messages from the TMC						
7			X			• TMC logs (post deployment) • RSU logs (post deployment)
8			X			• RSU logs (post deployment) • DSRC logs (post deployment) • OBU logs (post deployment)
9				X		• TMC logs (post deployment) • OBU logs (post deployment) • Temporal and spatial data of all connected vehicles (post deployment) • Information regarding connected vehicle’s involvement in any incident (post deployment)
Improved Information to Commercial Vehicle Fleet Managers						
10	X					• TMC logs indicating information provided to commercial vehicle fleet managers (baseline and post deployment) • Fleet manager logs of operational changes made (type and timing) based on input from the TMC – baseline and during the CV Pilot (post deployment)
11					X	• Pilot Demonstration interviews with the commercial vehicle fleet managers.
Effectively Transmitted and Received V2V Messages						

PM No.	Evaluation Approach: Before-After	Evaluation Approach: With-Without	Evaluation Approach: System Performance	Evaluation Approach: Behavior Assessment	Evaluation Approach: Qualitative Assessment	Data Need
12			X			• OBU logs recording sent and received V2V messages from other connected vehicles (post deployment) • DSRC logs indicating messages sent and received (post deployment) • RSU logs that recorded V2V messages being transmitted to other connected vehicles (post deployment)
13				X		• OBU logs regarding sent and received V2V messages (post deployment) • Temporal and spatial data of all connected vehicles (post deployment) • Information regarding connected vehicles' involvement in any type of incident (post deployment)
Automated Emergency Notifications of a Crash						
14			X			• Number of emergency notifications from connected vehicles (post deployment) • Total number of emergency notifications from all sources (post deployment)
Improved Speed Adherence and Reduced Speed Variation						
15	X					• Time-stamped speed of individual vehicles from roadside speed radar equipment at locations in the VSL corridors including vehicle length (for classification of vehicles into passenger cars and trucks) (before and after deployment) • VSL event logs indicating changes to VSL speed limit signs. (before and after deployment) • OBU logs from CV equipped vehicles including vehicle speeds (post deployment)
16	X					
17		X				
Reduced Vehicle Crashes						
18	X					• Crash data from WYDOT-maintained crash database for the project corridor starting 5-years prior to and continuing through CV demonstration period. Coordination with Wyoming Highway Patrol may be required depending on lag time from crash incident to inclusion in database for crash events that occur during the demonstration period (before and after deployment)

PM No.	Evaluation Approach Before-After	With-Without	System Performance	Behavior Assessment	Qualitative Assessment	Data Need
19	X					• Traffic volume data from existing roadside traffic monitoring equipment (before and after deployment) • Weather data from the corridor's Road Weather Information System (RWIS) sensors covering same time period as crash data (before and after deployment) • Data from CV equipped vehicles regarding involvement in crashes on project corridor (before and after deployment)
20	X					• Crash data from WYDOT-maintained crash database for the project corridor starting 5-years prior to and continuing through CV demonstration period. Coordination with Wyoming Highway Patrol may be required depending on lag time from crash incident to inclusion in database for crash events that occur during the demonstration period (before and after deployment) • Traffic volume data from existing roadside traffic monitoring equipment (before and after deployment) • Weather data from the corridor's Road Weather Information System (RWIS) sensors covering same time period as crash data (before and after deployment) • Location and Duration of Work Zones in Project Corridor starting 5-years prior to beginning of CV demonstration period (before and after deployment) • Data from CV equipped vehicles regarding involvements in crashes on project corridor (post deployment)
21	X					• Crash data from WYDOT-maintained crash database for the project corridor starting 5-years prior to and continuing through CV demonstration period. Coordination with Wyoming Highway Patrol may be required depending on lag time from crash incident to inclusion in database for crash events that occur during the demonstration period (before and after deployment)

PM No.	Evaluation Approach Before-After	 With-Without	 System Performance	 Behavior Assessment	 Qualitative Assessment	Data Need
						• Traffic volume data from existing roadside traffic monitoring equipment (before and after deployment) • Weather data from the corridor's Road Weather Information System (RWIS) sensors covering same time period as crash data (before and after deployment) • Data from CV equipped vehicles regarding involvements in crashes on project corridor (post deployment)
22			X			• Data from CV equipped vehicles regarding involvement in crashes on project corridor (post deployment)

7 System Performance Reporting

Note that the health of the system will be monitored in real-time and this discussion relates to reporting the performance measures described in the previous chapters.

System performance data will be reported on a bi-weekly basis during the winter months and on a monthly basis during non-winter months of the demonstration. This will allow for gathering and processing the data for reporting by the pilot team. It should be noted that data will be gathered much more frequently and stored for subsequent off-line analysis and shared with U.S DOT. Refer to Section 9 for details regarding data to be collected and the frequency of collection.

Other outcome measures that relate to crash reductions and mobility will be reported on a seasonal basis, with a focus on weather events. However, specific events (work zones, incidents, winter storms) may allow us to report outcome performance of the system on an ad-hoc basis as conditions warrant.

For the purpose of the pilot, the pilot team will create a template and dashboard for reporting all the performance measures and set up the data requirements and methodology in Phase II so that performance reporting occurs at the monthly cycle desired by WYDOT. This performance measure dashboard will be available to the pilot deployment team and will be shared with U.S DOT and the IE contractor as well in addition to the detailed data sets.

8 Support to Independent Evaluation

This section presents the initial set of non-safety and safety related evaluation needs identified by U.S DOT in anticipation of the Independent Evaluation (IE) for the Wyoming CV Pilot. These needs are preliminary, and may change as more information about the applications is gathered. Furthermore, this section provides answers to each need, indicating whether they can be met or not within the scope of the Pilot, see Table 8-1 and Table 8-2. The response is classified into three categories:

1) Yes, indicating that the necessary/requested information/action will be collected/implemented and that any result/outcome will be shared with the respective agency within the specified timeframe.
2) Partial, indicating that the need can be met partially in terms of collecting and/or sharing information—that is, the necessary/requested information/action will be either partially collected/implemented or result/outcomes will be partially shared with the respective agency or not necessarily shared within the specified timeframe or a combination of the previous.
3) No, indicating that the necessary/requested information/action will not be collected/implemented during the Pilot Deployment. Note: there aren't any data items in the tables below that have a "no" response.

The data elements presented in Table 8-1 will be collected as needed and defined generally in Section 8. The data will be shared with the IE monthly for analysis purposes.

Table 8-1. Preliminary Non-Safety Evaluation Needs.

ID	Evaluation Need	Response
Mobility, Environment, and Public Agency Efficiency (MEP) Evaluation Needs		
IMEP.1	Need non-real time access to raw BSMs heard by RSEs, within the Site boundaries at specific pre-defined locations and times to support IE efforts.	Yes
IMEP.2	Need non-real time access to vehicle and road condition data received by WYDOT from snow plows, maintenance fleet, emergency vehicles and trucks, within the Site boundaries, and supporting meta data.	Yes
IMEP.3	Need non-real time access to road weather advisories and warnings received by snow plows, equipped trucks, and unequipped trucks by dissemination method (i.e., in-vehicle systems or CVOP), type (e.g., VSL status, hazardous conditions, road conditions), date, time, and location (where received), within the Site boundaries, and supporting meta data.	Yes
IMEP.4	Need non-real time access to traveler information and spot weather warnings (e.g., fog, ice, wind, flood conditions) sent to passenger vehicles by date, time, and location (where received), within the Site boundaries, and supporting meta data.	Yes
IMEP.5	Need non-real time access to road condition information sent to emergency responders by date, time, and location (where received), within the Site boundaries, and supporting meta data.	Yes

IMEP.6	Need non-real time access to road condition data, alerts, and advisories sent to trucks by type (e.g., weather advisories, parking information, work zone speeds and clearances), communication medium, date, time, and location (where received), within the Site boundaries, and supporting meta data.	Yes
IMEP.7	Need non-real time access to messages posted on the VSL by date, time, and ID of VSL signage, within the Site boundaries, and supporting meta data.	Yes
IMEP.8	Need non-real time access to freight dynamic routing plans by trip origin, trip destination, date, trip start time, and ID of vehicle, and supporting meta data.	Partial
IMEP.9	Need non-real time access to information and warnings received by snow plow operators by type (e.g., VSL status, hazardous conditions, road conditions), date, time, and location (where received), within the Site boundaries, and supporting meta data.	Yes
IMEP.10	Need non-real time access to road condition information sent by snow plow vehicles to following equipped trucks via V2V by type (e.g., fog, icy roads), date, time, and location (where generated), within the Site boundaries at specific pre-defined locations and times to support IE efforts, and supporting meta data.	Yes
IMEP.11	Need generated/calculated mobility and environmental performance measures for trips, facilities and frequencies, as identified in the Performance Measurement Plan, and supporting meta data.	Partial (no environment PMs)
IMEP.12	Need access to crashes and injuries by date, time, and location, within the Site boundaries, and supporting meta data.	Yes
IMEP.13	Need cost of operations data to assist the IE in identifying costs in the “with” and “without” cases, and supporting meta data.	Yes
IMEP.14	Need site-relevant public agency efficiency measures as identified in the Performance Measurement Plan, and supporting meta data.	Yes
IMEP.15	Need algorithm or technical approach used for calculating key performance measures identified in the Performance Measurement Plan.	Yes
IMEP.16	Need code, and supporting software documentation, if developed for the Pilot Deployment effort, for calculating key performance measures identified in the Performance Measurement Plan.	Partial (Will depend on the system design)
IMEP.17	Need procedures for data QA/QC, including site’s acceptable levels of accuracy by data element.	Yes
IMEP.18	Need IDs and locations of RSEs, VSL signage, and DSRC hot spots within the Site boundaries.	Yes
IMEP.19	Need to facilitate IE access to all Site staff and subcontractors, across all functions, as requested by the IE for interview, survey, or technical clarification.	Yes
IMEP.20	Need logs of actions taken by system managers by date, time, and location, within the Site boundaries.	Yes
IMEP.21	Need action plans available for system managers by type of event, within the Site boundaries.	Yes
IMEP.22	Need to facilitate IE access to logs of system and power outages by date, time, and affected devices/equipment, within the Site boundaries.	Yes
IMEP.23	Need to facilitate IE access to non-crash related incidents and lane closure data by date, time, and location, within the Site boundaries.	Yes

IMEP.24	Need to facilitate IE access to road work information (e.g., lane closures, active work zones) by date, time, and location, within the Site boundaries.	Yes
IMEP.25	Need simulation and analytical models, if developed or enhanced for the Pilot Deployment effort, for Site performance measurement and monitoring.	Yes
IMEP.26	Need to facilitate IE access to simulation models developed for the Site, even if developed using resources outside of the Pilot Deployment effort.	Partial (depends on system design)
	Security and Privacy Evaluation Needs	
ISP.1	Need security incident logs that include description (i.e., to the extent possible, the nature of the incident, and a description of the individuals and technologies relevant to or impacted by the incident), resulting impacts, actions taken, and lessons learned. (NOTE: Procedures need to be included as part of the Security Management Operating Concept and ConOps.).	Yes
ISP.2	Need to facilitate IE access to staff associated with the Site Security Planning and Management staff and support their participation in interviews, surveys, or other follow-up information gathering sessions. (NOTE: Support should be documented in the Evaluation Support Plan.).	Yes
ISP.3	Need privacy violation logs that include description (i.e., to the extent possible, the nature of the incident, and a description of the individuals and data relevant to or impacted by the incident), resulting impacts, actions taken, and lessons learned. (NOTE: Procedures need to be included as part of the Privacy Management Operating Concept.).	Yes
ISP.4	Need to facilitate IE access to staff associated with the Site Privacy Planning and Management staff and support their participation in interviews, surveys, or other follow-up information gathering sessions. (NOTE: Support should be documented in the Evaluation Support Plan.).	Yes
ISP.5	Need types of PII that had to be collected for operational use. (NOTE: Should be included in the Data Sharing Framework and the Privacy Management Operating Concept.).	Yes
	Financial and Institutional Evaluation Needs	
IFI.1	Need to define and describe the "without" system management (business) processes, including diagrams and maps. (NOTE: Should be documented in the ConOps.).	Yes
IFI.2	Need to define and describe the "with" system management (business) processes, including diagrams and maps. (NOTE: Should be documented in the ConOps and the CDP.).	Yes

Table 8-2. Preliminary Safety Evaluation Needs.

Evaluation Need	Description	Response
	Spot Weather Impact Warning Application Data Needs	
1. Vehicle speed in variable speed zone areas	A method to determine the speed of vehicles in variable speed zone areas, with and without application warnings.	Yes

2.	Headway in variable speed zone areas	A method to determine the relative speed to the lead-vehicle in variable speed zone areas, with and without application warnings.	Yes
3.	Weather related crash rates	Weather-related crash rates in variable speed zones, with and without application.	Yes
4.	Secondary crash rates	Secondary crash rates in variable speed zones, with and without application.	Yes
5.	Application performance statistics	A measure of how accurately the application works in the pilot deployment, measures that will allow the accuracy to be determined.	Yes
6.	Activation of ABS/traction control	Method of understanding the frequency with which equipped vehicles activate ABS and traction control in the reduced speed zone area, with and without application warnings.	Yes
7.	Driver response to valid warnings	A way to determine if, and how drivers respond to valid warnings.	Partial
8.	Frequency of unintentional lane excursions	Method to determine how frequently drivers momentarily deviate from their lane.	Partial
9.	Weather data	Weather data for variable speed zones.	Yes
10.	**Recommended speeds**	The speeds recommended to drivers by the application.	Yes
Reduced Speed/Work Zone Warning Data Needs			
11.	Vehicle speed in variable speed zone areas	A method to determine the speed of vehicles in reduced speed zone areas, with and without application warnings.	Yes
12.	Work zone related crash rates	Work zone-related crash rates in reduced speed zones, with and without application.	Yes
13.	Secondary crash rates	Secondary crash rates in reduced speed zones, with and without application.	Yes
14.	Application performance statistics	A measure of how accurately the application works in the pilot deployment, measures that will allow the accuracy to be determined.	Yes
15.	Driver response to valid warnings	A way to determine if, and how drivers respond to valid warnings.	Partial
16.	Recommended speeds	Speeds recommended to drivers.	Yes
Snow Plow Situational Awareness Data Needs			
17.	Weather related crash rates	Weather-related crash rates in equipped areas, with and without application.	Yes
18.	Secondary crash rates	Secondary crash rates in equipped areas, with and without application.	Yes
19.	Application performance statistics	A measure of how accurately the application works in the pilot deployment, measures that will allow the accuracy to be determined.	Yes

9 Data Collection and Management Plan

This chapter provides an overview of how the data collected as part of the pilot will be managed from a performance management and evaluation standpoint. Five types of data will be managed as part of this pilot.

- System data – Data collected from the CV Pilot system.
- Non-System data – Data collected from external systems and databases necessary to support performance measurement.
- Survey Data – Any data collected through surveys of travelers and truck drivers.
- Modeling and Simulation data –Any data collected or generated by modeling/simulation will be collected and managed.
- Interview Data – Qualitative data may be collected at various points to support the previously identified performance measures. This also includes lessons learned and institutional issues gathered through interviews with involved personnel.

The data will be collected and stored based on the details provided below. The data will be shared with USDOT on a monthly basis for analysis purposes.

9.1 System Data

The following system data will be collected as part of the pilot:

- Basic Safety Messages generated and received by various CV objects in the system – BSM messages include the following and will be collected and stored for analysis.
  - Message ID
  - Message count
  - Temp ID
  - Time
  - Latitude
  - Longitude
  - Elevation
  - Positional Accuracy
    - Semi Major Axis Accuracy
    - Semi Minor Axis Accuracy
    - Semi Major Axis Orientation
  - Speed
  - Heading
  - Longitudinal Acceleration
  - Yaw Rate
  - Vehicle Width

    - Vehicle Length
    - Path History
    - Path Prediction
- Other connected vehicle alerts and data will be logged with date/time stamp with location identified.
- Mobile road weather observations generated from equipped vehicles – mobile road weather includes air temp, pavement temp, precipitation type and intensity, and humidity. Data will be collected every 15 minutes on equipped vehicles and stored in the PikAlert database.
- Time-stamped alerts and advisories generated by TMCs received as part of the CV environment by vehicles – all alerts and advisories will be stored in the TMC database and made available for analysis.
- RSU logs – time-stamped logs of all communications sent and received through the RSUs will be downloaded daily and stored in the project data warehouse.
- DSRC logs – time-stamped logs of all communications sent through the DSRC equipment (either direction) will be downloaded daily and stored in the project data warehouse.
- OBU logs indicating alerts received, actions taken – time-stamped logs of all communications sent and received through the OBUs will be downloaded from vehicles daily, or as practical, and stored in the project data warehouse.
- PikAlert logs
    - Every 5 minutes:
        - Quality-flagged vehicle-based data observations
        - Per-segment summary statistics of vehicle and ancillary observations
        - Road condition assessments
        - Advisories and warnings on adverse weather conditions
    - Every 1 hour:
        - 72 hour forecast of weather and road temperature/condition corrected by vehicle observations
        - Road treatment recommendations
- TMC logs – includes all field data including road condition reports, operator actions taken, and alerts and advisories disseminated (and rejected). All data will be time-stamped and stored in the project data warehouse for analysis.
- Wyoming Traveler Information (WTI) updates – all traveler information and mobile app information will be stored in the project data warehouse for analysis.
- Crash notification records generated by CV vehicles will be time-stamped and stored in the project data warehouse for analysis.
- Security breaches and logs – time-stamped and stored in the project data warehouse for analysis.
- Partner fleet manager data – includes actions taken to manage their commercial vehicle fleets based on TMC input. Specific logs will be developed and completed with date/time, action taken, supportive information, etc. (will be logged in the project data warehouse for analysis).

The CV pilot will store data within the TMC databases in an encrypted format for data that is potentially or actually Personal Identifiable Information (PII). The servers that house this data will also 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 it has been sanitized for PII. The security management and privacy operating concept provides more guidance on the pilot's approach to managing PII.

9.2 Non-System Data

These may include data from traditional ITS systems such as RWIS, speed sensors, DMS logs etc. Any external data collection required for performance measurement would also fall under this category. Examples of data managed under this category are:

- Traffic data (speeds, volumes and other traffic conditions)
- Crash database records
- Road closure data
- Road Weather Information Stations (RWIS)
- DMS logs (including VSL)
- Construction and Maintenance Event Log

The pilot team will assemble this data for the corridor for the evaluation. This data is not likely to contain PII and will be available for submission to the RDE with appropriate metadata.

Traffic data will be primarily gathered using an existing network of roadside speed radar detectors that provide speed, vehicle classification (based on length), and vehicle headways. Traffic volumes along the corridor will be measured using these data logs. The speed radar detectors are primarily located in the four existing variable speed limit corridors along I-80. Detector data can either be in aggregated form (30 seconds to 5 minutes) or set to log individual vehicles. To support the performance measures described in this plan, the most useful mode of data collection will be for the radars to log individual vehicles, since this is required to determine speed adherence and speed variation. Data from the speed sensors is collected and logged continuously. During Phase II of the Pilot, key speed sensors in the corridor will be identified for use in the performance evaluation. It is anticipated that the data from these sensors will be queried on a weekly basis and analyzed for system performance.

WYDOT maintains a crash database for all reported crashes in the state. Lag times between crash event occurrence and the crash event being entered into the database can vary greatly depending on the jurisdiction reporting the crash. For the CV Pilot Corridor, Wyoming Highway Patrol will be the primary reporting entity. According to the WYDOT Safety Program, it takes an average of 8 days between crash occurrence and entry of the crash into the database. For the Pilot Deployment period it is anticipated that the database will be queried once a month for new crash reports on the corridor. An alternative method for identifying crashes could involve direct notification by the Wyoming Highway Patrol after major events or on a weekly basis. Crash events in the WYDOT database contain information about crash including first critical event, contributing factors, conditions, time of event, number of vehicles and persons involved, and others. WYDOT Highway Safety Program adopted a Minimum Model Uniform Crash Criteria (MMUCC) compliant crash form in 2008.

WYDOT TMC operators maintain a road closure database that lists the time, location, and reason for each road closure in the state. For the I-80 corridor, road closure segments are based on where gate closure infrastructure are installed and are typically at major cities along the corridor. Events in this database correspond to closing and openings of the different roadway segments.

Data are logged continuously by the TMC operators. It is anticipated that the data from these sensors will be queried on a weekly basis and analyzed for system performance.

The project corridor contains 40 RWIS to collect roadside weather data with most of the weather stations being located to support the VSL corridor operations. The sensor packages on these stations vary by location but most contain information about air and pavement temperature, relative humidity, pavement surface status, wind and wind gust speed, and visibility. RWIS data are reported every 15 minutes. During Phase II of the Pilot, key RWIS in the corridor will be identified for use in the performance evaluation. It is anticipated that the data from these sensors will be queried on a weekly basis or for specific weather events for the use in the performance evaluation.

Dynamic Message Sign (DMS) logs are generated through the TMC operations with an event created in the database any time the TMC communicates with a DMS. These logs contain the time of the communication and any changes to the DMS message. Some signs, like the scrolling film VSL signs, contain a code for the film location that must be translated to a posted speed. Most signs are LED signs with the DMS event indicating the text message to be displayed. Data from the DMS system is logged continuously. It is anticipated that the data from this database will be queried on a weekly basis or for specific weather events and analyzed for system performance.

Construction and maintenance activities are logged by WYDOT staff into a database and includes the location, duration and type of construction and maintenance activity that is scheduled along with any anticipated lane or roadway closures. These events are logged continuously. It is anticipated that the data from these sensors will be queried on a weekly basis and analyzed for system performance. It is anticipated that the data from this database will be queried on a weekly basis.

9.3 Survey Data

Some limited survey data will be collected 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, non-participating truck drivers, commercial vehicle fleet managers, personal automobile users, and WYDOT State DOT personnel. Survey data will be collected by the pilot deployment team and be sanitized to remove any PII before sharing with RDE.

9.4 Modeling and Simulation

In addition to the primary safety performance measures 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 IE. Outputs from the modeling and simulation runs will be shared as well.

9.5 Interview Data

The pilot expects to collect qualitative and lessons learned data through interviews with various involved personnel. Interview data will be sanitized for PII in respondent answers. Interview data will be stored by the pilot team and summaries of findings shared with U.S DOT and the IE. Interview data will not be posted to the RDE.

10 Roles and Responsibilities

The successful execution of this Performance Measurement and Evaluation Support Plan requires the strong commitment and participation of key team members, partners, and stakeholders. The responsibilities of each group is dependent on their project role. Table 10-1 below defines the roles and responsibilities of each group to execute a successful evaluation of the Wyoming CV Pilot Project.

Table 10-1. Roles and Responsibilities of the CV-Pilot Team.

Project Role	Responsibility (Performance Measurement support)
Wyoming CV Pilot system development and execution	• Ensure system design supports needed data collection based on related system requirements. • Support Performance Measurement efforts.
Wyoming CV Pilot Performance Measurement team	• Maintain an up-to-date and relevant Performance Measurement and Evaluation Support Plan that reflects current CV Pilot system design/build. • Work with system design/build team to ensure all data collection requirements are included. • Conduct PM & ES Plan as defined including data collection, analysis, and reporting. • Support Independent Evaluators with data and other assistance as needed. • Prepare final Performance Measurement Report.
Independent Evaluators	• Work with Wyoming CV Pilot Demonstration Team to identify needed data and assistance. • Conduct independent evaluation and share results.
System Partners/Vendors	• Provide and support a system that supports performance measurement and ensures the collection and efficient delivery of needed data.
WYDOT TMC, including meteorologists	• Actively participate in CV Pilot deployment and operation. • Participate in system training. • Operate systems as designed/instructed. • Support data collection, as required. • Participate in surveys/interviews, as requested. • Prepare action logs, as required.
Commercial Vehicle Fleet Managers	• Participate in system training. • Support data collection, as required. • Participate in surveys/interviews, as requested • Prepare action logs, as required.
Connected trucks/drivers	• Participate in system training. • Operate systems as designed/instructed. • Support data collection, as required.

	• Participate in surveys/interviews, as requested. • Prepare action logs, as required.
Connected snow plows/patrol/drivers	• Participate in system training. • Operate systems as designed/instructed. • Support data collection, as required. • Participate in surveys/interviews, as requested. • Prepare action logs, as required.
Other travelers	• Participate in online surveys/interviews

11 Schedule

The schedule for performance measurement and evaluation support activities, shown in Table 11-1, follows the key Wyoming CV Pilot project milestones, deliverables, and phases.

Phase I activities include completing this planning document, providing input to the development of the system requirements, and supporting the application deployment planning efforts. These activities will be accomplished through September 2016.

Phase II activities include:

- Collecting baseline data and documenting the baseline conditions. This will focus on the 2016-2017 winter season.
- Supporting system design and building activities to ensure performance measurement and evaluation support data collection aspects are included.
- Revisions to the Performance Measurement and Evaluation Support Plan, including the baseline documentation.

These activities will span the Phase II schedule beginning in October 2016 through May 2018.

Phase III activities will initiate and execute the Performance Measurement and Evaluation Support Plan. Data collection and analysis will be conducted to address each of the 24 measures. Data management activities, including performance reporting will be accomplished per the definition contained herein. The Wyoming Project Team is proposing data collection from November 2017 through May 2019 to encompass two winter seasons. The first winter season (2017-2018) will focus performance evaluation on a growing set of connected vehicles (likely WYDOT and Trihydro vehicles). The second winter season (2018-2019) will add other commercial vehicle fleets to the performance evaluation activities. The final analysis and documentation (Performance Measurement Report) will be completed by November 2019.

Table 11-1. Wyoming CV Pilot Project Schedule.

	2016										2017												2018												2019											
Activity Phase I	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Complete Planning Document	■	■	■																																											
Input to System Reqs.	■	■	■																																											
Support Application Deployment Plan				■	■	■	■																																							
Phase II																																														
Document Baseline Conditions									■	■	■	■	■	■	■																															
Support System Design and Build Activities								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																			
Revise PM & ES Plan, including Baseline documented																■	■	■	■	■																										
Phase III																																														
Execute PM & ES Plan																					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Data Collection																					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Data Management /Perform. Reporting																					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Prepare PM Report																																						■	■	■	■	■	■	■	■	

12 Conclusions

This Performance Measurement and Evaluation Support Plan defines how the Wyoming Team will evaluate the CV Pilot Demonstration and support the Independent Evaluator in the accomplishment of their work. The Plan identifies 22 specific performance measures contained within 9 performance categories which represent the major expected benefits and outcomes of the Pilot system including:

- Improve road weather condition reports received into the TMC
- Improve ability of the TMC to generate alerts and advisories
- Efficiently disseminate broad area traveler information
- Effectively disseminate and receive I2V and V2I alert/advisory messages from the TMC
- Improve Information to commercial vehicle fleet managers
- Effectively transmit and receive V2V messages
- Automate emergency notifications of a crash
- Improve speed adherence and reduce speed variation
- Reduce vehicle crashes

The 22 performance measures include specific targets and incorporate quantitative and qualitative approaches to comprehensively measure the benefits and outcomes of the Wyoming CV Pilot system. These benefits are focused on major improvements in safety, mobility and agency efficiency. It is envisioned that this Plan will be revised to reflect the current Wyoming CV Pilot system as it is further developed, designed, and built. A revised Plan is expected to be prepared, including a documented baseline, at the conclusion of Phase II.

Data needs and evaluation approaches are identified for each performance measure. This Plan forms the basis for a successful evaluation and support to upcoming system development. Specific activities that this work will support include:

1. Identifying and incorporating performance measurement related system requirements.
2. Strong participation in upcoming system deployment planning and partner development to ensure a data collection and performance measurement focus.
3. In Phase II, work closely with the design and development team members to ensure the data collection elements and evaluation support commitments are included and prepare the team for successful performance measurement activities to be accomplished in Phase III.
4. Working closely with the selected firm that will conduct the independent evaluation to provide the needed data and other support in completion of their tasks.

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