Connected Vehicle Pilot Deployment Program Phase 2

Data Management Plan – Wyoming

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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). This document presents the Data Management Plan, which describes the data that will be collected and how the data will be managed throughout the Wyoming CV Pilot. The DMP will also define a framework for sharing the data with USDOT, the Research Data Exchange and the Independent Evaluator. This plan will be used by the Wyoming team to ensure the necessary data is available to support a successful Wyoming Performance Measurement process, as well as the nationally focused independent evaluation.

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1 Introduction

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 CV Technology in the United States. CV Technology is a broad term to describe the applications and the systems that take advantage of vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications 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 April 2018) followed by an eighteen-month demonstration period in the third phase (starting in May 2018).

Systems and applications developed in the pilot will enable drivers to have 360-degree 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.

1.1 Purpose of the Plan

The purpose of the Data Management Plan (DMP) is to describe the data that will be collected and how the data will be managed throughout the Wyoming CV Pilot. Furthermore, the DMP will define a framework for appropriately sharing the data with USDOT, the Research Data Exchange and the Independent Evaluator. This plan will be used by the Wyoming team to ensure the necessary data is available to support a successful Wyoming Performance Measurement process, as well as the nationally focused independent evaluation, as defined in the Phase 1 Performance Measurement and Evaluation Support Plan (Kitchener et al., 2016).

The preparation of this plan is guided by the description of Task 2C in the Notice of Funding Opportunity (NOFO) number DTFH6116RA00007, Connected Vehicle Pilot Deployment Program – Phases 2 and 3. Additionally, this document follows the subsequent guidance provided by USDOT.

1.2 Organization of the Plan

This document is organized accordingly:

- Chapter 1: Introduction – provides the purpose of the Data Management Plan and an overview of the Wyoming system at a level needed to understand the data elements

- Chapter 2: Data Management Approach – provides details of data sharing, data privacy, Intellectual property issues, data quality control, and archiving and preservation approaches.
- Chapter 3: Data Management Plan – provides the data types, sources, and collection methods, frequency of data collection, estimated size requirements, and relationship to performance measures.
- Chapter 4: Glossary – lists the terms and acronyms used throughout this document.
- Chapter 5: References – lists the documents used as reference in this document.
- Appendix A – presents a summary of the measures of performance used in this project.

1.3 Wyoming System Overview

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 April 2018) followed by an 18-month demonstration period in the third phase (starting in May 2018). At a very high level, the pilot scope includes the following implementation elements:

- **Deployment of about 75 roadside units (RSU)** that can receive and broadcast messages using DSRC along various sections on I-80.
- **Equip around 400 vehicles, a combination of fleet vehicles and commercial trucks, with on-board units (OBU).** Of the 400 vehicles, at least 150 would be heavy trucks. All vehicles are expected to be regular users of I-80. Several types of OBU are being procured as part of the pilot and differ based on their communication capabilities, ability to integrate with the in-vehicle network, and connectivity to ancillary devices and sensors. All OBUs will have the functionality to broadcast Basic Safety Messages (BSM) Part I and will include a human-machine interface (HMI) to share alerts and advisories to drivers of these vehicles.
- **Develop several V2V and V2I (and I2V) applications** that will enable communication with drivers for alerts and advisories regarding various road conditions. These applications include support for in-vehicle dissemination of advisories for collision avoidance, speed management, detours, parking, and presence of work zones and maintenance and emergency vehicles downstream of their current location.
- **Enable overall improvements in WYDOT's traffic management and traveler information practices** by using data collected from connected vehicles. Targeted improvements include better activation of variable speed limits (VSL) and improved road condition dissemination via 511, Dynamic Message Sings (DMS) and other WYDOT sources.

The CV Pilot is considered a System of Systems, with two systems of interest: The *Vehicle System* and the *Wyoming CV System*. The *Vehicle System* includes five Sub-Systems that represent the various vehicle and equipment types to be used in the pilot. These Sub-Systems vary in their data collection and sharing capabilities. The *Wyoming CV System* includes the infrastructure used in the pilot and back-office systems in charge of the various processes that lead to the generation and distribution of advisories and alerts. Together, the Vehicle and *Wyoming CV System*s support a variety of V2V and V2I applications. Both systems interface with external systems, including WYDOT, USDOT and the National Weather Service (NWS).

The CV Pilot Project will, at its core, provide key information to the drivers through five on-board applications: i) Forward Collision Warning (FCW); ii) I2V Situational Awareness (SA); iii) Distress Notification (DN); iv) Work Zone Warning (WZW); and v) Spot Weather Impact Warning (SWIW). In

addition, the CV Pilot project will support overall traffic management and traveler information services offered by WYDOT.

Through these applications and functions, WYDOT hopes to improve operations on the corridor especially during periods of adverse weather and when work zones are present. By means of 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, improved and new information outlets.

Details of the Wyoming CV Pilot system are available in the Comprehensive Pilot Deployment Plan (FHWA-JPO-16-297), see Gopalakrishna et al. (2016).

1.3.1 External Interfaces

In addition to the Vehicle and Wyoming Systems, the following external interfaces support the CV Pilot Project by supplying and distributing information. Their interaction with the systems is presented in Figure 1-1.

- **I2V DSRC Communications Interface** (Interface WE1) Wireless DSRC interface provides communication between Wyoming CV System and Vehicle System through exchange of messages conforming to SAE J2735 and SAE J2945/1.
- **Location and Time Service (LTS)** (Interfaces WE2 and WE 3) – Provides location and time information, which is later used to geotag and timestamp all information produced by the systems of interest.[1]
- **National Weather Service (NWS) and Road Weather Information System (RWIS)** (Interface WE4) – NWS provides regional weather data shared through National Oceanic and Atmospheric Administration's Meteorological Assimilation Data Ingest System. **RWIS** provides atmospheric and pavement condition information collected through Environmental Sensor Stations (ESS) deployed as part of the WYDOT RWIS network in the field.
- **WYDOT 511 Application** (Interface WE5) – Provides information to the public regarding I-80's road weather and traffic conditions (e.g., road closure). The application is currently being updated to also share crowdsourced truck parking information with the CV Pilot.
- **WYDOT Road Condition Report System (RCRS)** (Interface WE6) – An Android tablet-based application that resides in WYDOT snow plows which enables field personnel (e.g., snowplow operators) to report weather and roadway pavement conditions following WYDOT's 8 Code (roadway condition), 9 Code (atmospheric) and 10 Code (other road condition) system.
- **WYDOT Incident Control (IC)** (Interface WE7) – Provides timestamped and geotagged incident information on incidents along I-80 obtained from the WHP and other sources (e.g., maintenance).
- **WYDOT Construction Administration (CA)** (Interface WE8) – Provides timestamped and geotagged information of WYDOT's scheduled and unscheduled work-zone activities along I80.

[1] The location is obtained from a GPS using WGS-84 coordinates system, and time is provided using UTC from GPS time.

- **Wyoming Traveler Information (WTI)** (Interface WE9) – Supports traveler information services to the public and to fleet management centers via various means (website, 511, 511 App, text, email, and alerts).
- **WYDOT Third Party Interface (TPI)** (Interface WE10) – A standardized interface based on the TMDD standard that can be used to support delivery of traveler information to external centers and information service providers.
- **WYDOT Transportation Reports and Action Console (TRAC)** (Interface WE11) – An operator console used in the TMC to monitor and manage planned, ongoing, and forecast events and actions on facilities monitored by the TMC. The TRAC provides a tabular list of currently ongoing events that require operator attention. These events may be entered manually and can be reported based on other systems like RCRS, radio communications with field personnel and citizen reports.
- **WYDOT Commercial Vehicle Operator Portal (CVOP)** (Interface WE12) – A subscription-based website created by WYDOT for providing advanced notification of forecasted conditions to commercial travelers and fleet managers. Currently there are over 800 companies subscribed to the CVOP. As part of the CV Pilot System, the CVOP will be enhanced to include current weather information for segments on I-80.
- **WYDOT ITS Maintenance** (Interface WE13) – Provides a mechanism to report service outages and resumption of services of WYDOT's ITS equipment.
- **Independent Evaluator (IE) (Interface WE14) –** Provides WYDOT CV Pilot data to the IE for use in independent analysis and impact evaluation across multiple CV pilots.
- **USDOT Situational Data Warehouse (SDW)** (Interface WE15) – A service operated by USDOT that stores near real-time data and shares them with the remote users and developers for further distribution. As shown, this interface also supports communication of messages through **Satellite Service Provider (SSP)** satellites, allowing the system to transmit traveler-related information.
- **USDOT Security Certification Management System (SCMS)** (Interfaces WE16 and WE17) – Generates security certificates to manage messages securely from connected devices. As shown, this interface also supports communication of messages through **SSP** satellites, allowing the system to share SCMS-related information.

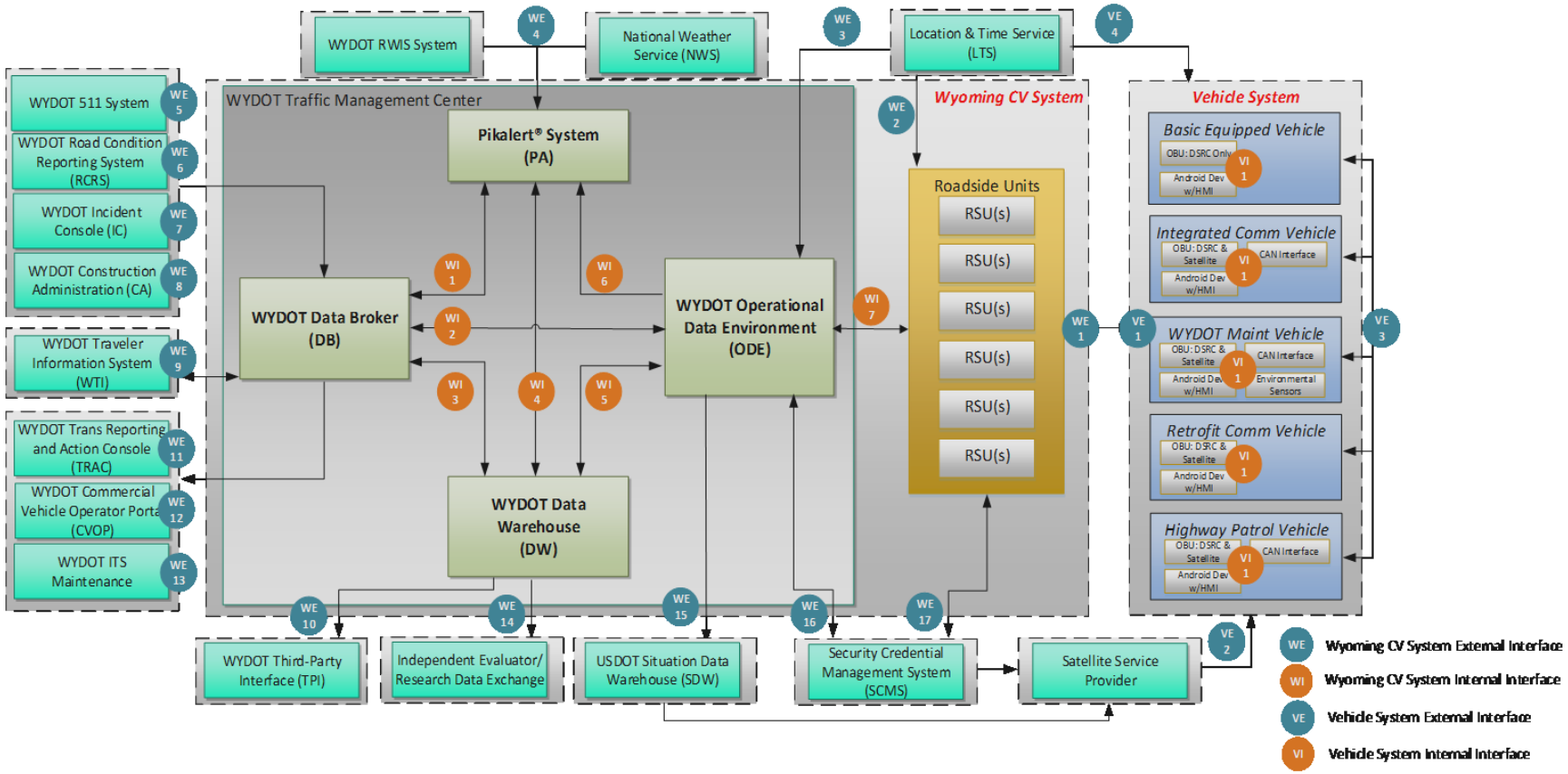

Figure 1-1. Physical View of WYDOT CV Pilot System Architecture. Source: WYDOT

1.3.2 Wyoming CV System

The *Wyoming CV System* includes the infrastructure used in the pilot and the back-office systems in charge of the various processes that lead to the generation and distribution of advisories and alerts for CV Pilot vehicles. The *Wyoming CV System* will be located at the WYDOT TMC. Additionally, this system provides external interfaces to share the advisories and alerts with the public and commercial vehicle operators.

The *Wyoming CV System* is composed of five Sub-Systems:

- Roadside Units (RSU)
- Operational Data Environment (ODE)
- Pikalert® System (PA)
- Data Broker (DB)
- Data Warehouse (DW)

1.3.2.1 *Roadside Units*

This Sub-System describes the physical units for deployment as part of the system along I-80. RSUs include DSRC connectivity, application support, data storage, and other support services to enable CV applications, such as necessary certificates. WYDOT RSUs can be either fixed or portable equipment depending on the use. In general, RSUs serve as a two-way communication portal between connected vehicles that provide information through DSRC and the Operational Data Environment. About 75 RSUs are planned to be deployed in the pilot.

1.3.2.2 *Operational Data Environment*

The WYDOT Operational Data Environment Sub-System receives information collected with connected devices, checks its quality, and then shares it with other Sub-Systems in charge of analyzing and distributing the information. The ODE also will export TIM messages to the Situational Data Warehouse for USDOT-related activities and to share with XM Satellite Radio. The ODE will be hosted at WYDOT TMC and uses the same codebase as the USDOT ODE. High-level requirements for the ODE are contained within the Task 4 ODE ConOps from the Southeast Michigan (SEMI) Test Bed Advanced Data Capture Field Testing (Henclewood, et al. 2015). These include requirements for Validation, Integration, Sanitization, and Aggregation, which are combined in this document with the description of ODE processed data.

1.3.2.3 *Pikalert System*

The Pikalert System supports the integration and fusion of CV and non-CV weather data to develop alerts and advisories regarding adverse weather conditions along I-80. CV data are received from the ODE, while non-CV data derive from weather sources and the WYDOT Data Broker. To generate the alerts and advisories, the Pikalert System assigns CV and non-CV data to 1-mile segments on I-80 every 5 minutes. The CV data is quality checked, then passed to the Road Weather Hazard module (RWH). The RWH uses these data to produce the alerts and advisories for adverse weather and for a 72-hour forecast of road weather conditions and hazards. The generated information is then shared with the DB for further distribution. Pikalert can also access historical data stored at the DW.

1.3.2.4 *WYDOT Data Broker*

WYDOT DB receives information from the ODE, Pikalert and some external systems, analyzes them, and shares them with the corresponding system or service including other sources. The DB supports

the information brokerage of road weather alerts and advisories to WYDOT's Third-party interface (TPI), Transportation Reporting and Action Console (TRAC), Wyoming Traveler Information System (WTI), Road Condition Reporting System (RCRS), and Commercial Vehicle Operator Portal (CVOP). Additionally, this system takes in incident information from the Incident Console, work zone data from the Construction Administrator and parking availability information from the 511 Application. The DB also sends the information back to the ODE to support the dissemination of Traveler Information Message (TIM) to the RSUs and can also access historical data stored at the DW if needed.

1.3.2.5 *WYDOT Data Warehouse*

The WYDOT Data Warehouse stores various TMC- and CV-related data. The Data Warehouse includes timestamped and geotagged logs of CV and non-CV data—information collected, generated and shared within the *Wyoming CV System*—that will be used for performance measurement.

1.3.3 Vehicle System

The *Vehicle System* represents the deployment of on-board equipment, sensors, and a human-machine interface that will support CV applications. All vehicles that are part of the *Vehicle System* will have the following core capabilities:

- Ability to share and receive information via DSRC communication from other connected devices (vehicles and RSUs).
- Ability to broadcast Basic Safety Message Part I.
- Ability to receive Traveler Information Messages (TIM).
- A human-machine interface that allows alerts and advisories to be communicated with the driver.

Additionally, several vehicles that are part of the *Vehicle System* have further capability. Based on this, the *Vehicle System* is divided into five Sub-Systems, which define the various vehicle types for this pilot based on their data collection and communication capabilities. Each Sub-System and its rationale are described below.

1.3.3.1 *WYDOT Maintenance Vehicles*

This Sub-System represents the maintenance fleets operated by WYDOT. These include highway patrol and snow plow vehicles assigned to the I-80 corridor. These vehicles represent a set of vehicles over which WYDOT has full control as part of their operations. As such, the vehicles will be equipped with the full package of sensors and equipment necessary for the CV Pilot. Around 60 maintenance vehicles (snow plows) are expected to be part of this subsystem, which will have the ability to:

- Receive TIMs via DSRC and Satellite (or other remote communication methods).
- Integrate with the vehicle network via a CAN bus connection.
- Broadcast BSM Parts I and II.
- Collect weather sensor data (external weather sensors and possibly from the CAN bus).

1.3.3.2 *WYDOT Highway Patrol Vehicles*

This Sub-System represents the highway patrol fleet assigned to the I-80 corridor. While also operated by WYDOT, these vehicles represent a set over which WYDOT has less flexibility given the nature of their operations. Around 40 highway patrol vehicles are expected to be part of this subsystem, which will have the ability to:

- Receive TIMs via DSRC and Satellite (or other remote communication methods).
- Integrate with the vehicle network via a CAN bus connection.
- Broadcast BSM Parts I and II.

1.3.3.3 *Integrated Commercial Vehicles*

This connected trucks Sub-System represents a subset of commercial trucks owned and operated by fleet partners involved in the pilot that can be integrated with the vehicle network. In contrast to the WYDOT Maintenance Vehicles, and similar to Highway Patrol Vehicles, no external weather sensor data will be collected from these systems (i.e., only data from the vehicle). To summarize, this Sub-System will include the abilities to:

- Receive TIMs via DSRC and Satellite (or other remote communication methods).
- Integrate with the vehicle network via a CAN bus connection.
- Broadcast BSM Parts I and II.

In essence, these vehicles represent the capability to use vehicle data collected from trucks in the pilot. WYDOT anticipates that about 200 trucks will have this functionality.

1.3.3.4 *Retrofit Commercial Vehicle*

This Sub-System is for trucks and other fleet vehicles that do not include integration with Controller Area Network (CAN bus) data integration. This Sub-System is intended to simulate a commercial-off-the-shelf (COTS) system that enables a vehicle to communicate data through DSRC to other connected devices and receive TIMs through DSRC or satellite. About 20–30 vehicles are expected in this category.

1.3.3.5 *Basic Equipped Vehicle*

This Sub-System includes trucks equipped with just the core functionality for the *Vehicle System*, listed in the beginning of this Section. About 100–150 trucks are expected in this category. These trucks enable WYDOT to equip vehicles inexpensively with the basic capability necessary to be part of the CV Pilot. All safety applications are supported by this Sub-System.

2 Data Management Approach

Wyoming's data management approach is consistent with previous work and other related project documents, including:

- Phase 1 Performance Measurement and Evaluation Support Plan (PMESP)
- Phase 1 System Requirements Specification (SyRS)
- Phase 1 Human Use Approval Summary (HUAS)
- Phase 1 Security Management Operating Concept (SMOC)
- Phase 2 Data Privacy Plan (DPP)
- Phase 2 System Architecture Document (SAD)

The contents in this chapter, as well as Chapter 3, will help to inform

The Wyoming CV Pilot System Design Document (SDD) and Interface Control Documents (ICD) are currently under development. Therefore, some of the details regarding data structure and format are not yet available for inclusion in this document. The SDD and ICD will be available in draft form in June 2017 and final form in September 2017. The information contained in this document will help inform the SDD and ICD and vice versa.

The sections that follow describe our approaches to data sharing, data privacy, intellectual property issues, data quality control, and archiving and preservation.

2.1 Data Sharing

It is the intent of the Wyoming team to ensure project data is collected and stored in a manner which will allow efficient and effective sharing of the data with other interested parties, including the Independent Evaluator. Data will be shared through the WYDOT Data Warehouse (DW), in collaboration with the Operational Data Environment (ODE). Data will be shared with the Research Data Exchange (RDE), the Independent Evaluator (IE) through a yet to be developed database (this would include appropriate Personally Identifiable Information (PII) data). Figure 2-1 illustrates a high-level Wyoming CV Pilot data sharing logic to support performance measurement and evaluation.

The next chapter defines the data elements that will be collected and available for sharing. The Wyoming team will share any requested data identified in Chapter 3 with USDOT and Independent Evaluator to support project evaluation, using proper protection and security procedures.

The Wyoming team is committed to ensuring secure data communication and protecting the privacy of individuals. These efforts will be guided by the approach described in the Wyoming CV Pilot Deployment Data Privacy Plan (Zumpf, et al., 2017).

The frequency of data sharing will depend on the data being shared and the needs of those it is being shared with. The Performance Measurement and Evaluation Support Plan indicated a bi-weekly data share frequency; however, the Wyoming team is flexible in regards to the frequency of data sharing and plans to establish the details as we better understand the need for the data to support evaluation and other activities.

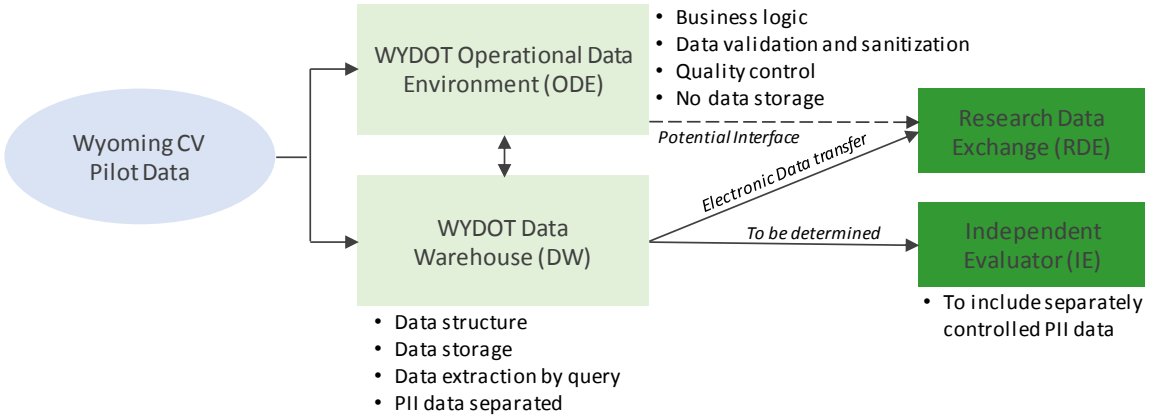

Figure 2-1. WYDOT CV Pilot Data Sharing Logic

2.1.1 Operational Data Environment

The ODE is an integral part of the Wyoming CV System and is described in section 1.3.2.2 above. It is important to note that the Wyoming ODE will be hosted at WYDOT TMC and uses the same codebase as the USDOT ODE. From a data sharing perspective, the ODE will validate the data that is received from the RSUs, and perform quality checks on the data to ensure valid information is used for performance measurement and evaluation activities. The ODE will not store any data. The ODE will interface with the WYDOT Data Warehouse where the data will be structured and stored. If an interface from ODE to RDE is available, it will be used to transfer data.

2.1.2 WYDOT Data Warehouse

The WYDOT Data Warehouse will store all the CV Pilot data and be the source of all data shared with outside interested parties. The structured database, to be developed during system design, will allow for data extraction through saved or ad-hoc queries. It is anticipated that data will be shared with primarily three systems: Research Data Exchange, Independent Evaluator database, and other authorized researchers. The sharing will likely be through an electronic data transfer with each outside database based on recurring or one-time data requests.

2.1.3 Research Data Exchange

The USDOT Research Data Exchange (RDE) was established to share connected vehicle data (BSMs, mobile devices and infrastructure sensors) among nationwide deployments and the CV Pilot sites. The Wyoming team is committed to sharing data with the USDOT RDE at periodic intervals. Wyoming will consider uploading data to the RDE when the System Performance Reports are submitted, per the PMES Schedule. The Wyoming CV Pilot will create a dataset (with corresponding Metadata) that will be shared with the RDE to facilitate access by authorized persons.

2.1.4 Independent Evaluator

It is understood that the Independent Evaluator (IE: Texas A&M Transportation Institute - TTI) will be defining the data required and data sharing approach that they plan to use to collect CV Pilot data

from the three sites for evaluation purposes. At this time, it is not known the complete list of data elements desired, what system they plan to use to organize and store the data, how they plan to exchange the data, or other logistical requirements. The data identified in our Phase 1 Performance Measurement and Evaluation Support Plan will be shared, including both baseline and post-deployment data. The PMESP also includes the data requested by Volpe. Additionally, it is understood that the IE database system will accommodate separately controlled needed PII data for evaluation purposes. Wyoming will transmit the needed PII data to the IE system (not the Saxton Lab, as previously considered).

The Wyoming team will have its CV Pilot data stored in the DW and stands ready to accommodate the data needs of the IE when the details become known. While the IE team will not have direct access to the DW, the Wyoming team will create exports as necessary for the IE.

2.2 Data Privacy

The Wyoming CV Pilot Data Privacy Plan (Zumpf, et al., 2017) describes how we intend to protect the privacy of users and ensure secure communications. Furthermore, the DPP determines and documents the extent to which this system will collect and store PII and PII-related information, and ensures that there is a legitimate need for this information in order to meet the goals of the system and that the data is only accessible for and used for these legitimate purposes. The DPP also describes, at a high level how this pilot will use the Security Credential Management System (SCMS) for proposed applications.

The DPP describes the approaches to assess data security and privacy, analyzes each CV Pilot application, and employs controls (technical, policy, standards, and physical) to ensure data security and privacy and how team compliance will be assured.

The DPP is considered a complementary document to this Data Management Plan and will be used to guide the collection, sharing, and use of the Wyoming CV Pilot Demonstration data. The reader is encouraged to carefully examine the DPP to gain a clear understanding of how data security and privacy approaches will be employed.

2.3 Intellectual Property Issues

The Wyoming team has reviewed all CV project data and determined that no intellectual property issues exist. CV project data collected with internal systems will be the property of WYDOT. Negotiations with outside CV project vendors has required that the data delivered by their systems be the property of WYDOT, and they have agreed. Furthermore, by stipulation in the USDOT contract with WYDOT, all CV project data collected by WYDOT will ultimately be the property of USDOT.

Software related intellectual property rights will be negotiated separately with the outside vendors and is not addressed in this section.

2.4 Data Quality Control

The WYDOT CV Pilot will leverage the data quality control features implemented in the ODE and in Pikalert (as summarized below). ODE data validation applies identifiable rules to data to ensure they meet minimum levels of acceptable quality, and are suitable for use in WYDOT specific applications.

The Pikalert Vehicle Data Translator Module ingests mobile data and executes Quality-Control (QC) routines, necessary to support the road weather assessments.

2.4.1 ODE Data Quality Control

As described in the SEMI-ODE ConOps, the ODE collects data in real-time from multiple sources and publishes quality checked data to subscribers, removing any PII contained in the data prior to publication. The following discussion is adapted from the SEMI-ODE ConOps and the SEMI-ODE System Design Description.

ODE data validation applies identifiable rules to data to ensure they meet minimum levels of acceptable quality, and are suitable for use in a specific application. When data does not meet the established minimum levels of acceptance, this data is flagged so that subscribing applications are aware of the data's validity. ODE rules for data validation are summarized by the following:

1. The ODE determines if the message is corrupted. If a message cannot be decoded using software adhering to the ASN.1 standard, validation is halted since the data transmission may have corrupted the data or there may have been an error in the original encoding of the data onboard the vehicle (or other source). When this validation fails, error logging will capture the date, time and the contents of the corrupted message.
2. The ODE removes any ingested data that was generated in a geographic location outside the geographic area specified by the subscription request.
3. The ODE removes any ingested data that was generated outside the temporal window specified by the subscription request.
4. The ODE marks as invalid any ingested data for which the value falls outside a predefined range, for example speed readings in excess of 200 MPH.
5. The ODE distributes all invalid data to the requesting applications, but marks invalid data with an error code that indicates why the data was deemed invalid.
6. The ODE marks invalid data with a specific and human-readable description of why the data was deemed invalid (e.g., "vehicle speed of 207 mph exceeds upper range limit of 200 mph").

In all cases, detected anomalies are logged to an appropriate log file.

The ODE validates all elements of the BSM messages against a customizable table of values stored in a static file. If all data element values fall in their valid ranges, the data will lack the violations data element and will be streamed without any special indication that any value was invalid.

2.4.2 Pikalert Data Quality Control

The Pikalert Vehicle Data Translator (VDT) Module implements several QC algorithms to assess the quality of vehicle data that is ingested. At the basic level, the VDT ingests mobile data and performs simple QC routines, such as ensuring that the mobile observations are located on the Earth and within an appropriate hour window (e.g., 0-24 hours) and the observations fall within standard expected values (e.g., a vehicle speed of 200 mph would fail). Then, mobile observations are run through more rigorous QC which involve comparison of vehicle observations with nearby ancillary data (such as nearby station air temperature) as appropriate to the observation type. The QC algorithms flag whether or not an observation has passed a particular test for all tests applicable to each variable. Once all tests are performed, the Combined Algorithm Test issues a confidence value from 0 (no confidence) to 1 (full confidence). This value is used to filter which observations are used to produce the Road Segment Statistics, which are then passed to the Road Weather Hazard module. Bounds for

many tests (such as the Anticipated Range Test) are user-configurable. Table 2-1 identifies the tests performed and provides a brief description.

Table 2-1. Pikalert Data Quality Control Tests.

VDT Test	Description
Anticipated Range Test	Each observation (e.g., air temperature, headlight status) is flagged if it falls outside the sensor's expected range
Time Step Test	Unexpectedly large changes in a short time are flagged
Persistence Test	Observations that remain stationary when unexpected, such as an hour of an air temperature of 26.1 deg C, are flagged
Spatial Test	Meteorological variables are tested for consistency with nearby surface stations such as RWIS stations
Climate Range Test	Meteorological variables are flagged if they fall outside the given month's expected climatological range, plus a small tolerance for extreme weather
Data Filtering Test	Observations with erroneous time or location stamps are flagged
Model Analysis Test	Meteorological variables are tested for consistency against a background surface analysis model
Neighboring Vehicle Test	Meteorological variables are tested for consistency with other nearby mobile observations
Combined Algorithm Test	Flags from the eight QC tests are weighted and combined to produce a confidence value of 0 to 1

The details associated with each test are described in The Vehicle Data Translator V3.0 System Description (Drobot, et al. 2011).

2.4.3 Other Data Quality Control

Speed data collected from the roadside sensors will be monitored for low and high speed observations and the percentage of outliers logged to identify sensors in need of maintenance and calibration. Speed observation outliers will be flagged as such in the data set. Similarly, crash records are QC reviewed by the issuing WYDOT agency prior to being released for our performance measurement use.

2.5 Archiving and Preservation

The primary information for data protection and security is in Section 6.2 of the Security Management Operating Concept (FHWA-JPO-16-288; Gopalakrishna, et al. 2016). This information is summarized here for readability.

WYDOT hosts an Oracle database responsible for the storage and distribution of all CV data. This system uses persistent identifiers that are available throughout the lifecycle of the data. CV data placed in this data warehouse will be retained for the period of the pilot. WYDOT has adequate online storage so that archiving will not be necessary during the pilot.

All server systems within the data center, including the systems that support the Oracle database, will have an operating system (OS) and application patches applied on a regular basis. Additionally,

critical patches are installed as soon as practical. These servers have physical data protection implemented with RAID 5 and a hot spare drive. A Secure Network Monitoring Protocol tracks and notifies WYDOT maintenance staff of drive failures.

Critical systems are maintained in geographically separate cities for redundancy and to ensure systems can be recovered in the event of a disaster.

Backups will be performed on a daily basis and stored in a fireproof locked vault/safe. AII information on backup media will be encrypted, whether the backup media is part of WYDOT's rotation or a cloud hosted service. Media retention is planned to be a minimum of 3 months.

Database backups are currently maintained for several weeks and include a combination of internal binary-level backups and exports.

Data administration for the data warehouse is controlled by the data warehouse administrator. Developers who access the database must have a reason to access the data and sign a Computer Environment Access and Non-Disclosure Agreement with WYDOT. Developers and consultants will be assigned unique database accounts with appropriately restricted access to information.

The Oracle database will implement data encryption and audit logging for PII-related information.

3 Data Management Plan

This chapter defines the data to be collected and related data management specifics. The data sources, collection approach, and frequency of collection are provided for each data item. Additionally, the related performance measure that is supported by the data and whether or not baseline data will be collected for each data item is also provided. Specific data required to evaluate each performance measure is identified in the PMESP. The SDD and corresponding ICDs, currently under development, will define the detailed data structures that will be contained in the ODE and DW. Understanding these details will allow the development of future data queries to support performance measurement and evaluation. The Wyoming Team expects to define the data needed in in enough detail to develop the data queries to support measurement of each PM. This detailed data identification will be contained in the updated PMESP toward the end of Phase 2.

The Wyoming CV Pilot will demonstrate five CV applications, plus benefits to traffic management and traveler information systems. The CV applications utilize the vast majority of the data items and therefore we decided to describe all the data items in this Chapter and not divide them by CV application—this results in not duplicating information and streamlining the data descriptions. The next subsections summarize the data mapping to Wyoming CV applications.

3.1 Data Types and Sources

The Wyoming CV Pilot data that will be collected to support performance measurement and evaluation are grouped into the following four categories:

- System data – Data collected from vehicle systems and CV Pilot systems.
- Non-System data – Data collected from external systems and databases necessary to support performance measurement.
- Survey and Interview Data – Data collected through electronic surveys of commercial vehicle fleet managers and truck drivers. Additionally, data that may be collected through in-person interviews of WYDOT personnel and other stakeholders.
- Modeling and Simulation data – Data supportive of modeling/simulation activities during performance measurement and evaluation.

As depicted in Figure 1-1, system and non-system data (encrypted) will be exchanged between the connected vehicles' OBUs, roadside infrastructure (RSUs and other), and other systems and the ODE for processing (and de-encryption) and then to the DW for storage. Data, such as TIMs/alerts/ warnings, will also be exchanged from the ODE to RSUs and OBUs. This data will also be stored in the DW. The DW will be the primary source of shared data. In conjunction with the ODE processing power, data queries will be established, or generated ad-hoc, to extract the necessary data from the DW and then shared with authorized interested parties. Detailed data flows can be found in the System Architecture Document (English, et al. 2017).

Table 3-1 provides the data items and related details in these categories. The paragraphs that follow describe the data collection and management details by category.

3.1.1 System Data

System data are data generated by the Wyoming CV Pilot project and includes elements such as BSMs, mobile road weather observations, vehicle CANBUS data, Pikalert forecasts and MAWs, WYDOT TMC system data and generated TIMs/alerts/warnings. Table 3-1, provides a list of system data items and description. Some of the detailed list of data elements are contained in the Wyoming Pilot Deployment System Requirements Specification document and the Technical Roundtable Data Element Spreadsheet currently under development.

An area that needs further explanation is BSM data sent and received. Connected vehicles will continuously broadcast BSMs at a rate of 10 hertz. However, not all those messages will be stored on the OBU. Sent BSMs that will be stored based on two criteria (this only applies to WYDOT fleet vehicles and integrated commercial vehicles; basic and retrofit commercial vehicles will not have the capacity to store all this data):

- A snapshot single BSM will be stored every 30 seconds at all times the vehicle is operational at highway speeds.
- For every interaction, BSMs will be stored 10 seconds before, during, and after an interaction at a rate of 10 hertz. An interaction is defined as receipt of information from another CV device (an RSU, another connected vehicle OBU, satellite data transmission, etc.).

All received BSMs, TIMs, or other information will be stored on the connected vehicle OBU (whether from an RSU or another OBU). Again, this only applies to WYDOT fleet vehicles and integrated commercial vehicles; basic and retrofit commercial vehicles will not have the capacity to store all this data. When the OBU passes an RSU, data stored on the device will be transmitted via DSRC and deleted from the device. When the vehicle is out of range of the RSU, logs are stored for a maximum of 7 days.

All the system data identified in Table 3-1 will be stored in the Wyoming Data Warehouse and available for performance measure and evaluation. Data that contains vehicle identifiers from the WYDOT fleet and other PII will be encrypted in the Data Warehouse. This PII data will be removed before being shared with outside entities. As an example, the Wyoming Highway Patrol data regarding an incident on I-80 may contain PII data. The TRAC system records that could possibly contain PII data will be sanitized to ensure no PII data is available to unauthorized personnel.

3.1.2 Non-System Data

Non-system data are data relevant to performance measurement and evaluation that is external to the system. This includes vehicle speed data, historical WYDOT collected data (from 511, RWIS, ITS maintenance, VSL events, DMS events, and road closures), national weather service information, satellite provider data, and crash records. Table 3-1 provides a list of non-system data items and description.

Table 3-1. Data Type and Sources.

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

Data Type	Data Element Description	Source	Collection Approach	Frequency	Performance Measure	Baseline Data?
	Refer to the technical roundtable data elements definition spreadsheet currently under development for a complete list.			**Received BSMs:** From another vehicle, at all times when CV is within range. **At RSUs** – as available from a vehicle.		
Mobile road weather observations	• Precipitation type • Solar radiation • Wiper frequency • Ground temp • Ambient temp, • Barometric pressure • Humidity See System Requirements for a complete list of data elements.	Vehicle data logger	Download to RSUs, when available	**At RSUs** – as available	All PMs	No
Vehicle interaction events – V2V and V2I	• Timestamped event logs by type	OBUs	Download to RSUs, when available	**At RSUs** – as available	All PMs	No
System Data – CV System						

Pikalert road conditions	Pikalert generated segment-based (1 mile):
	• Atmospheric
	  ○ Temperature
	  ○ Probability of precipitation
		Pikalert system logs	Direct connection from Pikalert to TMC and Data Warehouse	Every 5 minutes	All PMs	No

Data Type	Data Element Description	Source	Collection Approach	Frequency	Performance Measure	Baseline Data?
	○ Wind speed ○ Wind direction • Road weather ○ Pavement temperature ○ Subsurface temperature ○ Forecast • Customizable forecast time and update, initial configuration of hourly forecasts out to 72 hours See System Requirements for a complete list of data elements					
Pikalert motorist advisories and warnings	• Motorist advisories and warnings (MAWs) including: ○ Precipitation hazards ○ Road condition hazards ○ Visibility hazards See System Requirements for a complete list of data elements.	Pikalert system logs	Direct connection from Pikalert to TMC and Data Warehouse	Every 5 minutes, or when available	PM 4	No
TMC generated TIMs, alerts and warnings	• Traveler Information Messages, alerts and warnings from TMC and Satellite providers. Refer to the technical roundtable data elements definition spreadsheet currently under development for a complete list.	TMC system logs	Direct connection to Data Warehouse	Continuous	PM 5	No
WYDOT TRAC data	• Highway patrol incident reports • Operator Action Logs • Citizen reports.	TMC system logs	Direct connection to	Continuous	All PMs	Yes

Data Type	Data Element Description	Source	Collection Approach	Frequency	Performance Measure	Baseline Data?
	See System Requirements and TMDD data feed specifications for specific data elements.		Data Warehouse			
WYDOT construction console events	I-80 Construction events including • Start time • End time • Location • Type of construction	TMC system logs	Direct connection to Data Warehouse	Continuous	All PMs	Yes
WYDOT incident console events	See System Requirements and TMDD data feed specifications for specific data elements on incidents	TMC system logs	Direct connection to Data Warehouse	Continuous	All PMs	Yes
Non-System Data						
Individual vehicle speed data (88 speed sensors mostly located to support VSL operations)	• Date, • Time, • Speed, • Lane, • Vehicle length, • Vehicle classification.	I-80 selected Wavetronics radar-based speed sensors	Real time; WYDOT trunk communications	Continuous	PMs 14-16	Yes
WYDOT RWIS data (41 sensors mostly located to support VSL operations)	I-80 road weather information stations data including • Air temperature • Pavement temperature • Wind Speed, Wind Gusts • Precipitation • Visibility,	RWIS system logs	Direct connection to Data Warehouse	Every 5 minutes	All PMs	Yes

Data Type	Data Element Description	Source	Collection Approach	Frequency	Performance Measure	Baseline Data?
	• Road surface conditions.					
WYDOT VSL system events	Timestamped VSL activations, deactivations, speeds set on all I-80 VSL signs. See System Requirements and TMDD data feed specifications for specific data elements.	TMC system logs	Direct connection to Data Warehouse	Continuous	All PMs	Yes
WYDOT DMS records	Timestamped DMS activations, deactivations and messages on I-80 signs. See System Requirements and TMDD data feed specifications for specific data elements.	TMC system logs	Direct connection to Data Warehouse	Continuous	All PMs	Yes
WYDOT road closures	• I-80 road closures • Beginning point • Ending point and • Start time.	TMC system logs	Direct connection to Data Warehouse	Continuous	All PMs	Yes
Crash data records	Vehicle crash records including • Number of crashes (primary and secondary) • Crash locations • Crash dates and times • Number of vehicle involved • Vehicle Types involved • Crash rate for trucks and other vehicles, • Crash Contributing Factors	WYDOT Highway Safety	Specific request	5-year history for baseline. Otherwise, monthly download	PMs 17-21	Yes

Data Type	Data Element Description	Source	Collection Approach	Frequency	Performance Measure	Baseline Data?
	• CV vehicles involved in a crash (post deploy) • work zone related crashes • Critical injuries.					
Survey and Interview Data						
CVO fleet manager survey responses	Survey results focused on satisfaction and actions taken by fleet managers based on TMC information.	Electronic survey	Web-based data entry	Initially for baseline; and then periodically as appropriate	PMs 8-9	Yes
CVO driver survey responses	Survey results of commercial vehicle drivers regarding use of CV technologies during demonstration.	Electronic survey	Web-based data entry	Periodically as appropriate	PM 10	No
WYDOT staff surveys and interviews	Survey and interview results of WYDOT staff regarding operations before and after CV technology deployment.	Combination of Electronic survey and on-site interviews	Web-based data entry and notes	Initially for baseline; and then periodically as appropriate	All PMs	Yes
Modeling and Simulation Data						
Analysis/ simulation model data and assumptions	Project data used to calibrate and utilize driver simulator and traffic simulation models in support of safety related performance measurement.	University of Wyoming	Upon request	As requested	PMs 14-21	No

Vehicle speed data will come from radar-based speed sensors. These sensors exist today and were installed by WYDOT primarily to support establishing speed limits and the activation of VSL systems. There is a total of 88 speed sensors on the I-80 corridor. All these sensors are available; however, a select subset of speed sensor data will be collected focusing on the VSL corridors. Individual vehicle data will be collected for analysis, as well as aggregated data (30 second intervals).

3.1.3 Survey and Interview Data

Electronic-based surveys and on-site interviews are planned as part of the performance measurement activities, as shown in Table 3-1. The stakeholder groups could include commercial vehicle fleet managers, commercial vehicle drivers, WYDOT TMC operators, WYDOT maintenance, and Highway Patrol officers. These activities may take place before (baseline) and after CV technologies are deployed and being demonstrated. The focus of the surveys and interviews will be to supplement system data to better understand operational actions taken and the reasons for the actions, use of CV technologies, impacts of CV technologies, satisfaction with the information provided, and conditions that led to certain behaviors. Collection of PII type data will be limited as much as possible and removed during analysis to only represent grouped data.

3.1.4 Modeling and Simulation Data

The use of traffic simulation models using VISSIM software is planned as part of the safety-related performance measurement activities. 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. Driver behavior will be observed from CV equipped vehicles and from the Driver Simulator lab during training activities. Model calibration data, assumptions, network files created for the modeling, as well as outputs from the modeling and simulation runs will be housed in the University of Wyoming and made available to USDOT and the IE as requested.

The Phase 2 model calibration and assumptions will be documented as part of the Pre-Deployment Conditions and will be included in the Phase 2 System Performance Report. Requests for the model or model data can be requested from the University of Wyoming team members.

3.2 Data Collection and Transmission

Table 3-1, above, provides a data source and collection approach for each data item. As described previously, project data will be collected, processed, and stored on a real-time basis for later performance measurement and evaluation activities.

3.2.1 Overall Data Storage

The Wyoming team has developed preliminary data storage estimates to support future evaluation efforts by the Wyoming team and the IE. The estimates are provided at this time only as a rough guideline to assist the IE in preparing to receive the data for evaluation. The results of this analysis are shown in Table 3-2, which indicates the interactions with connected vehicles estimate dwarfs the other data storage estimates in terms of their impact on designing data storage systems. The interactions

between CVs value is highly dependent on how often connected vehicles will be traveling within range of each other and sharing information. If this happens fairly frequently, it could generate a tremendous amount of data. However, data storage at a vehicle-level will be constrained by OBU data capacity. During the system design process, options to possibly limit the data collection in these circumstances will be examined.

The approach to developing these estimates are based on initial analysis of likely frequency of events happening and represent a total data storage size estimate for all vehicles over the 18-month demonstration period. Data and factors used include:

- Estimated size of BSM data files
- Estimated frequency and number of BSMs generated
- Estimated number of CV interactions with RSUs
- Estimated amount of data able to be downloaded to RSUs at average speeds and DSRC performance
- Estimated number of CV V2V interactions
- Estimated mobile environmental sensor data size and number of downloads
- Estimated TMDD data size and number of messages
- Estimated number of Pikalert forecasts, alerts, and advisories
- Estimated average Pikalert data size
- Estimated TIM messages and size for each estimate
- Estimated WYDOT TMC data based on historical data
- Estimated speed and crash data size based on historical data

Table 3-2. Preliminary Data Size Requirements

Data Category	Total Data Storage Estimates	Assumptions/Comments
Sent BSMs stored on vehicles	200GB	BSM JSON compressed option
RSUs collection of stored BSMs	3TB	All 75 RSUs
Interactions between CVs	20-50TB	Dependent on CVs traveling within range of each other and sharing information
Environmental sensor data	25GB	Estimated 50 vehicles with sensors
Traffic management data	15GB	TMC inputs and outputs
Pikalert data	30GB	Forecasts and Motorist Alerts and Warnings
Traveler information messages	5GB	Sent from TMC
WYDOT TMC systems	20GB	Includes some non-system data
Speed and crash data	10GB	Supporting safety evaluation

3.2.2 Frequency

It is the goal of the Wyoming team to collect as much data as practical within system and financial constraints to support performance measurement and evaluation. The frequency column in Table 3-1 indicates when data will be collected. The frequency of data collection is dependent on data type and system operational capabilities and constraints. The frequency ranges from continuous to as

requested. Continuous means when VSL or DMS signs are changed, that information is immediately sent to the ODE and DW. For instance, the frequency of RSU data collection is continuous and dependent on data being either sent or received with the geographical boundaries of the unit. However, crash data will be collected on a monthly basis of all crashes that occurred during the past month.

3.2.3 Relationship to Performance Measures

Table 3-1 indicates which performance measures are supported by each data item. The Table also indicates which data items support all PMs and which support specific PMs. For example, the BSMs and RSU/OBU logs support evaluation of all the PMs; however, the individual vehicle speed data only support PMs 14-16. The full list of performance measures, extracted from the Performance Measure and Evaluation Support Plan, are available in Appendix A for reference.

Table 3-3 maps the performance measures to the Wyoming CV applications. This mapping, along with the data elements mapping to PMs (in Table 3-1 above), illustrates how the evaluation efforts will measure the level of success of the CV applications.

3.2.4 Baseline Data

Table 3-1 identifies, for each data item, whether or not it will be collected to support the establishment of the baseline (last column in the table). The baseline will define the “before” conditions, prior to CV system deployment. As such, this data will be collected during the 2017-18 winter season before any CV technology is present in the I-80 corridor. These before conditions are specific to each performance measure and are consistent with the Performance Measurement and Evaluation Support Plan.

The data items with a “yes” in the “Baseline Data?” column indicates that they will be collected to support the “before” case, as well as during the project demonstration (Phase 3). The two data points (before and after CV technology deployment) will be compared to effectively measure the performance of the system or related impacts. The data items with a “no” in the same column will only be collected during project demonstration (post-deployment).

Table 3-3. Performance Measurement Mapping to Wyoming CV Applications

	WYDOT CV Applications					
Performance Measure	FCW	SA	DN	WZW	SWIW	Traffic Mgmt,
PMs 1-3: Improved Road Weather Condition Reports Received into the TMC		X		X	X	X
PM 4: Improved Ability of the TMC to General Alerts and Advisories		X		X	X	X
PMs 5-7: Effectively Disseminate and Receive I2V and V2I Alert/Advisory Messages from the TMC		X	X	X	X	X
PMs 8-10: Improved Information to Commercial Vehicle Fleet Managers		X		X	X	X
PMs 11-12: Effectively Transmit and Receive V2V Messages	X	X	X	X	X	X
PM 13: Automated Emergency Notifications of a Crash		X	X	X	X	X
PM 14-16: Improved Speed Adherence and Reduced Speed Variability		X	X	X	X	X
PM 17-21: Reduced Vehicle Crashes	X	X	X	X	X	X

Legend
FCW: Forward Collision Warning
SA: I2V Situational Awareness
DN: Distress Notification
WZW: Work Zone Warning
SWIW: Spot Weather Impact Warning

4 Glossary

Our glossary of terms and acronyms are provided below in Table 5-1 and Table 5-2, respectively.

Table 4-1 Glossary of Terms.

Term	Definition
Basic Safety Message	Connected V2V safety applications are built around the capability to transmit BSMs, following the SAE J2735 standard. The BSM is transmitted over DSRC over a range of approximately 300 meters. In general, BSMs are broadcast frequently to provide connected vehicles with data content necessary for the different safety-oriented applications. The BSM is divided into two parts: • Part I, transmitted approximately 10 times per second, contains the core data elements: Message Count, Temporary ID, Time (through a Second Mark), Latitude, Longitude, Elevation, Positional Accuracy, Transmission State, Speed, Heading, Steering Wheel Angle, Acceleration, Brake System Status, and Vehicle Size. BSM • Part II, transmitted less frequently, is added to Part I depending on events (e.g., ABS activated) and contains a variable set of data elements drawn from many optional data elements (availability by vehicle model varies)
Broadcast	Sharing data with no specific destination. All broadcasted data is sent unencrypted but is signed with a certificate (based on IEEE 1609.2).
Data	Data is raw (unorganized and unprocessed) digital messages sent between components. From SAE J2735: Representations of static or dynamic entities in a formalized manner suitable for communication, interpretation, or processing by humans or by machines.
Data Ingest	Obtaining and importing data for use or storage.
Host Vehicle	A connected vehicle that receives messages from a remote vehicle. In this document, the host vehicle is also used to describe the originator of a vehicular transmission of information to an RSU.
Information	Processed data that is organized, structured or presented in a given context to make it useful
Message	A well-structured set of data elements and data frames that can be sent as a unit between devices to convey some semantic meaning in the context of the applications (adapted from SAE J2735).
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

Term	
	similar to the Retrofit Safety Device (RSD) used in the Safety Pilot Program.
RAID 5	RAID (redundant array of independent disks) computer storage configurations employ the techniques of striping, mirroring, or parity to create large reliable data stores from multiple general-purpose computer hard disk drives. The most common types are RAID 0 (striping), RAID 1 and its variants (mirroring), RAID 5 (distributed parity), and RAID 6 (dual parity). RAID levels and their associated data formats are standardized by the Storage Networking Industry Association (SNIA) in the Common RAID Disk Drive Format (DDF) standard.
Receive Data	A connected device accepts a data package broadcast or transmitted by another connected device.
Remote Vehicle	A connected vehicle that periodically and dynamically broadcasts a message about its general situation to a host vehicle.
Requirements	Set of information necessary to accomplish one action.
Roadside Units	This represents the package of DSRC radios, computing, communications that will be installed on the roadside on I-80
WYDOT Road Segment	A road segment is defined as a link in TMDD v3.03c: a roadway or transit right-of-way between two nodes. WYDOT has implemented road segments to fully cover I-80 in both directions.
Transmit	Sharing data directed to a specific receiver. In the case of transmission between Systems, all transmitted data is signed and encrypted where required based on SAE J2945/1.
Transportation Management Center	Center that collects information and informs the public about changing travel conditions.
WGS-84	Latest revision of the standard for use in cartography, geodesy, and navigation including by GPS.

Table 4-2. Acronym List.

Acronym/Abbreviation	Definition
ABS	Anti-lock Braking System
BSM	Basic Safety Message
CDP	Comprehensive Deployment Plan
DB	Data Broker
DW	Data Warehouse
CA and ConAdmin	Construction Administration
CAN bus	Controller Area Network bus
ConOps	Concept of Operations
CV	Connected Vehicle
CVOP	Commercial vehicle operator portal
DMS	Dynamic Message Signs
DSRC	Dedicated Short Range Communications

Acronym/Abbreviation	Definition
FHWA	Federal Highway Administration
HAR	Highway Advisory Radio
HMI	Human Machine Interface
I2V	Infrastructure-to-vehicle
I-80	Interstate 80
IC	Incident Console
ICD	Interface Control Document
IE	Independent Evaluator
IEEE	Institute of Electrical and Electronics Engineers
ISP	Information Service Provider
ITS	Intelligent Transportation System
LTS	Location and Time Service
MEP	Mobility, Environment, and Public Agency
MMUCC	Model Minimum Uniform Crash Criteria
NWS	National Weather Service
OBU	On-Board Equipment
ODE	Operational Data Environment
OTA	Over the Air
PA	Pikalert System
PMES	Performance Measurement and Evaluation Support
PSID	Provider Service Identifier
RCRS	Road Condition Reporting System
RF	Radio Frequency
RSD	Retrofit Safety Devices
RSU	Roadside Units
RWIS	Road Weather Information System
SCMS	Security Credential Management System
SDW	Situation Data Warehouse
SEMI-ODE	Southeast Michigan Operational Data Environment
SNTP	Simple Network Time Protocol
TIM	Traveler Information Message
TMC	Transportation Management Center
TMDD	Traffic Management Data Dictionary
TPI	Third-Party Information Service Providers
TRAC	Transportation Reports and Action Console
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
VDT	Vehicle Data Translator
VSL	Variable Speed Limit
WHP	Wyoming Highway Patrol
WYDOT	Wyoming Department of Transportation
WMA	WAVE Service Advertisement
WTI	Wyoming Traveler Information system

5 References

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

Table 5-1. References

#	Documents, Sources Referenced
1.	Gopalakrishna, et al. (2016). *Connected Vehicle Pilot Deployment Program Phase 1, Concept of Operations (version 2), ICF/Wyoming (FHWA-JPO-16-287)*. U.S. Department of Transportation.
2.	Gopalakrishna, et al. (2016). *Connected Vehicle Pilot Deployment Program Phase 1, Application Deployment Plan (version 2) – ICF/Wyoming (FHWA-JPO-16-292).* U.S. Department of Transportation.
3.	Gopalakrishna, et al. (2016). *Connected Vehicle Pilot Deployment Program Phase 1, System Requirements Specification (version 2) – ICF/Wyoming (FHWA-JPO-16-291).* U.S. Department of Transportation.
4.	Kitchener, et al. (2016), *Connected Vehicle Pilot Deployment Program Phase 1, Performance Measurement and Evaluation Support Plan (version 2) – ICF/Wyoming (FHWA-JPO-16-290).* U.S. Department of Transportation.
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8.	Baseline Data Collection Plan (internal document)
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10.	English, et al. (2017). *Connected Vehicle Pilot Deployment Program Phase 2, System Architecture Document, WYDOT CV Pilot (FHWA-JPO-17-451).* U.S Department of Transportation.
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12.	Booz Allen Hamilton (2016). *Southeast Michigan Test Bed: Advanced Data Capture Field Testing; Task 4: System Design Description DRAFT Version 3.1.* U.S. Department of Transportation.
13.	Drobot, et al. (2011). *The Vehicle Data Translator V3.0 System Description Final Report (FHWA-JPO-11-127).* U.S. Department of Transportation.

Appendix A. Summary of Performance Measures

Table A- 1. List of 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 section/day pre and post CV Pilot (quantity)	30% increase
2	Number of road sections with at least one reported road condition per hour pre and post CV Pilot (coverage)	25% increase
3	Average refresh time of road condition reports in each section pre and post CV Pilot (latency)	30% decrease
	Improved ability of the TMC to Generate Alerts and Advisories	
4	Pikalert™ generated Motorists Alert Warnings (MAWs) that were accepted by TMC operators	90% accepted
	Effectively Disseminate and Receive I2V and V2I Alert/Advisory Messages from the TMC	
5	Number of messages sent from the TMC that are received by the RSU	90% of sent alerts/advisories were received by RSU
6	Number of messages sent and received between the RSU and WYDOT fleet vehicle's OBU (when vehicles are in the vicinity of a RSU)	75% sent were received in either direction
7	Connected vehicles that likely took action following receipt of an alert • Parked • Reduced speed • Came to a stop safely • Exited	80% of vehicles likely took action based on alert
	Improved Information to Commercial Vehicle Fleet Managers	
8	Number of operational changes made by fleet managers due to information from TMC (compare before and after the CV Pilot) • Routing • Timing • Parking availability • Cancelled trips	20% increase in operational changes during CV Pilot
9	Commercial vehicle managers are satisfied with information provided by the TMC (compare before and after the CV Pilot) • Road conditions • Road weather forecasts • Parking information	90% of responding commercial vehicle fleet managers expressed satisfaction with information during CV Pilot
10	Commercial vehicle driver's experienced benefits due to CV technology during major incidents and events on I-80	N/A

	Effectively Transmit and Receive V2V Messages	
11	Number of V2V messages properly received in surrounding vehicles from sending vehicle (WYDOT fleet vehicles in vicinity of each other)	75% of alerts sent from an equipped vehicle were received by other vehicles
12	Connected vehicles that took action following receipt of a V2V alert ● Parked ● Reduced speed ● Came to a stop safely ● Exited	80% of vehicles took action based on V2V alert
	Automated Emergency Notifications of a Crash	
13	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	
14	Total vehicles traveling at no more than 5 mph over the posted speed (compare before and after CV Pilot)	20% improvement over baseline of total vehicles traveling no more than 5 mph over posted speed during CV Pilot. Baseline will determine what percentage is traveling no more than 5 mph over posted speed prior to CV Pilot.
15	Total vehicles traveling within +/- 10 mph of 85th percentile speed (compare before and after CV Pilot)	20% improvement over baseline of total vehicles traveling within +/- 10 mph of the 85th percentile speed during CV Pilot. Baseline will determine what percent is traveling within +/- 10 mph of the 85th percentile speed prior to CV Pilot
16	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	
17	Number of connected vehicles involved in a crash ● Initial crashes ● Secondary crashes[2] (total and specifically rear-end crashes	N/A
18	Reduction of the number of vehicles involved in a crash (compare a 5-year average before Pilot to CV Pilot data) ● Track connected versus non-connected vehicles	25% reduction in the number of vehicles involved in a crash
19	Reduction of total and truck crash rates within a work zone area (compare a 5-year average before Pilot to CV Pilot data) ● Track connected versus non-connected vehicles	10% reduction in total and truck crash rate within work zones
20	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

[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).

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

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